Environmental Modelling & Software 90 (2017) 126–146

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Systematically designating conservation areas for protecting habitat quality and multiple ecosystem services

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ARTICLE INFO

Article history:
Received 28 July 2015
Received in revised form
26 October 2016
Accepted 6 January 2017

Keywords:
Simulation model
Systematic conservation planning
Spatial autocorrelation
Connectivity
Habitat quality
Zonation
InVEST
Ecosystem services

ABSTRACT

Habitat quality and ecosystem supply are important factors when identifying conservation areas. Traditionally, conservation planning approaches focus solely on habitat. In this study we calculated habitat quality and five other ecosystem service values through the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) and also identified hotspots for each ecosystem service value through the Local Indicator of Spatial Association (LISA). Conservation areas that protect habitat quality and ecosystem services were simulated using the Zonation software with three scenarios of ecosystem service distribution. Four Boundary Length Penalties were also tested in terms of how well they produce suitable reserve sites. Finally, we developed the LISA-Zonation program which performs systematic conservation planning based on InVEST outputs. The ecosystem services hotspots represent spatial autocorrelations among neighboring cells and ecosystem service values, yielding conservation strategies which balance ecosystem service values with spatial connectivity. Our novel approach finds spatial autocorrelation of ecosystem services to identify conservation areas that provide potential benefits to people.

Software availability

Name: LISA-Zonation 1.0
Programming language: R, QGIS 2.20
Developers: Yu-Pin Lin, Wei-Chih Lin
Availability: http://homepage.ntu.edu.tw/~yplin/Software.htm
Hardware required: PC
Software required: X64 Windows OS

1. Introduction

Ecosystem services are central to modern conservation strategies. Traditionally, conservation planning has focused on the species and habitat component of natural capital, without due consideration to the many important ecosystem services supplied by that natural capital (Brooks et al., 2006). Thus, models designed to quantify supply of ecosystem services are developing rapidly. The mapping of ecosystem services is one of the most important methods for incorporating services into conservation policies. Mapping ecosystem services also contributes to our understanding of ecosystems requiring effective management (Burkhard et al., 2013; Crossman et al., 2013a,b). Although the concept of ecosystem services is mature to the point that it can inform policy-making, scientific understanding and implementation in real-world decision making remains a challenge (Ruckelshaus et al., 2015).

Recent efforts have been made to improve the evaluation and protection of ecosystem services in the conservation sciences (Daily et al., 2009). Numerous studies have used ecosystem services to generate conservation plans (Balvanera et al., 2014; Chan et al., 2006; Egoh et al., 2007; Egoh et al., 2010, 2011; Chan et al., 2011;

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http://dx.doi.org/10.1016/j.envsoft.2017.01.003
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Moilanen et al., 2011). The inclusion of ecosystem services in conservation or land use planning offers an integrated multidisciplinary approach to evaluating the benefits of various conservation objectives (Balvanera et al., 2014; Egoh et al., 2007) because of the potential to explicitly link conservation with human wellbeing (Chan et al., 2011). An integrated approach that focuses on the human benefits of conservation plans should lead to a better implementation of conservation actions within land use planning (Knight et al., 2006; Egoh et al., 2007).

Systematic conservation planning is a technique to identify optimal scenarios of habitat protection (Margules and Pressey, 2000; Lehtomäki and Moilanen, 2013) and restoration (Crossman and Bryan, 2006, 2009). Conservation planning models, such as Zonation, can be applied to ecosystem services (Moilanen et al., 2011; Thomas et al., 2013) to identify the best areas for preserving target habitat and the ecosystem services supplied by that habitat. Although much is known about individual ecosystem services, less attention is paid to the inter-relationship between multiple ecosystem services and the multiple ecosystem service benefits potentially available from systematic conservation planning approaches (Bennett et al., 2009; Chan et al., 2011). Typically the spatial relationships (Anderson et al., 2009), such as spatial autocorrelation between multiple ecosystem services is assumed (Troy and Wilson, 2006; Anderson et al., 2009) or is not considered (Chan et al., 2006). More recent studies have discussed the spatial correlations between biodiversity and ecosystem services (Bai et al., 2011; Maes et al., 2012; Bhagabati et al., 2014); some studies investigated the autocorrelation and heterogeneity of multiple ecosystem services (Wen et al., 2010; Maes et al., 2012; Plieninger et al., 2013; Su et al., 2014) and confirmed the existence of spatial autocorrelation for patterns of ecosystem service values and their changes (Wen et al., 2010; Plieninger et al., 2013; Su et al., 2014).

