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Designing a multi-species spatially explicit nature reserve network construction framework based on extinction probability: A case study of Wuyishan city

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ABSTRACT

With the purpose of species' long-term persistence, nature reserve network construction has been acknowledged as a simple yet effective way to protect species to avoid anthropogenic activities. This study focused on the identification and construction of multi-species spatially explicit reserve networks in nature reserves. A three-step framework was proposed considering both species representation and elimination of the negative impact the anthropogenic barriers impose on species turnover. We detected the subset of anthropogenic barriers responsible for the failure of species' direct dispersals between fixed representative reserves and then added constructed reserves to remove these influences. The proposed framework was applied to *Macaca thibetana* and *Lophura nycthemera*, two sensitive species in Wuyishan. The results showed that when designing a reserve network only for *M. thibetana*, four representative reserves, one constructed reserve and two migration routes were identified. Taking both *M. thibetana* and *L. nycthemera* as targeted species, a reserve network including ten representative reserves, three constructed reserves and fifteen dispersal routes was selected, covering 43.17% of the total area of Wuyishan Nature Reserve. The selection of constructed reserves significantly lowers the extinction probabilities of both *M. thibetana* and *L. nycthemera* in either reserve or the whole network. In addition, by comparing the fixed reserve network with current functional zoning of WYS, 83% of the reserve network lay in the core zone, while 11.28% and 5.72% located in the buffer zone and transition zone, respectively. The results suggested that the current core zone in Wuyishan Nature Reserve General Planning should be extended by replanning and restricting the tourism and roads to be out of the constructed reserves and the direct dispersal pathways between constructed reserves and the corresponding reconnected representative reserves. Such a framework is a necessary post-evaluation that can provide an effective way facing multi-species protection and provide guidance to policy decisions.

1. Introduction

In China, while nature reserves are constructed and managed for biodiversity conservation, because of their natural scenic beauty, they are often attractive to tourists. The development of tourism together with the socio-economic activities of local residents transforms natural areas to land dominated by human use, resulting in loss, degradation, and fragmentation of species habitat. This makes it essential to identify collective areas to protect the species in the nature reserves.

As a simple yet effective way to protect species from anthropogenic habitat loss, selection of reserve networks, where lands are protected and managed to maintain species, has attracted significant attention in the past two decades (Polasky et al., 2001; Onal and Briers, 2002; Liu et al., 2009). The ultimate purpose of establishing a reserve network for conservation is to ensure species' long-term persistence, toward which species should be appropriately represented in the network in the first place (Pressey et al., 1993; Csuti et al., 1997). Methods for designing representative reserve networks, therefore, have been an important focus of recent conservation literatures (e.g., Church et al., 1996; Camm et al., 1996; Pressey et al., 1996, 1997; Polasky et al., 2000; Pawar et al., 2007). However, because setting aside reserves for conservation purpose imposes restrictions on human socio-economic activities, these methods often aim at solutions that achieve a defined minimum level of species representation, which makes them inadequate for

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use in the nature reserves. In order to conform to the primary function of biodiversity conservation, reserve networks designed for species in nature reserves should include all sites that are of relatively high probability to contain the species.

The spatial arrangement of reserves is another particularly important concern when designing a reserve network, given the potential role in species' long-term persistence by allowing dispersal. In recent years, a broad range of approaches has been proposed to accommodate spatial consideration in reserve selection. These approaches deal with some spatial design criteria as either constraints or objectives, such as performing adjacent rule (Lombard et al., 1997; Briers, 2002; Fuller et al., 2006; Zafra-Calvo et al., 2010), minimizing the boundary length or a linear combination of boundary length and total reserve area (Fischer and Church, 2003; Onal and Briers, 2003; McDonnell et al., 2002; Cabeza et al., 2004a), minimizing the maximum intersite distance or the sum of pairwise distances between all planning sites (Onal and Briers, 2002), measuring the total distance between neighboring sites (Onal and Briers, 2005; Onal and Wang, 2008) and the summed distance to mandatory sites (Alagador and Cerdeira, 2007), maximizing the sum of the inverse distances between pairs of sites (Rothley, 1999), enforcing buffers surrounding selected critical sites (Williams and ReVelle, 1998), keeping sites occurring within the stated proximity distance or the dispersal range of species (Briers, 2002; Van Langevelde et al., 2002; Williams, 2008; Cerdeira et al., 2010) and maximizing connectivity (Briers, 2002; Siitonen et al., 2003; Van Langevelde et al., 2002; Cerdeira et al., 2005; Fuller et al., 2006; Onal and Briers, 2006; Moilanen and Cabeza, 2002; Cabeza, 2003; Moilanen et al., 2005; Van Teeffelen et al., 2006; Rayfield et al., 2009; Bauer et al., 2010). By doing so, selected reserve networks are assumed to capture the optimal configurations that will ensure species' long-term survival while satisfying defined representation goals. Yet, due to the representation need mentioned above, this kind of spatial consideration should not be emphasized when one is designing reserve networks for species in nature reserves. Alternatively, a special concern may be given to existing anthropogenic barriers that impose detrimental impact on species dispersal.

