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The Landscape Ecological Quality of Two Different Farm Management Models: Polyculture Agroforestry vs. Conventional

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Abstract: Low-intensity, diversified agricultural land use is needed to counteract the current decline in agrobiodiversity. Landscape ecology tools can support agrobiodiversity assessment efforts by investigating biodiversity-related ecological functions (pattern–process paradigm). In this study, we test a toolkit of landscape ecology analyses to compare different farm management models: polyculture agroforestry (POLY) vs. conventional monoculture crop management (CV). Farm-scale analyses are applied on temperate alluvial sites (Po Plain, Northern Italy), as part of a broader multi-scale analytical approach. We analyze the landscape ecological quality through landscape matrix composition, patch shape complexity, diversity, metastability, and connectivity indices. We assess farm differences through multivariate analyses and t-tests and test a farm classification tool, namely, a scoring system based on the relative contributions of POLY farms, considering their deviation from a local CV baseline. The results showed a separate ecological behavior of the two models. The POLY model showed better performance, with significant positive contributions to the forest and semi-natural component equipment and diversity; agricultural component diversity, metastability; total farm diversity, metastability, connectivity, and circuitry. A reference matrix for the ecological interpretation of the results is provided. Farm classification provides a quick synthesis of such contributions, facilitating farm comparisons. The methodology has a low cost and quickly provides information on ongoing ecological processes resulting from specific farm management practices; it is intended to complement field-scale assessments and could help to meet the need for a partially outcome-based assessment of good farm practice.

Keywords: agrobiodiversity; agroforestry; landscape ecology; farm scale; Northern Italy

Citation: Chiaffarelli, G.; Sgalippa, N.; Vagge, I. The Landscape Ecological Quality of Two Different Farm Management Models: Polyculture Agroforestry vs. Conventional. *Land* **2024**, *13*, 1598. https://doi.org/10.3390/land13101598

Academic Editor: Jana Spulerova

Received: 29 August 2024
Revised: 27 September 2024
Accepted: 28 September 2024
Published: 30 September 2024

1. Introduction

Conventional agricultural practices have led to consistent and widespread landscape simplification, the loss of agrobiodiversity, and the spread of alien species, particularly in productive areas with minimal constraints on agricultural activities, such as temperate alluvial plains [1–3]. The implementation of low-intensity and diversified agricultural land use practices has the potential to contribute to the reversal of these negative trends [4]. Several European policy instruments address these issues [5–10]. The CAP and Rural Development programs have identified a series of corrective measures to be implemented on European farmland over the last decades, ranging from a reduction in chemical inputs, the protection of agricultural soil health, and crop diversification (crop rotation, cover crops, set-aside, etc.) to the management of landscape features and the implementation of agroforestry [11,12]. Despite these efforts, the level of integration of these practices in contemporary European agriculture is, for the most part, low to medium [13]. Furthermore, their contributions have not yet halted the decline of agrobiodiversity [14].

The evaluation of the impact of such mitigation measures through practice-based assessments and subsidy allocation carries the risk of misallocation and the failure to achieve the desired ecological targets [15]. In order to adequately address these issues and monitor the efficacy of mitigation strategies, a plethora of science-based tools have been developed, many of which are outcome-based approaches to securing biodiversity gains [16–20]. Outcome-based approaches are becoming increasingly accurate and effective; however, their cost-effectiveness constraints limit their potential for widespread application. Mixed result- and practice-based assessment schemes may be viable solutions, such as outcome-based assessment schemes with baseline management requirements or management-based schemes with an optional outcome-based top-up, which may depend on the scale of the application [16]. For example, at the farm scale, several ecological processes occur under the influence of field-scale applied practices and local-scale land use configuration (depending on the landscape management of individual farms), which influence the field-scale biodiversity (outcome) [21]. In this case, the biodiversity outcome could be monitored directly through field-scale, multi-taxa surveys (which offer greater accuracy but are also more costly and time-consuming) and/or indirectly through farm-scale assessments of landscape structure and ecological functions, which could serve as surrogates for biodiversity values (lower accuracy, lower cost, and time-consuming) [22,23]. The utilization of landscape ecology tools [24–28] can facilitate the integration of practice-based and outcome-based biodiversity assessments. Landscape ecology indices provide a synthesis of the multifaceted interactions between landscape patterns and ecological processes, which control a part of biodiversity structure and dynamics [21]. Indeed, landscape indices parallelly address the structural characteristics of the landscape (in relation to management options) and its functional ecological characteristics (in relation to outcomes derived from management options). Nonetheless, their ecological interpretation should be cautious and robustly based on deep previous scientific evidence on such ecological inference, which is specific to the landscape type under analysis [29]. Landscape indices' mutual behavior should be considered when making ecological inference [30]: their use as surrogates for biodiversity values [22] requires the comparison of multiple indices values, framed by multiple spatial scales analyses to organically interpret their mutual redundancy and their context-specific information load [30–33]. Concerning agricultural landscapes, an extensive literature is available on the correlation between specific landscape ecology indices and ecological outcomes in agricultural landscapes [21]. Different biodiversity support functions among farmed landscapes are evidenced through landscape indices: buffering [25,34], corridor [35–42], fragmentation [43–46], matrix quality influence [32,39,44,47], metastability traits [48–50], pest control [51,52], multifunctionality [43,53–55], source/sink patterns [56–59], promotion of generalist versus specialist behaviors [4,46,60–62], and vulnerability traits [48–50,63]. In our study, we test the use of a toolkit of landscape ecology analyses to compare different farm management models (polyculture agroforestry vs. conventional crop management). The applied toolkit has been tuned through previous multi-scale applications in the same territorial context [64–66] and is designed to complement wider landscape ecology assessments. The polyculture agroforestry (POLY) model under study is based on crop production systems (main crop: rice) that apply crop diversification through crop rotations (in some cases also including perennials), polyphyte cover crops, landraces cultivation, in-field and inter-field agroforestry implementation (hedgerows and tree lines), and management of semi-natural landscape features (small wooded areas, wood belts, forests, wetlands). This farm model represents agroecological farming practices currently used in temperate areas [13]. The conventional (CV) model is based on annual crop production based on rice monoculture, no crop rotation, no cover crops, no agroforestry components, and minimal semi-natural components (depending on local landscape characteristics). We account for their relative contributions to supporting biodiversity on farms, referring to the landscape ecology theory of agricultural landscapes.

