Estimation and prediction of plant species richness in a mosaic landscape

Rainer Waldhardt*, Dietmar Simmering and Annette Otte
Institute of Landscape Ecology and Resources Management, Division of Landscape Ecology and Landscape Planning, Justus-Liebig-University Giessen, IFZ, Heinrich-Buff-Ring 26-32, D-35392 Giessen, Germany; *Author for correspondence (e-mail: rainer.waldhardt@agrar.uni-giessen.de)

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Abstract

Traditional agricultural mosaic landscapes are likely to undergo dramatic changes through either intensification or abandonment of land use. Both developmental trends may negatively affect the vascular plant species richness of such landscapes. Therefore, sustainable land-use systems need to be developed to maintain and re-establish species richness at various spatial scales. To evaluate the sustainability of specific land-use systems, we need approaches for the effective assessment of the present species richness and models that can predict the effects on species richness as realistically as possible. In this context, we present a methodology to estimate and predict vascular plant species richness at the local and the regional scale. In our approach, the major determinants of vascular plant species richness within the study area are taken into consideration: These are according to Duelli’s mosaic concept the number of habitat types and of habitat patches within area units. Furthermore, it is based on the relative frequencies of species within habitat types. Our approach comprises six steps: (i) the determination of present habitat patterns within an observation area, (ii) the creation of a land-use scenario with simulated habitat patterns, (iii) the determination of species frequencies within habitat types of this area, (iv) a grouping of habitat-specific species, (v) the estimation of the probabilities for all species (or habitat specialists) to occur, either in stepwise, exponentially enlarged landscape tracts (local scale), or in the entire observation area (regional scale), and (vi) the validation of the estimated species numbers. The approach will be exemplified using data from the municipal district of Erda, Lahn-Dill Highlands, Germany. The current species numbers to be expected on the basis of probability calculations were compared with those recorded on the basis of extensive field work. This comparison shows that, on the basis of our simple calculations, the current local plant species richness can be predicted well, with a slight underestimation.

Introduction

In terrestrial ecosystems, many changes of biodiversity within the next 100 years will probably be due to land-use change (Matson et al. 1997; Sala et al. 2000). Traditional agricultural mosaic landscapes, in particular, are likely to undergo dramatic changes by either intensification of land use or abandonment (Baldock et al. 1996; MacDonald et al. 2000; Burel et al. in press). Both developments are likely to have adverse socio-economic and environmental impacts (Bouma et al. 1998). Therefore, concepts for appropriate and sustainable land-use systems need to be developed in order to maintain and re-establish biodiversity at local to regional scale.

In this context, the development of suitable methods for assessing components of current diversity and for the prediction of the effects of land-use change on
biodiversity is an urgent task of landscape-ecological research. However, decisions regarding future land-use concepts and resources management are not made by scientists, but by agricultural policy, conservation authorities, landscape planners, and, last but not least, farmers. Hence, scientific tools for the prediction of effects of land-use changes must be scientifically sound, reliable and generally applicable in managed landscapes. Additionally, they should be user-friendly, cost-efficient and easily communicable to non-scientific users and audiences (cf. Stohlgren et al. 1997a).

Landscape ecologists have proposed numerous correlative approaches to link i) landscape indices (cf. O’Neill et al. 1988; Hulshoff 1995; Haines-Young and Chopping 1996; Wrbka et al. 1999; Luoto 2000; Luoto et al. 2002, Opdam et al. 2003), ii) environmental data and management information (McCracken et al. 2000, Wilson et al. 2003) or iii) organismic indicators (cf. Duelli and Obrist 1998; Lawesson et al. 1998; Fleishman et al. 2000; Sahlen and Ekestubbe 2001; Waldhardt and Otte 2003) with biodiversity measures. However, these attempts have not yet led to a methodology that would meet the requirements mentioned above. The most obvious problems are scale dependency and the lack of consistency in correlations between indices / indicators and environmental response variables (cf. Turner et al. 1989; Gustafson 1998; Levin 2000; Tischendorf 2001).

Another crucial problem for landscape ecologists is the proper choice of the basic unit for the analysis of relations between biodiversity and land use. For obvious reasons the farm level seems to be well suited (cf. Freemark and Kirk 2001; Weibull et al. 2003.), since the farm is actually the unit at which management decisions with their specific effects on biodiversity are taken. However, in mosaic landscapes the fields belonging to one farm are often scattered about the entire farmland of sometimes even more than one municipality. This makes it difficult to detect spatially explicit relations between land use and biodiversity on the farm level. Thus, a reasonable approach for mosaic landscapes is to choose the field as the basic unit of analysis (cf. McCracken et al. 2000; Waldhardt and Otte 2003), since this is the unit at which management is applied. As well, fields have the advantage to be spatially discrete and, considering site conditions and land use, they represent a more or less homogenous environment.

Promising results in the development of predictive models for biodiversity measures at the regional scale have recently been obtained by focusing on species-area relations (cf. Rosenzweig 1995; Stohlgren et al. 1997a; Ma et al. 2002; Pysek et al. 2002). Species richness is only one component of biodiversity, but it is widely regarded as an essential basis for other components of biodiversity, such as biocenoses, characterized by specific structures and functions (Noss 1990; Waldhardt and Otte 2000). Therefore, a concentration on species richness for the analysis of effects of land-use change is justified.

Equilibrium Theory of Island Biogeography (MacArthur and Wilson 1963; MacArthur and Wilson 2001), which is at the core of the approaches mentioned above, has been widely discussed and tested for species richness of distinct habitat islands (e.g., Johnson and Simberloff 1974; Harris 1984; Case and Cody 1987; Shafer 1990; Köchy and Rydin 1997). However, while having a good predictive value for distantly scattered insular and natural habitats, the expectations of Island Theory fail to match with empirical data on species diversity in agricultural landscapes with their complex patterns of numerous habitats (Duelli 1992). This deficiency was taken into account by the formulation of the mosaic concept (Duelli 1992; Duelli 1997). The mosaic concept was originally developed with a focus on the diversity of arthropods but applies to other taxonomic groups as well. It is based on the assumption that species numbers increase with (i) habitat variability (i.e., number of habitat types per area unit), and (ii) habitat heterogeneity (i.e., number of habitat patches per area unit).

While, according to Island Theory, increasing species numbers are correlated with increasing patch areas, the mosaic concept anticipates an increase in species numbers owing to an increase in the number and size variation of habitat patches. Even though the mosaic concept represents a valuable new approach for the evaluation and prediction of species richness in agricultural landscapes, to our knowledge, there have been no studies that explicitly examined this concept with respect to the development of predictive models for species richness at the landscape scale.

The aim of our study was to develop a methodology that – based on the mosaic concept – permits (i) an effective assessment of the present vascular plant species richness in a small-scale agricultural landscape, and (ii) estimations of the effects of land-use change on species richness. Our approach considers the two most important characteristics of landscape structure, i.e., habitat types and number of habitat patches. Land-use change can, dependent on the size