Here we use the spatial patterns and autocorrelations of habitat quality and multiple ecosystem services to identify efficient areas for conserving ecosystem services. Our novel approach takes into account the spatial connectivity of selected conservation areas and aims to select proportional representation of multiple ecosystem services rather than focus just on total amount of services. We first use the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) tool to quantify six ecosystem services using land use and climate data. We then identify areas to conserve using three approaches, two of which combine Zonation with the autocorrelation of habitat quality and each ecosystem service. We introduce the Local Indicators of Spatial Association (LISA) statistic (Goovaerts, 2009) to analyse autocorrelation and identify ecosystem service hotspots. We develop a LISA-Zonation program in QGIS that performs autocorrelation analysis and implements Zonation for simulating potential conservation areas for habitat quality and multiple ecosystem services. Finally, we compare the potential conservation areas simulated under different scenarios of proportional selection.

2. Materials and methods

2.1. Study area

The study area is the Wutu watershed located east of Taipei in Taiwan (Fig. 1). The total area of the Wutu watershed is 204 km^2, and is covered mainly by forest (83% of the total area). Other land uses include built-up areas, agriculture, grassland, bare land, and water (Table 1). The elevation of this watershed ranges from 15 m to 873 m above sea level (Fig. S1). Slopes greater than 20° cover 16.3% of the total area (Fig. S1). Climate data were obtained from the Data Bank for Atmospheric Research (DBAR; https://dbar.ttfri.narl.org.tw/). Precipitation data were estimated at 100 $m \times 100$ m grid cell resolution and interpolated using data from observation stations near or within the Wutu watershed study area. The Huo-Shao-Liao Mountain is the wettest location in Taiwan, and precipitation in the study area is highest in the southern and eastern areas.

2.2. Model overview

Fig. 2 summarises the modeling steps. We use Zonation (Moilanen, 2007) to identifiy areas for protecting habitat quality and ecosystem services (HQ-ESs) in the study area. Initially, the habitat quality and ecosystem services of carbon storage, water yield, soil retention, and nutrient (nitrogen and phosphorous) retention were modeled using InVEST, which was Version 2.2.2 released on 3/3/2012. Developed by the Natural Capital Project, InVEST (Tallis et al., 2011) comprises a series of modules that estimate ecosystem service supply and value using land use/cover patterns and climate conditions (Goldstein et al., 2012; Nelson et al., 2009, 2010). This model has been widely applied to evaluate the impacts of changes in land use on ecosystem services (Polasky et al., 2011) and to support land-use development planning (Goldstein et al., 2012). Land use and climate data from 2008 provided the major inputs into InVEST.

Three scenarios were used to assess the influence of HQ-ES spatial clustering on simulating potential HQ-ES conservation areas in Zonation. Under Scenario 1, the spatial distributions of HQ-ESs were used in Zonation to identify appropriate areas for meeting conservation targets. In Scenario 2, hotspots of HQ-ESs were first identified using LISA with the resultant hotspots input into Zonation. In Scenario 3, weighted HQ-ES hotspots, calculated by multiplying LISA-derived HQ-ES hotspots with InVEST ecosystem service values, were input into Zonation.

The LISA-Zonation R program developed for Scenarios 2 and 3 uses R and QGIS 2.2.0 to integrate the LISA method into Zonation. The QGIS Desktop 2.2.0 version requires a minimum of a 1.6 GHz processor, 1.0 GB RAM, and Windows XP or later. LISA-Zonation was developed using R and designed for identifying areas for protecting ecosystem services with not only high ecosystem service values but also high spatial autocorrelations among neighboring cells. The structure of LISA-Zonation comprises two main components: spatial autocorrelation analysis with LISA, and conservation priority with Zonation (Fig. 3). Habitat quality and ecosystem service layer outputs from InVEST, in the QGIS shapefile format, provide the basic dataset that is input into the LISA-Zonation program to calculate hotspots for habitat quality and each ecosystem service.

In each scenario, reserve areas with representation targets of 10, 20, and 30 percent were considered, meaning the top 10, 20, and 30 percent of cells as ranked according to the least biological loss simulated by Zonation were selected. In addition, different boundary length penalties (*BLPs*), such as 0, 0.1, 0.5, and 1, were adopted in each scenario.

2.3. Quantifying supply of habitat quality and ecosystem services

The habitat quality and ecosystem services we estimated using InVEST were carbon storage, habitat quality (as a proxy for biodiversity), water yield, soil retention, and nutrient (nitrogen and phosphorous) retention. Table 2 lists the data inputs for calculating each ecosystem service and the data sources for each input data. The input data used in the InVEST model were predominately obtained from government authorities, previous research, and reports. The retention efficiencies for nitrogen and phosphorus were assigned according to the land use type and are listed in Table 2.