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Effects of agricultural landscape heterogeneity on arthropod biodiversity

M. Bascietto[1], E. Malusà[2], A. Lamontanara[3], E.M. Furmanczyk[2], M. Tartanus[2], G. Podedworny[2] and L. Orrù[3]

Abstract

Understanding how agricultural landscape heterogeneity influences beneficial arthropod biodiversity is fundamental for developing sustainable orchard management strategies. In this study, we analyzed the relationship between vegetation structure, quantified through landscape metrics based on normalized difference vegetation index (NDVI), and arthropod diversity. NDVI data from remote sensing were processed to classify the landscape into phenological classes representing different vegetation dynamics. The resulting spatial patterns were used to compute metrics of landscape compositional and configurational complexity. Beneficial arthropods were sampled in various organic apples and raspberry in Poland and their alpha diversity was estimated using the ACE, Chao1, Simpson, and Shannon indices. Linear models were applied to evaluate the influence of landscape complexity on arthropod diversity. The results indicate that increased landscape compositional complexity and diversity are significantly associated with higher arthropod species richness, supporting the hypothesis that landscape complexity enhances ecosystem biodiversity in agricultural systems.

Keywords: landscape complexity; phenology, NDVI; arthropod diversity.

Introduction

The transition towards agricultural practices based on agrobiodiversity requires the understanding of the ecological mechanisms at work in agroecosystems at the landscape level. The interaction of these mechanisms with the agricultural practices and the landscape structure and complexity can indeed affect the supply of agroecosystem services (Tscharntke et al., 2012). Agricultural landscapes consist of complex mosaics of crops, semi-natural habitats, and non-crop elements. These structures influence the availability of resources and microhabitats for beneficial arthropods, including pollinators and natural enemies. Landscape complexity encompasses both its compositional aspect, reflecting the diversity of land-cover types, and its configurational aspect, describing their spatial arrangement (Turner et al., 2015).

Understanding spatial patterns of vegetation dynamics is essential for ecological monitoring and habitat assessment. Phenological profiles based on normalized difference vegetation index (NDVI) offer an effective means to quantify landscape heterogeneity and delineate potential habitats based on vegetation dynamics. This study investigates the relationship between NDVI-derived landscape compositional complexity metrics and the diversity of beneficial arthropods in orchard-dominated agroecosystems.

Material and Methods

NDVI data were computed from the Near-Infrared and Red bands in ESA Sentinel-2 satellite imagery over a one-year period (2023). A Random Forest classifier grouped temporal NDVI

[1] Council for Agricultural Research and Economics (CREA), IT-00015 Monterotondo (RM), marco.bascietto@crea.gov.it
[2] The National Institute of Horticultural Research, PL-96-100 Skierniewice
[3] Council for Agricultural Research and Economics (CREA), IT-29017 Fiorenzuola d'Arda (PC)

profiles into phenological classes (or phenoclasses). These classes represent distinct types of vegetation phenological behaviour and describe characteristic seasonal dynamics in vegetation activity, such as timing, amplitude, and stability of greenness, and are commonly used to classify and map vegetation functional patterns over large areas (e.g., Zhang et al., 2003). From the spatial distribution of phenoclasses, several landscape metrics were calculated, using the R package Landscapemetrics: Largest Patch Index (measuring the percentage of the landscape covered by the largest patch in the landscape); Splitting Index (effective number of equally-sized patches); Area CV (expressing the relative variability in patch size); Modified Simpson's Evenness Index (characterizing how balanced the proportions of phenoclasses are).

Arthropods were sampled once per month during the main vegetation season using pan traps, foliage taps and the evoSense sensors that monitor insect activity in the field by recording the wingbeat frequency of flying insects. The sampling was perfomerd in two apple orchards located in Grojec district (Central Poland) and four raspberry plantations located in the Opole Lubelskie district (Southeast Poland). Grojec territory is characterised by a strongly specialised apple production, with medium size orchards; the Opole Lubelskie territory where the raspberry plantations were located is characterized by very fragmented fields of limited size, where various crops are grown. In each site, one orchard/plantation was conducted with conventional methods and the others organically. Alpha diversity of arthropods was quantified using ACE, Chao1, Simpson, and Shannon indices calculated with the vegan R package. Relationships between landscape metrics and biodiversity indices were tested using linear regression models.

Results and Discussion

To explain how biodiversity is influenced by landscape metrics, a linear model was used to analyze the relationships between biodiversity data and different landscape metrics. Four metrics showed a significant relationship with biodiversity measures. ***Largest Patch Index (LPI)*** (Fig 1A) is a simple measure of dominance. LPI resulted associated with the ACE index (p-value: 0.02874; Adjusted R-squared: 0.334). It was evident that when the LPI value increased, (i.e. when one type of patch is dominant and occupies a significant portion of the landscape) the biodiversity measured with the ACE index decreases. The ***splitting index (SPLIT)*** (Fig 1B) resulted significantly associated with richness (ACE: p-value: 0.006237; Adjusted R-squared: 0.497). Since SPLIT quantifies the landscape fragmentation, higher values indicate that the landscape is more spatially heterogeneous. We found that higher values of the splitting index corresponded to higher values of richness measured with the ACE index. ***Area CV*** (Fig 1C) metric also showed a significant association with the ACE index (p-value: 0.03035; Adjusted R-squared: 0.3274). This index measures the relative variability of patch sizes: if the patches have very different sizes from each other, the index will be high. The fields considered in the present study with a higher CV value were characterized by a large dominant patch with other very small ones. The highest value of this index was associated with a lower value of biodiversity richness. ***Modified Simpson's Evenness Index (MSIEI***) (Fig 1D) resulted significantly associated with the ACE index (p-value: 0.01878; Adjusted R-squared: 0.3835). MSIEI is a measure of landscape evenness: high MSIEI value indicates a even distribution of patch types, while low values indicate a non-uniform distribution of phenological classes and therefore low landscape fragmentation. Lower values of the MISIE index were associated with lower biodiversity.