- Specifically, our study aims to:

- Assess the differences in the ecological quality of the farm landscape (biodiversity-related features) between two different farm management models: polyculture agroforestry (POLY) vs. conventional crop management (CV).
- This first objective will be pursued through the application of a set of landscape ecological indices at the farm level. The applied indices will be screened, and low-correlated variables will be obtained; then, we will check the aggregation of the farm models and identify the most influential variables; finally, we will check the significance of the differences between the two management models.
- Test a farm assessment methodology based on landscape ecology tools, where polyculture agroforestry farms are classified based on their deviation from a local conventional baseline, to compare the effectiveness of each polyculture agroforestry farm, considering the specificities of each landscape context.
- This second objective will be achieved by identifying reference thresholds for the indices finally selected. These thresholds are used to interpret the ecological relevance of the deviation of each POLY farm from a local conventional baseline: each farm is classified according to its landscape ecological quality and the best farm management case is identified.

The analyses were carried out between four sites (Western Po Plain, Northern Italy) representing local-scale landscape systems, among which we have selected individual farms representing the two management models. The ecological characteristics of local and extra-local landscape systems have already been assessed in previous studies [64]: the wider-scale assessment is a prerequisite for the farm-scale analyses presented here. In turn, the here-presented analyses provide a farm-scale framework for the interpretation of finer-scale biodiversity assessments and are designed as a rapid and cost-effective complement to field-scale assessments. In this sense, the applied approach belongs to the partially outcome-based biodiversity assessment models.

2. Materials and Methods

2.1. Case Studies

The analyses were carried out on 4 sites (C, D, G, P) located in the temperate alluvial Western Po Plain (Piedmont and Lombardy regions, Northern Italy) (Figure 1). The study sites represent exemplary landscapes of industrialized agriculture, where corrective ecological interventions are most needed. Since the 1950s, the entire Po Plain has undergone a complete and extensive conversion to intensive conventional agriculture, coupled with intense artificialisation through industrial and logistic clusters and grey infrastructure. The Po Plain has the highest rate of land consumption in the country [67]. Today, the Western Po Plain mainly produces annual and fodder crops such as rice, maize, and soya. Such historical and economic features have resulted in highly anthropized agricultural landscapes. Natural and semi-natural components are generally absent or relic, and suffer from high fragmentation and widespread frequent anthropic disturbance. Taken together, such features have led to extensive biodiversity loss and invasive alien species outbreaks [4,68–71]. Such impacts were confirmed among the study sites through previous assessments on wider landscape ecological features [64–66] and field-scale biodiversity values [72].

Sites belong to the same macro-bioclimate (temperate continental) but show slight differences in their climatic and bioclimatic traits (Table 1) [73–75]. They all belong to alluvial deposits, of different ages and pedogenesis degrees (Table 1) [76,77], which have been managed for agricultural production since the bronze age. Table 1 synthesizes the results of the investigation into wider-scale landscape contexts, featuring the main ecological traits of the local and extra-local context of each site [64–66]. These previous analyses outline the significant impact of the wider-scale agricultural landscape over-simplification, especially in C and P sites, which show the lowest forest and semi-natural equipment, landscape diversity, and biological territorial capacity values, both at an extra-local and local scale (Table 1).

Among each site, we identified one POLY farm and five CV farms, for a total of 20 CV farms (Figure 1). Farm selection and boundary identification criteria are reported in Section 2.2.1. Table 1 resumes the main traits of each of the 4 POLY farms (Table 1). Further details on CV farm characteristics and their overall and intra-site variability (in coherence to each site's local-scale landscape traits) are reported in the supplementary materials (Table S1, Figure S1).