2. Problem statement

In this paper we address a reserve selection/design problem in nature reserves which combines aspects of some of the problems which have appeared previously in the literature, including multi-species protection and the priority of artificial constructed reserves optional. This new problem involves selecting parcels in order to achieve three objectives: (1) establishing the principles of constructed reserves selection, (2) designing reserve networks for multiple species and (3) deciding conservation priority of reserves in a network.

Several studies have concentrated on selecting reserve networks for protecting species in nature reserves (Wessels et al., 1999; Lombard et al., 2001; Kati et al., 2004; Zafra-Calvo et al., 2010; Liu et al., 2014). Similarly, the proposed selection framework also emphasizes the representation of the species of interest, implying that a reserve network will not maintain the species if they do not contain them in the first place. The difference is that, with the purpose of conforming to the primary function of biodiversity conservation, it considers each site that is with relatively high species occurrence probability after implementing a reserve size constraint, while the previous studies share the objective of achieving a defined minimum representation with minimum land cost.

As with some of the previous studies (Zafra-Calvo et al., 2010), the spatial demand of the species is taken into account by the proposed framework. It has been demonstrated that the spatial distribution of reserves is of considerable importance in maintaining the species which it is aimed at protecting (Rodrigues et al., 2000; Cabeza and Moilanen, 2003). Another proposal by Cabeza et al. (2004b) suggests a serious consideration of species' spatial requirement when one is selecting reserve network for a region at smaller spatial scale with smaller selection units. While the previous studies seek to obtain compact reserve networks for species in nature reserves when satisfying the representation goals, this kind of spatial consideration, however, will not be necessary if each site with relatively high probability to contain a species is chosen. Specifically, the proposed selection framework concerns the hindrance influence of the existing artificial barriers on species turnover. Thus, as the second step toward achieving the final purpose of maintaining species in the long term, it designs constructed reserves to remove the negative impact.

We present a new framework that can be used to select reserve networks for protecting species in nature reserves. This framework is characterized by its three-step selection manner. First, because of the focus on a nature reserve, the framework selects reserves that are composed of contiguous sites with high and medium species occurrence probabilities to satisfy the representation requirement. Second, the framework designs additional reserves in an attempt to eliminate the human-induced impact imposed on species turnover so as to improve the capacity of the spatial configuration of reserve network contributing to species' long-term persistence.

We apply the framework to the case of two sensitive species, *Macaca thibetana* and *Lophura nycthemera* in Wuyishan Nature Reserve, China. Wuyishan Nature Reserve (WYS) is situated at the juncture of the cities of Wuyishan, Jianyang, Shaowu and Guangze County, Fujian Province (latitude: 27.55–27.9° N, longitude: 117.45–117.85° E), and covers a total area of 565.27 km^2. It is the largest and most comprehensive semi-subtropical forest system in the southeast China, with exceptionally diverse biological resources. According to the report of Wuyishan Nature Reserve General Planning Project, approximately 2500 rural residents lived in WYS in 2001. Moreover, three tourism districts and several construction projects within have been set up. *M. thibetana*, known as the Chinese stump-tailed macaque, is a large gregarious mammal only found in East and Central China. Previous survey (Wang and Xiong, 1989) shows that *M. thibetana* is less able to adapt to the environmental changes, thus habitat loss, degradation and fragmentation due to human activities may intensely threaten its survival in WYS. *L. nycthemera*, an arboreal bird, is also sensitive to human activities. It has been documented that *L. nycthemera* can be seldom found within the range of 1 km from roads (Cheng et al., 2009).

3. Methodology

We here develop a heuristic solution procedure in three stages (see Fig. 1). In the first stage, we use the Maximun Entropy Algorithm to project species *i*'s potential geographic occurrences. The resulting probabilistic distribution data are used to partition a nature reserve into sites with high occurrence probability, medium occurrence probability and low occurrence probability. Both of the first two categories are chosen to determine representative reserves that supply enough space for species' survival. Moreover, sites that describe human disturbances are also selected if they separate the reserves composed of contiguous sites with high and medium species occurrence probabilities. Next, for each pair of representative reserves between which the direct dispersals are hindered by identified artificial barriers, a constructed reserve is designed to remove the human-induced impact in order to reconnect the reserves. The principles of constructed reserves selection are established, and the assessment approach that measures the