ANALYSIS

Biological reserves, rare species and the trade-off between species abundance and species diversity

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Abstract

The preservation of species diversity generally suggests protection of either the greatest number of species possible or all species. Requiring representation of each species in at least one parcel in the system and seeking the minimum number of parcels in the reserve system to achieve this requirement is termed the Species Set Covering Problem (SSCP). Nonetheless, it is important, as well, to consider the rarest of species, as their populations are the most in need of protection to assure their survival. This paper uses 0–1 programming models and an existing data set to study species protection, rarity, species abundance and species diversity.

We employ for this purpose an integer programming model that uses the SSCP format to require at least one representation of each and every species, but that seeks in addition protection of the rarest species. This is achieved by maximizing redundant coverage of those species designated as rare. Results are then compared to those of the SSCP.

Recognizing that resources available for conservation purchases could well be insufficient to represent all species at least once, we structure a model comparing coverage of the greatest number of species and redundant coverage of rare species. We develop a trade-off curve for this multi-objective problem in order to evaluate the opportunity cost of covering more species as redundant coverage of rare species decreases—and vice versa.

Finally, various possible rarity sets and various budget proxies are considered along with their impacts on conservation policies, Pareto optimality and species diversity.
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1. Introduction

The Convention on Biological Diversity was opened for signature at the United Nations Conference

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on Environment and Development in Rio in 1992 and entered into force at the end of the following year. The ratifying nations committed to achieve a significant reduction of the current rate of biodiversity loss by 2010.

One of the important strategies to conserve biodiversity is the setting aside of (public and private) land for the creation or enlargement of biological reserves to preserve key habitat and species living within those reserves.

Over the past 20 years, an increasing amount of research has aimed at delineating nature reserves for promoting the conservation of biodiversity. The preservation of species diversity often suggests protection of the greatest number of species, of all species and/or of rare species.

This new field of "reserve selection and design science" strongly parallels another, older, field, that of "facility location science" (see ReVelle et al., 2002). As a matter of interest, locating the least number of facilities (say, fire stations), such that all demand nodes (say households) are covered by stations within a certain distance or time standard, is methodologically identical to selecting the least number of eligible land parcels for a nature reserve such that all species in need of protection are present in at least one parcel. Facilities and land parcels, like households and species, are indivisible or integer variables. Similarly, as financial resources may be insufficient to cover all demand nodes or all species, another problem is to protect respectively as many demand nodes or species as possible with a limited number of facilities or of land parcels. The two location science models explained above are named the LCSP–for Location Set Covering Problem–and the MCLP–for Maximal Covering Location Problem–and were elaborated in the 1970s by Toregas et al. (1971) and Church and ReVelle (1974). More recently, these same ideas have been applied to reserve selection and design science. First, Kirkpatrick (1983) and Margules et al. (1988) articulated the first models later recognized and developed as the counterpart model of the LSCP by Possingham et al. (1993) and Underhill (1994). Next, Church et al. (1996) and Camm et al. (1996) formulated the counterpart species protection model of the MCLP, although, in general, the original species protection researchers did not recognize the antecedent models of location science.

These models were later refined in different ways. Ando et al. (1998) and Polasky et al. (2001) considered the difference in land values and formulated budget-constrained models. Probabilistic models with an uncertain incidence of species within sites and no guarantee of survival have been set up (e.g. Haight et al., 2000; Camm et al., 2002). Models with spatial attributes, requiring, for example, land parcels to be selected in a compact and/or contiguous way have recently been proposed, among others, by Nalle et al. (2002) and Mc Donnell et al. (2002). Reserve design science, that is, the science of nature reserves with spatial characteristics, has been thoroughly reviewed by ReVelle et al. (2002) and Williams et al. (in press).

All the above models focus on protecting either all or the greatest number of species although some of the models add spatial considerations as well. If we interpret the achievement of biodiversity as the need to protect as many species as possible, it follows that populations of the rarest species are in critical need of protection. Indeed, species richness and the presence of rare species are the most frequently cited criteria for site selection by conservationists (Prendergast et al., 1993). Recently, Arthur et al. (2004) took rare species into account by using a probabilistic formulation for maximizing expected coverage while ensuring that recognized endangered species meet a minimum coverage probability threshold. The purpose of this paper is to explicitly consider protection of "rare" species and to trade-off species abundance and species diversity in a deterministic setting. The former is obtained by maximizing the parcel appearances of those rare species; in other words, the diversity concept used here is linked to the representation of rare species: their occurrence in the system increases diversity. Coverage of all species is then traded off against representation of rare species in order to compare abundance and diversity.

The remainder of the paper is organized as follows. The next section details the data set which will be used to implement and exercise the models. Section 3 reviews the counterpart problem of the LSCP. Section 4 presents a model of redundant coverage of rare species given coverage of all species. Section 5 details the multi-objective problem of preserving as many species as possible and preserving rare species in as many parcels as possible and evaluates the trade-off