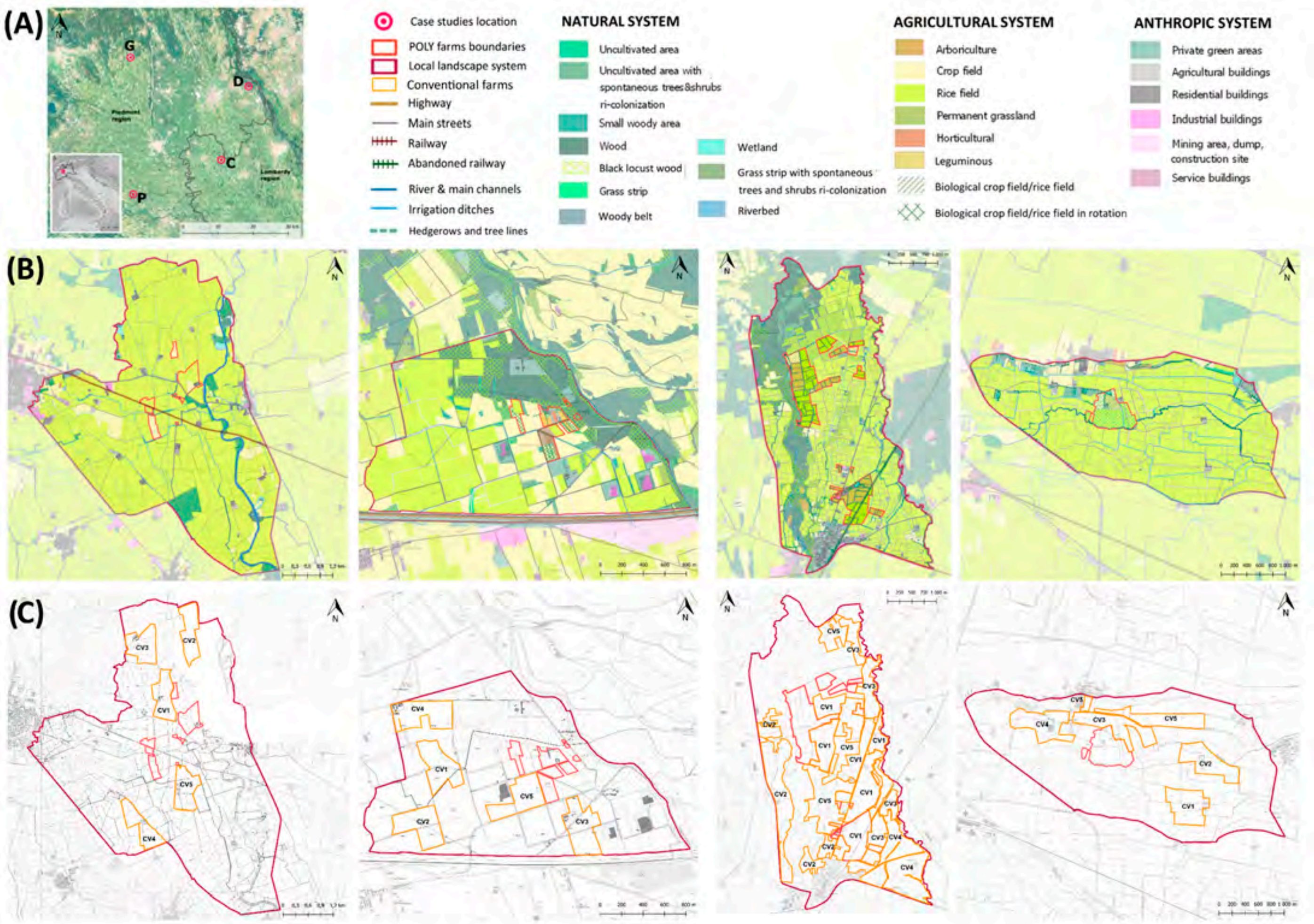

Figure 1. (**A**) The 4 sites' locations in Western Po Plain (from left to right: C, D, G, P); (**B**) the main local-scale land use traits of each local-scale landscape system; (**C**) POLY farms (red line) and CV farms' (orange line) boundaries among each local site.

Table 1. The main pedological (World Reference Base (WRB) and soil taxonomy (ST) pedological groups), climatic, bioclimatic, and landscape ecology traits [64–66] of the 4 local-scale sites and the main traits of POLY farm agricultural models, belonging to each of the 4 sites.

		SITES:	C	D	G	P
TERRITORIAL CONTEXT	PEDOLOGY	ST/WRB CLASSES	Luvisols; Arenosols	Inceptisols	Alfisols (ancient terraces); Inceptisols	Inceptisols; Entisols
		Geomorphology	Fluvial terrace	Fluvial terrace	Riss alluvial terrace	Fluvial deposits
		Main soil texture	Loamy-sand; Sandy-loam	Loamy-skeletal	Fine silty	Loamy-coarse; Loamy-sand

		Development	Medium pedogenesis	Low pedogenesis	Intense pedogenesis	Low pedogenesis
		Permeability	Medium–low permeability	High permeability	Surface hydromorphy	Medium permeability
		pH	Sub-Acid [5.5–6.5]	Acid to Sub-acid [5.3–6.3]	Acid [4.6–5.4]	Sub-alkaline to alkaline [7.4–8.4]
		Land use capacity	IIw (waterlog)	III (stoniness)	III (oxygen availability)	II (oxygen availability)
	CLIMATE [1990–2022 data]	Annual rainfall [mm]	668	973	872	737
		Annual mean Temperature [°C]	13.1	11.8	12.3	13.2
		Average Maximum Temperature [°C]	18.6	17.9	18.9	18.8
		Average Minimum Temperature [°C]	8.19	6.4	7.0	8.5
	BIOCLIMATE [1990–2022 data]	Bioclimate (variant)	Temperate oceanic (submediterranean)	Temperate continental	Temperate continental (steppic)	Temperate continental (steppic)
		Bioclimatic belt	Upper mesotemperate Low humid	Upper mesotemperate Low humid	Upper mesotemperate Upper subhumid	Upper mesotemperate Low subhumid
	LANDSCAPE ECOLOGY TRAITS [64]	EXTRA-LOCAL SCALE: Matrix	Agricultural: 88.6%	Agricultural: 55.0%	Agricultural: 60.1%	Agricultural: 86.7%
		EXTRA-LOCAL SCALE: Forest & semi-natural	5.2%	27.2%	30.6%	6.7%
		EXTRA-LOCAL SCALE: Artificial	6.3%	17.8%	9.3%	6.7%
		EXTRA-LOCAL SCALE: Landscape diversity	1.09	2.13	1.70	1.11
		EXTRA-LOCAL SCALE: Biological territorial capacity	1.17	1.88	2.39	1.26
		LOCAL SCALE: Matrix	Agricultural: 93.1%	Agricultural: 69.6%	Agricultural: 68.63%	Agricultural: 93.0%
		LOCAL SCALE: Forest & semi-natural	4.2%	23.5%	26.5%	4.4%
		LOCAL SCALE: Artificial	2.7%	6.8%	4.9%	2.6%
		LOCAL SCALE: Landscape diversity	0.79	1.55	1.81	0.74
		LOCAL SCALE: Biological territorial capacity	1.18	2.22	2.56	1.16
		LOCAL SCALE: Connectivity	0.24	0.33	0.39	0.36
POLY FARMS	SURFACE	Hectares	47 ha	27 ha	12 ha	128 ha
	CROPS	Main annual crops	Rice in rotation with millet, black-eyed bean, rye, oat, pea	Horticulture, rotation between corn, rice, barley, buckwheat	Rice in rotation with millet, black-eyed bean, rye, oat	Rice in rotation with barley and soybean
		Perennial crops		Walnut, nut, apple		
		Annual crops rotation	x	x	x	x

