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Biodiversity and ecosystem services—A case study for the assessment of multiple species and functional diversity levels in a cultural landscape

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ABSTRACT

The expansion of large-scale plantations has a major impact on landscapes in the Tropics and Subtropics. Crops like soy bean, oil palm and rubber have led to drastic changes in land cover over the past decades, thereby altering ecosystem functions and services (ESS). Associated shifts in ESS such as climate regulation, erosion and water cycles, biodiversity as well as soil fertility or the provisioning of raw materials have been assessed through several models and software solutions (InVEST, ARIES, MIMES). However, suitable methods for the integration of a range of biodiversity assessments in agricultural landscapes are scarce.

With this study, we introduce a methodology for incorporating multiple levels of species diversity into models to allow an integrated evaluation of ESS. We collected data sets from both published and unpublished sources on the distribution of vascular plants, selected pollinator groups, ground beetles, ungulates as well as amphibians, mammals, reptiles and birds in rubber-dominated landscapes, with a focus on our study sites in Southwest China and Thailand. Based on this information, we developed a common classification scheme that enables the integration of different facets of biodiversity (species diversity and functional diversity) to complement an interdisciplinary ESS assessment.

Species diversity data were normalized against the most divers habitats reported (using habitat scores) to assess the impact of rubber cultivation on multiple levels of biodiversity. This resulted in a comparable matrix of different land use types and their suitability as habitat for the respective species groups allowing the aggregation of very diverse indicators. The findings were applied to two alternative land use scenarios in southern China to highlight the potential effects of land use and management decisions on species and functional diversity. Our results highlighted that the conservation oriented scenario did score higher for habitat suitability in both total species (+5%) as well as IUCN Red List species (+6%) assessments compared to the current state or business as usual scenarios (-2% and −3% compared to current state).

The process presented here allows for an application within established ESS software programs, in our case InVEST, using aggregated indices while additionally providing enhanced opportunities for comparable, spatially explicit assessments of the expected impact of the analyzed scenarios on specific species groups.

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1. Introduction

Although biodiversity is not an Ecosystem Service (ESS) in the narrow sense, it is inextricably linked to ESS because biodiversity influences their provision (MEA 2005). Several analytical tools exist to allow for replicable and quantifiable ESS analyses, such as InVEST (Integrated Valuation of Ecosystem Services and Trade-offs), ARIES (ARtificial Intelligence for Ecosystem Services, 2016a,b; Villa et al., 2014) and MIMES (Multiscale Integrated Model of Ecosystem Services), which all belong to the group of independently applicable and generalizable landscape-scale models (Bagstad et al., 2013a).

InVEST is provided by the Natural Capital Project (The Natural Capital Project 2015, 2016) and has a modular approach. Its tools are based on deterministic production functions; two of them cover biodiversity issues: habitat quality and habitat risk assessment. The habitat model of InVEST has already been used in different scientific analyses (e.g. Dhakal et al., 2014; Terrado et al., 2016). ARIES includes not only the provisioning of ESS and possible trade-offs,

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but also the flow and the use of ESS. The current release includes eight ESS and even though there is no explicit model on biodiversity, the link between biodiversity and ESS is stated frequently. Although InVEST and ARIES differ greatly in their methodology, a comparison of the two tools yielded similar results for the ESS carbon, water and scenic view sheds for a case study in Arizona (Bagstad et al., 2013b). MIMES aims at supporting sustainable and ecosystem-based management planning with a special focus on incorporating concepts to capture the dynamic character of coupled human and natural systems. Biodiversity is included in the modeling process as being part of the biosphere, but neither explicitly mentioned as output nor included in the research questions so far presented in the literature (Boumans et al., 2015).

Out of these three possibilities we chose InVEST for our analyses because it has the most detailed routine for the evaluation of biodiversity within the framework of available ESS assessment tools. By combining aspects of habitat suitability with the potential to analyze alternative scenarios of land use decision, it was the most suitable tool to meet our research questions. In addition it is open-source, well-documented and the models have a high generalizability (Bagstad et al., 2013a).

Human activities have a strong impact on the distribution of habitats, land cover and landscape patterns throughout the world. Deforestation, transformation, degradation and intensification impact the quality and quantity of ESS provided by a given landscape; the potential as habitat for species being one of these (Ahrends et al., 2015). The expansion of rubber (*Hevea brasiliensis)* in mainland Southeast Asia (MSEA) is providing a suitable case study to asses some of these impacts (Ziegler et al., 2009), as a range of studies have covered the implications for single species groups, but so far a general assessment is amiss.