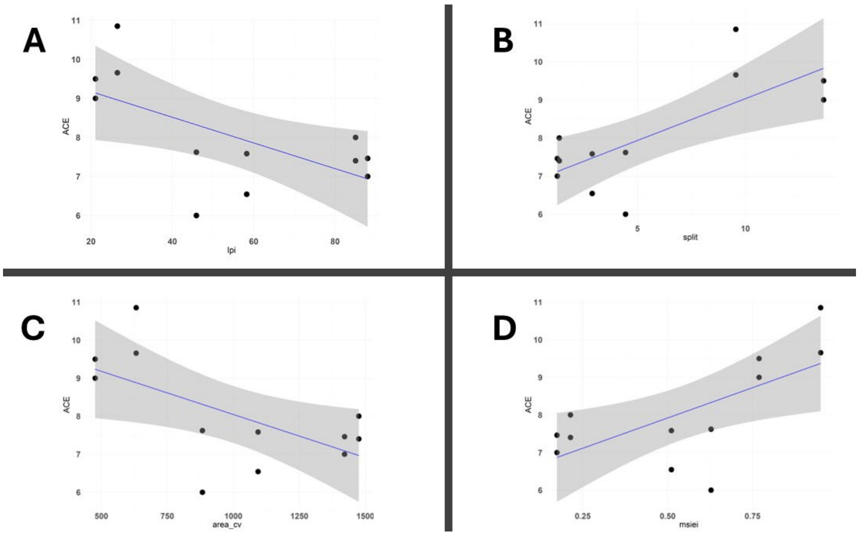

Figure 1: Linear regression plot for biodiversity showing the relationship between the species richness measured with the ACE index (y axis) and the following landscape metrics on the x axis: A) Largest Patch Index, B) Splitting index, C) Area CV index and D) Modified Simpson's Evenness Index.

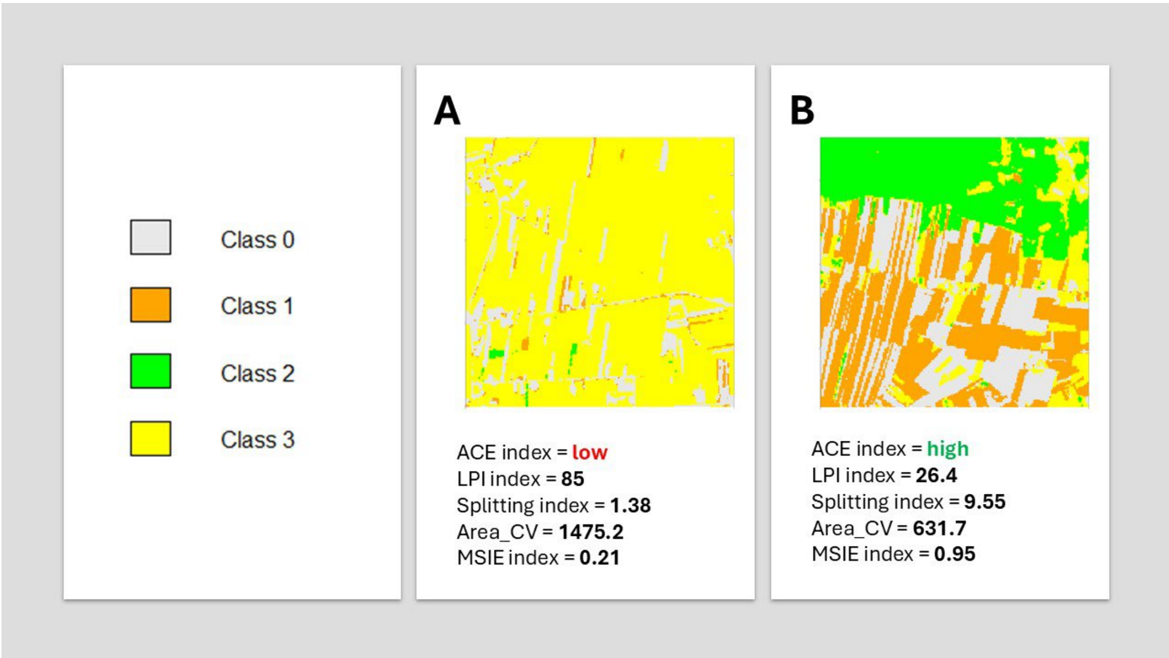

Figure 2: Normalized Difference Vegetation Index (NDVI) map showing the spatial distribution of different patches in the least (A) and most (B) complex landscapes.

Overall, the data indicated that an increase in landscape fragmentation was significantly associated with an increase in arthropods richness, measured by the ACE index, but not in diversity, irrespective of the farm management system. More complex landscapes, with a higher diversity of vegetation phenoclasses, supported more species-rich communities of arthropods, which can benefit also farms that are not implementing measures to increase biodiversity (e.g. conventional ones). These findings suggest that fine-scale habitat heterogeneity can enhance ecological niches and provides continuous resources for beneficial arthropods, in line with previous works showing that organic farming can increase richness and abundance, particularly of pollinators and to a smaller degree for other arthropods, depending on crop type and landscape context (Seufert, Ramankutty, 2017; Tuck et al., 2014). The approach of the study demonstrates the potential of NDVI time-series data for mapping habitat structure and predicting biodiversity trends in agricultural landscapes, which could help elucidating cross-scaling mechanisms functioning at multiple spatial scales when long-term time series are accumulated, linking landscape ecology in terms of biodiversity dynamics (Teng et al., 2020).

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