	Cover crops	Polyphyte meadows	Polyphyte meadows (not all years)	Polyphyte meadows	Polyphyte meadows
LINEAR AGROFORESTRY	Between fields hedgerows and treelines	x	x	x	x
	In-field hedgerows and treelines			x	
LANDSCAPE FEATURES	Small woody areas and woody belts	x	x	x	
	Woods		x	x	
	Wetlands			x	x

2.2. Landscape Ecology Analyses: The Applied Methodology

Landscape ecology analyses are applied at the farm scale, considering all surfaces included in farm boundaries, to compare different farm management models. Landscape ecology indices are applied and screened and then used to detect differences between farms. The indices showing significant differences are then used to assess farms' performances through a scoring system based on gaps between the two different management models. This farm-scale methodology can complement wider-scale landscape ecological assessments, as well as field-scale biodiversity assessments, as we outlined in previous works [64–66,72]. Figure 2 resumes the applied farm-scale methodology; it also shows the wider-scale analytical components, part of the multi-scale analytical methodology that frames the here-presented farm-scale analyses. The wider multi-scale analytical framework is based on a pattern–process–design approach [64].

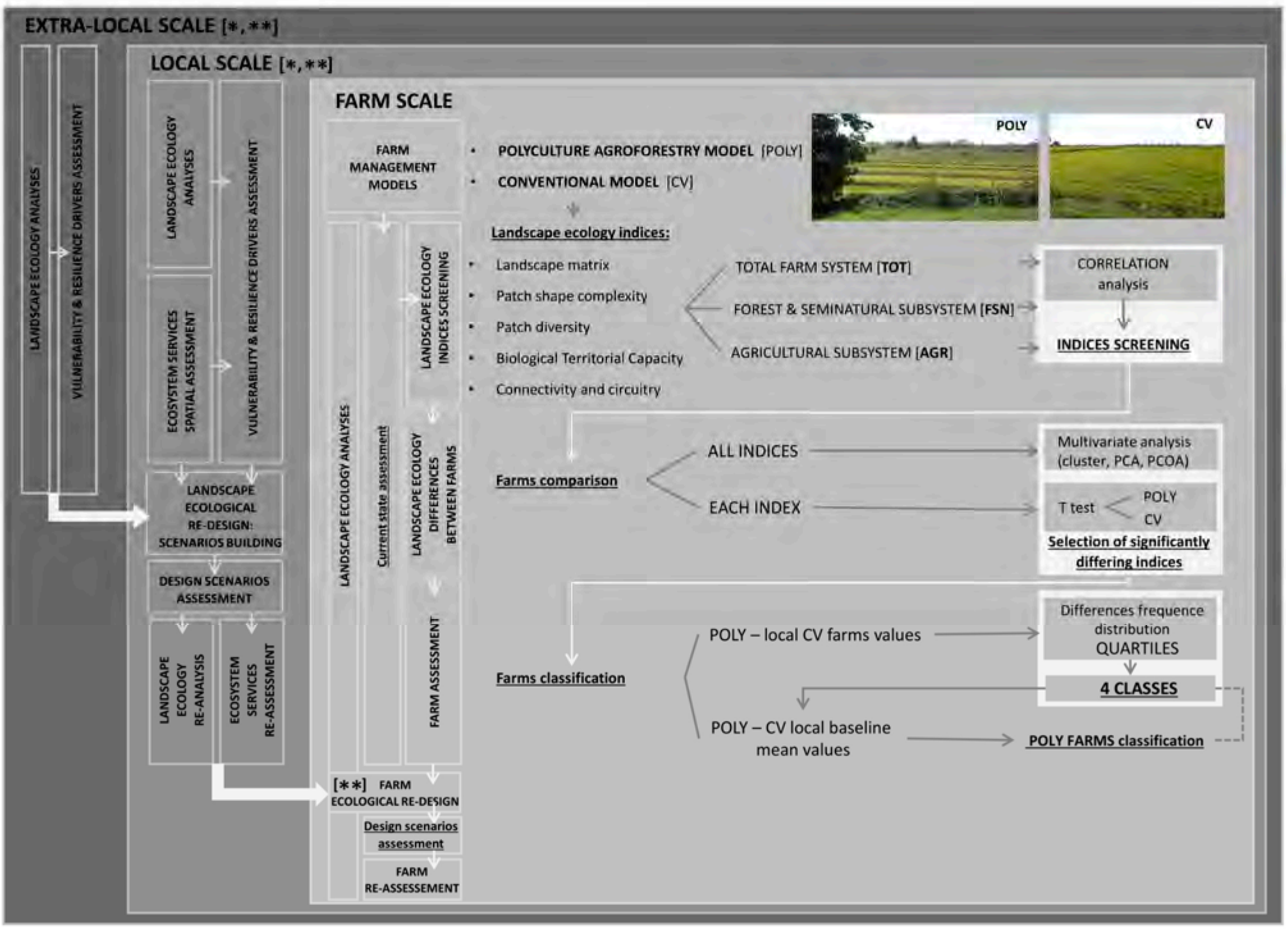

Figure 2. Flow chart synthesizing the applied multi-scale methodology. In this work, we present the results of farm-scale analyses. References for the analyses that are not reported in the present article are reported as follows: * = [29]; ** = [31].

2.2.1. Farm Management Models

Two farm management models are compared:

- A polyculture model based on agroforestry practices and crop diversification through polyculture (POLY).

  The following criteria were set to select POLY farms:
  Consistent crop diversification and rotation (in our case study: rice in rotation with other crops), extensive cover cropping during set-aside, agroforestry management (between field hedgerows and treelines actively managed, protected or newly inserted; purposely inserted in-field hedgerows and treelines); active management, protection or newly insertion of areal landscape features (small woody areas and woody belts, woods, wetlands).
  Besides such traits, which directly influence landscape structure, the following complementary criteria for POLY farm selection were used:
  Absence or significantly reduced external inputs use (fertilizers, pesticides, herbicides), reduced soil management intensity, and use of landraces and local cultivars.
  Such complementary criteria relate to POLY farms' distinctive features which indirectly depend on or influence the above-listed land use and landscape configuration traits among farmlands.

- A conventional model (CV) based on monoculture.

  CV farms were selected based on the following criteria:
  Predominant monoculture, absent or highly limited crop rotations through time and space, absence or limited cover cropping, absence or limited presence of actively and purposely managed linear and areal landscape features (between field and in-field hedgerows and treelines, woodlands, wetlands).
  Complementary criteria distinguishing CV farms were:
  high dependence on external inputs (fertilizers, pesticides, herbicides) and intense soil management.

