Ecological Indicators 91 (2018) 278–286

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

A framework to identify indicator species for ecosystem services in agricultural landscapes

Klaus Birkhofer[a,b,*], Adrien Rusch[c,d], Georg K.S. Andersson[b,e], Riccardo Bommarco[f], Juliana Dänhardt[g], Barbara Ekbom[f], Annelie Jönsson[b,g], Regina Lindborg[h], Ola Olsson[b], Romina Rader[i], Martin Stjernman[b], Alwyn Williams[j], Katarina Hedlund[b], Henrik G. Smith[b,g]

[a] Department of Ecology, Brandenburg University of Technology Cottbus-Senftenberg, Germany
[b] Department of Biology, Biodiversity and Conservation Science, Lund University, Sweden
[c] French National Institute for Agricultural Research (INRA), France
[d] Univ. Bordeaux, Bordeaux Sciences Agro, France
[e] Instituto de Investigación en Recursos Naturales, Agroecología, Desarrollo Rural, Universidad Nacional de Río Negro (UNRN), Argentina
[f] Swedish University of Agricultural Sciences, Department of Ecology, Uppsala, Sweden
[g] Centre for Environmental and Climate Research (CEC), Lund University, Sweden
[h] Landscape Ecology, Department of Physical Geography, Stockholm University, Sweden
[i] University of New England, School of Environmental & Rural Science, Australia
[j] School of Agriculture and Food Sciences, University of Queensland, Australia

ARTICLE INFO

Keywords:
Agricultural intensification
Biodiversity
Ecosystem service assessment
Indicator analysis
Multifunctionality
Trade-offs
Synergies

ABSTRACT

Improving our understanding of the relationships between biodiversity and the delivery of ecosystem services is crucial for the development of sustainable agriculture. We introduce a novel framework that is based on the identification of indicator species for single or multiple ecosystem services across taxonomic groups based on indicator species analyses. We utilize multi-species community data (unlike previous single species approaches) without giving up information about the identity of species in our framework (unlike previous species richness approaches). We compiled a comprehensive community dataset including abundances of 683 invertebrate, vertebrate and plant species to identify indicator species that were either positively or negatively related to biological control, diversity of red-listed species or crop yield in agricultural landscapes in southern Sweden. Our results demonstrate that some taxonomic groups include significantly higher percentages of indicator species for these ecosystem services. Spider communities for example included a higher percentage of significant positive indicator species for biological control than ground or rove beetle communities. Bundles of indicator species for the analysed ecosystem service potentials usually included species that could be linked to the respective ecosystem service based on their functional role in local communities. Several of these species are conspicuous enough to be monitored by trained amateurs and could be used in bundles that are either crucial for the provision of individual ecosystem services or indicate agricultural landscapes with high value for red-listed species or crop yields. The use of bundles of characteristic indicator species for the simultaneous assessment of ecosystem services may reduce the amount of labour, time and cost in future assessments. In addition, future analysis using our framework in other ecosystems or with other subsets of ecosystem services and taxonomic groups will improve our understanding of service-providing species in local communities. In any case, expert knowledge is needed to select species from the identified subsets of significant indicator species and these species should be validated by existing data or additional sampling prior to being used for ecosystem service monitoring.

1. Introduction

Intensified use of mineral fertilisers, pesticides and fossil fuels in agriculture to meet increasing demands for food and fibre undermines the sustainability of agriculture by harming biodiversity-based Ecosystem Services (ES) (Power, 2010). A proposed solution to this dilemma is ecological intensification of agricultural production, i.e. increasing yield by promoting biodiversity-based ES (Doré et al., 2011). Understanding the relationship between biodiversity and ES is therefore crucial for the development of sustainable agriculture (Duru et al.,

* Corresponding author at: Department of Ecology, Brandenburg University of Technology Cottbus-Senftenberg, Konrad-Wachsmann-Allee 6, 03046 Cottbus, Germany.
E-mail address: Klaus.Birkhofer@b-tu.de (K. Birkhofer).

https://doi.org/10.1016/j.ecolind.2018.04.018
Received 4 September 2017; Received in revised form 5 April 2018; Accepted 9 April 2018
1470-160X/

Table 1
Major characteristics for ecosystem service potentials and biotic communities that were analysed in this study.

	Unit	Scale	Range	Study landscapes	References
a) ES potentials					
Biological control potential	aphid biocontrol index	Field	0.12–0.86	31	Rusch et al. (2013)
Red-list biodiversity potential	weighted # red-listed species	Both	4–12	23	This study
Yield potential	t/ha*	Field	2.80–8.20	40	This study
b) Biotic communities					
Spiders (Araneae)	NA	Field	NA	41	Rusch et al. (2014)
Ground beetles (Carabidae)	NA	Field	NA	41	Rusch et al. (2014)
Rove beetles (Staphylinidae)	NA	Field	NA	41	Rusch et al. (2014)
Hoverflies (Syrphidae)	NA	Farm	NA	41	Jönsson et al. (2015)
Birds (Aves)	NA	Farm	NA	24	This study
Plants (Tracheophyta)	NA	Farm	NA	39	Rader et al. (2014)

* Yield values were corrected for differences in farming systems by using residuals after fitting farming system (conventional or organic) to yield quantities in $t\,ha^{-1}$ (Birkhofer et al., 2016).