The shift from low input agriculture to intensified systems additionally reduces functional and species diversity and consecutively, the availability of potentially useful habitat types for species originating from natural forest. Rubber plantations generally harbor less than half of the original fauna and flora species richness compared to natural forest. Most studies therefore found that many of these species are unable to exist permanently in rubber plantations(Beukema and van Noordwijk 2004) . There is clear evidence that the existence of natural forest area is essential for the conservation of large proportions of native forest species in rubber-dominated landscapes (He and Martin, 2015).

1.1. Study sites

The research area to which our model is applied is the Naban River Watershed National Nature Reserve (NRWNNR, 22°08′N 100°41′E) in Xishuangbanna, Yunnan Province, PR China. The nature reserve covers 271 km^2 and its elevation ranges from 500 m to 2300 m a.s.l., covering the watershed of the Naban River, a tributary of the Mekong River. It features an especially high diversity of natural vegetation types, as well as a variety of land use systems due to the topographically and ethnically diverse background of the region (Zhu et al., 2005). In Xishuangbanna, economic development and biodiversity conservation compete for the same land. So far, economic goals have dominated: from 1976 to 2003, 140,000 ha of tropical rainforest were replaced by rubber (Li et al., 2005). Since then, forest clearing has continued.

Data on mammal diversity were mainly collected in the Province Surat Thani in southern Thailand, in and around the Tai Rom Yen National Park (TRY). TRY is located in the East of the province and covers an area of about 400 km^2 with an elevation range from around 100–1200 m a.s.l.(Maddox et al., 2007; Pfeffer 2013) The protected area was created in 1991 and includes evergreen forest, partly characterized by limestone formations (DNP 2013), as well as cultural landscapes dominated by rubber plantations. This region is a traditional rubber cultivating area (Li and Fox 2012) that lies within the transition zone of the Indo-Burma and Sundaland biodiversity hotspots, home to more than 300 mammal species (Myers et al., 2000).

2. Material and methods

2.1. General approach

With this study we aim to introduce a methodology for incorporating multiple levels of species diversity into models to supplement the evaluation of ESS. We have combined original data from field work within our study sites with complementary data on biodiversity from detailed literature review studies. In order to make these results comparable we conducted a normalization process and integrated this data into the spatially explicit model habitat suitability model of InVEST.

2.2. Own studies on site

Floristic inventory data were analyzed considering the occurrence of rare and endemic species according to the IUCN (International Union for Conservation of Nature) red list of species, and the value of a vegetation type for human use, expressed through the number of medicinally usable plants. A total of 18,901 m^2 of land in NRWNNR were surveyed based on 610 plots, with different sizes (1m^2 for rice paddies to 400m^2 for forest plots) for different land use types (see Table 1). Some 1252 species from 635 genera and 158 families were identified. More details (sampling structure, size bias and categorization) are described in Cotter et al. (2014).

We assessed the presence of ungulates using camera traps, transect surveys and spoor plots in two different protection zones in 2010, for detailed data collection see (Treydte et al., 2013). Mammal diversity data were collected in the years 2013 and 2014 through camera traps, transect surveys and interviews with local farmers living in the periphery of the TRY National Park in Thailand. In Thailand, assessments were undertaken inside the natural forest, in the adjacent farmland and at the forest-farmland boundary. A total of 180 randomly selected farmers were interviewed around the TRY National Park about wildlife species and number of individuals that came to the farmland. Camera traps were repeatedly installed at 30 locations along the forest edge around the protected area. Further, 21 locations were sampled several km into the forest, along wildlife trails. Cameras remained at least two weeks in one location. In addition, data were collected on 25 one-km trail-transects within the forest and along 25 complementary transects up to one km into the farmland, in perpendicular distance to the forest border. All mammal species were considered but for small species such as mice, rats or squirrels identification to species level was often not feasible and most animals recorded were assigned to the overall taxonomic group of ‘rodents’, resulting in a non-proportional low species number for this group. Other groups for which we recorded sufficient species were ungulates, carnivores and primates. Various small species with a weight of less than 7 kg belonging to different taxonomic groups were compiled in the group ‘other small mammals’, e.g. treeshrews (*Tupaia glis*), pangolins (*Manis javanica*) and colugos (*Galeopterus variegates*).

2.3. Literature research

By using Scopus bibliographic database, we investigated published articles dealing with animal biodiversity in rubber plantations in comparison to natural habitats, and other land use types when indicated. For data analysis, we selected studies for two criteria: (a) precise and comparative information on species numbers in rubber plantations and natural habitats, (b) studies located in

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