In each study site, farms are selected among the same local-scale landscape system, which is set according to the landscape unit and ecotope concepts [50,64,78]. Specifically, one polyculture farm (POLY) and 5 theoretical conventional farms (CVs) are identified for each local context. Landscape ecology indices imply some restraints for correct comparison, starting from total surface homogeneity and low patches' spatial scattering [31]. Because of these restraints, we identified CV theoretical farm boundaries by sampling patches among the conventionally managed patches in the local-scale context, based on the following criteria (in priority order): total surface coincident to POLY farm; proximity to POLY farm; patches' bundling degree similar to POLY farm; coherence with local typical conventional farmland use composition (according to local-scale landscape ecology analyses [64–66], see Table 1); coherence with real farm boundaries. This approach allowed us to represent conventional case histories comparable to each POLY farm: real farms with a total surface like a POLY farm and with a sufficient patch bundling degree (patches should not be over-dispersed) were not available in all local-scale contexts. CV farms of the same local-scale context show a discrete internal variability, which represents the different CV local case histories, aligned to local-scale landscape traits [64–66] (see Table 1). CV farm traits are detailed in supplementary materials (Table S1, Figure S1).

2.2.2. Landscape Ecology Indices Application and Screening

Landscape ecology indices are computed on vector data (QGIS Desktop 3.26.0 software) representing the farm-scale eco-mosaic patches. Patch land use types are classed according to regional land use maps [76,77], which are validated through satellite images in doubtful cases [79] and through quick field surveys for higher detail and accuracy.

The landscape ecology indices set was identified according to previous studies on similar territorial contexts, focused on biodiversity support functions in agricultural landscapes [64–66,80]. The following landscape ecology indices are applied (further details are reported in Appendix A, Table A1):

- Basic structural traits:
- Landscape eco-mosaic matrix composition (MTX): agricultural components (AGRs), forest and semi-natural components (FSNs), artificial components (ARTs)
- Medium patch size (MPS)
- Shape complexity indices:
- Mean perimeter area ratio (MPAR)
- Shape index (SI) and its variants: mean shape index (MSI) and area-weighted mean shape index (AWSI)
- Patch fractal dimension (PFD) and its variants mean patch fractal dimension (MPFD) and area-weighted mean patch fractal dimension (AWPFD)
- Landscape diversity indices:
- Shannon diversity index (DIV1A) and its variants DIV1B (calculated on each landscape subsystem total area), DIV2 (ratio between DIV1A and maximum diversity value)
- Dominance index, calculated on DIV1A (DOM1) and on DIV1B (DOM2)
- Landscape structural diversity index, calculated on DIV1A and DOM1 (LSD1) and on DIV2 and DOM2 (LSD2)
- Landscape mean biological territorial capacity (MBTC), an indicator synthetically representing the metastability degree of the landscape system
- Landscape connectivity indices:
- Connectivity index (CON) and its variant WCON weighted on the links ecological quality classes (EQCs) (*cit.)
- Circuitry index (CIR) and its variant WCIR weighted on the links ecological quality classes (EQCs) (*cit.)
- Links/nodes ration (L/N) and its variant WL/N weighted on the links ecological quality classes (EQCs) (*cit.)
- Ration of links belonging to 1st and 2nd EQC (EQC_1_2) and to the 4th and 5th EQC (EQC_4_5)

Indices are computed on each POLY and CV farm as well as on the total farm surface values of each land use category. Mean values are then computed for the agricultural landscape subsystem (AGR), the forest and semi-natural one (FSN), and the total farm system (TOT), also including artificial land uses (ART). Land use types are classed in AGR, FSN, and ART subsystems according to Corine Land Cover classification [81].