2015). Although species richness can be a predictor for the levels of some ES (Balvanera et al., 2006; Harrison et al., 2014; Tilman et al., 2014), these relationships are not always strong (Lyashevska and Farnsworth, 2012; Gagic et al., 2015). Instead, ES are in many cases provided by abundant and functionally important species (Winfree et al., 2015) that indicate the provision of ES (Bastian, 2013). Considering the relationship between individual species and their abundances in local communities on one side, and ES levels on the other, might therefore facilitate the management of ES through species conservation and may provide better predictions of ES levels (Mokany et al., 2008).

Indicator species analysis was originally developed to identify species that indicate different environmental conditions and anthropogenic stress levels in local habitats (Dufrêne and Legendre, 1997; Baker and King, 2010; Siddig et al., 2016). Ground beetles, for example, have been used as bio-indicators for environmental gradients (Rainio and Niemelä, 2003) and arable weed species can act as indicators of overall biodiversity in agroecosystems (Albrecht, 2003). There is a growing awareness that only multi-taxon studies allow us to address the complex relationships between community changes and related functions (Allan et al., 2014). From an ecosystem service perspective, multi-taxon bundles would consist of species that are positively or negatively related to levels ES potentials ("potential" defined as the ability of landscapes to deliver an ES) (Haines-Young et al., 2012). Such approaches could also contribute to the identification of landscapes with a high overall potential for multifunctionality (sensu "ecosystem service multifunctionality" in Manning et al., 2018; e.g. Birkhofer et al., 2018) by monitoring bundles of species that act as indicators for sets of multiple ES. Previous studies addressed the indicator-based assessment of ES potentials by monitoring single species (species approach, Luck et al., 2003) or species richness patterns in local communities (species richness approach, Cardinale et al., 2012). There is, however, no empirical knowledge on how bundles of individual species across taxonomic groups can be utilized to indicate levels of ES (Harrison et al., 2014). In addition, our framework allows for the simultaneous analysis of all species in local communities (with the exception of very rare species) which reflects the fact that species are not independent entities in local communities, but instead interact with each other.

Here, we introduce a novel framework to identify indicator species from communities across taxa for a) predaceous arthropod taxa (Araenae, Carabidae and Staphylinidae) and levels of aphid biological control and for b) a large range of taxonomic groups (Araenae, Carabidae, Staphylinidae, Syrphidae, Aves and plants) and levels of overall biodiversity and yield potential in agricultural landscapes. The first analysis is motivated by the fact that communities of generalist predators contribute to biological control services (Symondson et al., 2002). This approach therefore holds particular potential for the future improvement of biological control strategies through conservation practices that target bundles of predator species. The second set of analyses is motivated by previous results that suggest that species in communities of individual taxa can act as indicators for biodiversity or yield (Wolters et al., 2006; Ekroos et al., 2013). This approach holds particular potential for the future assessment of biodiversity and yield potentials by monitoring a selected range of species that could be simultaneously utilized as indicators for overall biodiversity and yield in agricultural landscapes.

For the indicator analyses, we used a comprehensive community dataset of 683 invertebrate, vertebrate and plant species and altered the traditional concept (assessing indicators of changing environmental conditions) to a novel framework (assessing indicators of high or low ES levels). We hypothesize that the identified positive indicator species in the predator species vs. biological control analysis (a) can be causally linked to aphid biological control. We further hypothesize that indicator species in the second set of analyses (multi-taxon species list vs. biodiversity of red-listed species and crop yield) (b) are characteristic for agricultural landscapes with different levels of trade-offs between biodiversity and yield. In addition, our multi-taxon analyses highlight the suitability of individual taxonomic groups as indicators for different ES. Identifying multi-species indicator bundles for ES fills important knowledge gaps as it will help to improve our understanding of the linkage between biodiversity and ES (Maes et al., 2016). The proposed framework can be utilized in future studies focusing on community data to identify service-providing species or to utilize sets of species as simultaneous indicators of levels of ES in agricultural landscapes.

2. Material and methods

2.1. Study sites

Communities and ES potentials (Table 1) were quantified within 1 km radius landscapes centred around 41 farms in the province of Scania in southern Sweden in spring and summer 2011 (Fig. 1; hereafter referred to as "study landscapes"). This scale was chosen to facilitate the selection of study landscapes because several of the studied taxonomic groups are known to relate to landscape characteristics at this scale (e.g. beetles & spiders: Rusch et al., 2014, plants: Rader et al., 2014). This study only used landscapes with farms that cultivated spring barley (*Hordeum vulgare* L.). Barley is a common crop in agricultural production areas of Scania and therefore allows for selection of non-overlapping radii and a wide distribution of study landscapes in Scania. The majority of barley fields in the study landscapes was ploughed or treated with a cultivator (31 out of 41), but only about half of the fields were treated with herbicides (21). Note that plant communities were not assessed inside barley fields, but in field margins in this study. The selection of landscapes with a focus on barley production across Southern Sweden allows for some generalizations regarding