A correlation analysis is run on the entire farm-scale dataset to select a first subset of relatively independent indices, to minimize redundancy while keeping the sufficient characterization of landscape composition and configuration [31]. Then, a subsequent screening on indices is carried out by applying correlation analysis on each dataset subset (TOT, FSN, and AGR) after data standardization (rank transformation) to select a minimum set of not-redundant indices for each landscape subsystem (linear r Pearson correlation coefficient for normally distributed data; Spearman's rs for the non-normal distributions).

2.2.3. Landscape Ecology Differences between Farms

Our first aim was to detect differences between the studied farms and, specifically, to check for data aggregation in relation to our starting hypothesis of different ecological behaviors of POLY and CV farms. To answer this research question, we first run multivariate analyses on the TOT, AGR, and FSN data subsets, considering the indices selected through the correlation analysis indices screening (Section 2.2.2). Two-way hierarchical clustering was applied on the selected indices (TOT, FSN, and AGR subsystems) with an unweighted paired group average algorithm (UPGMA), using Euclidean distance for normally distributed data, and Gower distance for non-normal distributions. Then, principal components analysis (PCA) was run on normally distributed data, and principal coordinates analyses were run on non-metric data (PCoA). Biplots were built for PCA analysis, and indices loadings were checked using PCs. For PCoA, we checked for correlation between coordinates 1, 2, and 3 and all landscape ecology indices.

According to multivariate analysis results, the significance of differences between POLY and CV farms was checked for each index, comparing the 4 POLY farms' values with the 4 mean values of each 5 CV farms' local groups. We applied the t-test for equal means, using the Monte Carlo permutation non-parametric test for non-normal data and the Welch test for unequal variance.

2.2.4. Farm Assessment and Classification

The second aim of our study was to identify reference thresholds for the finally selected indices to classify farms on their landscape ecological quality. This was achieved by considering the deviation of each POLY farm from its local conventional baseline. We calculated the differences (absolute values) between each POLY farm value and its related 5 CV farms (n = 20) for the total farm system (TOT), the forest and semi-natural components (FSN), and the agricultural ones (AGR). This was carried out for each of the landscape ecology indices that showed significant differences between POLY and CV farms (see Section 2.2.3).

For each index, the quartiles of the difference between POLY and CV farms were used as thresholds to interpret the ecological relevance of the deviation of each POLY farm from a local conventional baseline. These thresholds delimit 4 classes (scoring system, ordinal values: 1, 2, 3, 4) for each index. These 4 classes were used to classify each POLY farm, based on the difference between each POLY farm and the mean value of its 5 local CV farms (CV_MEAN), which was considered as a local conventional baseline. Hence, for each farm and for each index, a score was assigned. We then summed all indices scores for each farm, obtaining a total farm score (SUM_ALL), and summing the scores obtained for the TOT farm system, the FSN, and the AGR subsystem. This allowed us to classify each farm on its landscape ecological quality and to identify the best farm management case history.

The ecological interpretation of the applied indices is based on bibliographic sources, which sustain the possibility of making ecological inferences from the landscape indices analysis [22,29–33]. To complement the farm assessment tool, we set up a reference matrix that synthesizes, for each applied index, the related ecological functions, referring to biodiversity support among agricultural landscapes.

All statistical analyses were led on Past 4.13 software, graphs were built on R4.3.2 software, and figures were edited on Adobe Illustrator 28.6, Inkscape 1.2, and GIMP 2.10.32 software.

3. Results

3.1. Landscape Ecology Indices Screening

Table A2 (Appendix A) resumes the descriptive statistics for the applied indices. Figure 3 shows the correlation coefficients between each landscape ecology index applied at the farm scale (Spearman's rs coefficients, $p < 0.05$ crossed). To identify the most informative/not redundant minimum set of landscape ecology metrics, we started by excluding the ones with the highest correlation coefficients and significance (Figure 3A). The following indices were selected as the ones with the lowest redundancy: MTX, MPS, MPAR, PFD, DIV1a, DIV1b, DOM1, and MBTC. The filtered indices (excluded from the analysis to minimize redundancy) are shape complexity indices variants (SI2, MSI2, AWSI2, MPFD, AWPFD) and diversity and dominance indices variants (DIV2, DOM2, LSD1, LSD2). Since excluded redundant indices represent analytical variants of the selected indices (i.e., they address the same ecological processes, depending on similar landscape structure composition and configuration traits), ecological information loss is minimized, while information redundancy is optimized. Concerning connectivity indices, we opted to keep them all through the analyses (except for multivariate analyses): despite their consistent correlation, their different ecological information load might be influential on the final ecological interpretation of results. After this first screening of the entire dataset, the more redundant indices among each landscape subsystem (TOT, FSN, AGR) were excluded through a second screening, according to their correlation patterns (Figure 3B). Hence, we selected the following non-correlated indices to run subsequent multivariate analyses:

- For the TOT farm system: DIV1A, DOM1, MBTC, CON, and WCIR indices are selected. The NAT and AGR indices are excluded (their information load is kept through DIV1A, DOM1, and MBTC indices), as well as connectivity indices variants (WCON, CIR, L/N, WL/N, EQC_1_2, EQC_4_5, whose information load is kept through the relevant correlation rate with CON and also the DIV1A and MBTC indices). Since MBTC values depend on the presence of NAT (higher MBTC) versus AGR (lower MBTC) components, the exclusion of NAT and AGR from the TOT landscape system analysis is not expected to cause ecological information loss. Similarly, for connectivity functions evaluation, both unweighted (CON) and weighted (WCIR) connectivity indices are represented, and no significant ecological information loss is expected (WCIR also accounts for the influence of the ecological quality of connectivity components, besides the simple effect of their presence, evaluated through CON).
- For the FSN subsystem: NP_%, MPS, DIV1A, DOM1, and MBTC indices are selected. Shape complexity indices are excluded from the analysis (MPAR, PFD), but their information load on landscape configuration differences is kept through the relevant correlation rate with diversity and MBTC indices. Generally, in checkboard-shaped agricultural landscapes, the shape complexity indices reflect land use intensity [82] and their values can be ecologically related to landscape diversity values [34,82,83]. For the AGR subsystem, the NP_%, MPS, DIV1A, MBTC indices are selected. The agricultural matrix index is excluded (MTX) but its related ecological information (the influence of the amount of agricultural surface) is kept through the NP_% index (representing the influence of the number of agricultural patches). As for the FSN subsystem, shape complexity indices are excluded, and their ecological information load is preserved through diversity (and also MPS) indices.

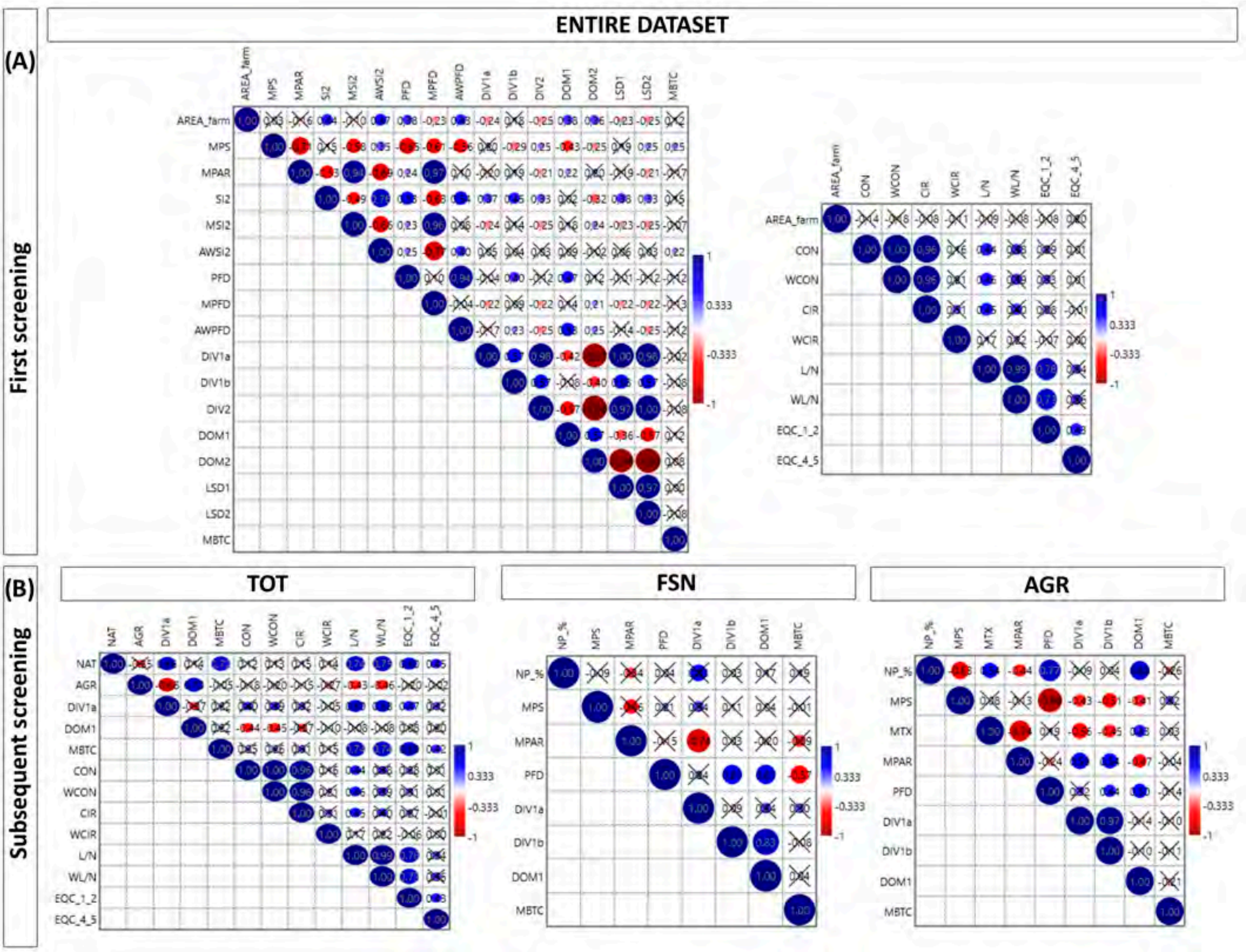

Figure 3. (**A**) Spearman's rs correlation coefficients values used for a first screening on the landscape ecology indices applied at farm scale: structural traits, shape complexity, diversity, and metastability indices (both TOT, FSN, and AGR subsystems); connectivity and circuitry indices (only TOT farm system). (**B**) Correlation analysis on the separated TOT, FSN, and AGR subsystems used for subsequent indices screening for multivariate analysis (TOT: Spearman's rs correlation coefficients; FSN and AGR: linear r Pearson correlation coefficients; $p > 0.05$ crossed). See Table A1 for details on the applied indices.

3.2. Results on landscape Ecology Differences between Farms

3.2.1. Multivariate Analysis Results

The application of hierarchical clustering to the TOT dataset highlighted a clearly separated clustering of POLY farms, with respect to the CV ones (Figure 4). POLY farms generally show higher MBTC, DIV1A, and CON values in the TOT farm system (see matrix in Figure 4). The same clustering pattern was highlighted for the AGR subsystem, where POLY farms are mostly distinguished by higher mean biological territorial capacity (MBTC) and AGR patch diversification (DIV1A) (see matrix in Figure 4). FSN subsystem clustering also showed separate clustering of POLY farms, except for one single CV farm clustered with POLY farms. In the FSN subsystem, POLY farms generally show higher FSN component diversity values (DIV1A) and FSN patch amounts (NP_%), even though a certain variability is detected between POLY farms (see matrix in Figure 4).

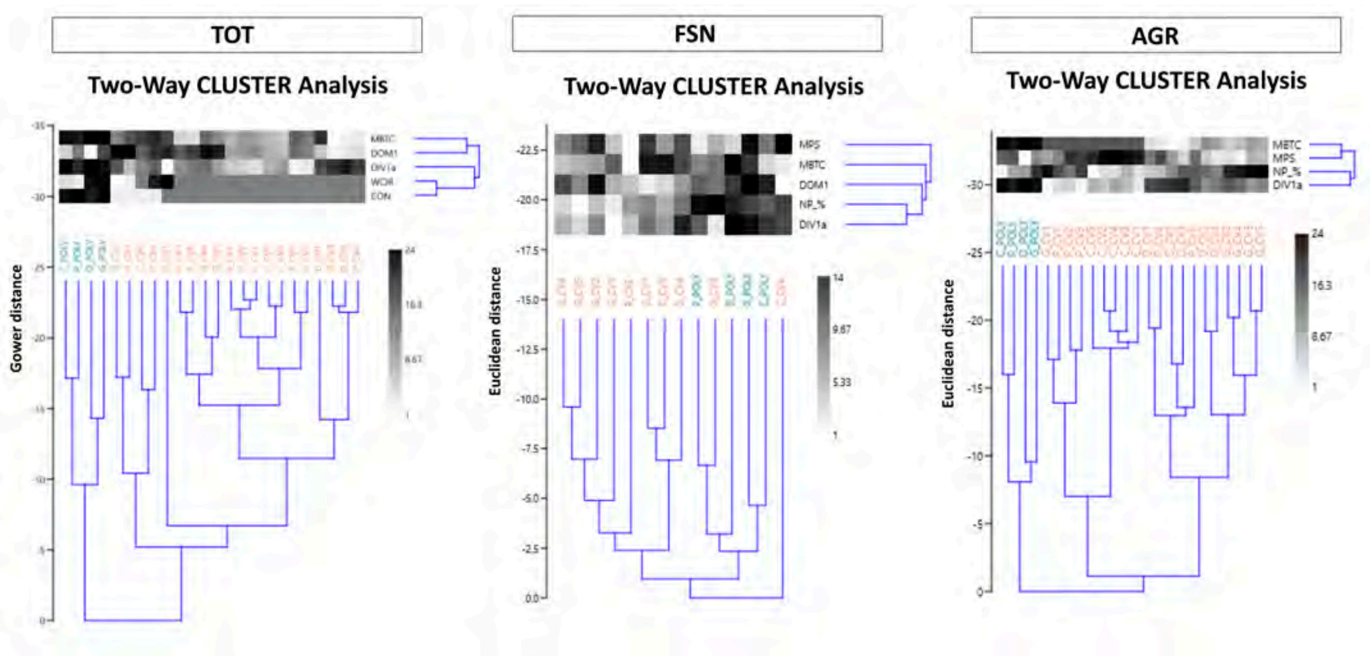

Figure 4. Two-way hierarchical clustering results from the TOT farm system's dataset (left side, non-normally distributed data, clustering based on Gower distance); FSN and AGR subsystems' datasets (middle and right side, normally distributed data, clustering based on Euclidean distance). The involved indices are shown on the top-right of each matrix; in green: POLY farms; in orange: CV farms.

Ordination analyses generally confirmed the POLY-CV farms' aggregation patterns, highlighted by the cluster analyses (Figure 5). For the TOT farm systems, data were not normally distributed: principal coordinate analysis was run (PCoA) based on Gower distance (applied transformation exponent: c = 2). Coordinates 1 and 2 represent 58.8% of the total variance; their PCoA plot shows a clear separation of POLY and CV farms; also, the plot of coordinates 1–3 confirms this pattern (46.9% of total variance); the plot of coordinates 2–3 shows some overlapping of POLY farms with six CV farms (38.9% of total variance), even if most CV farms are clearly separated along coordinate 2 (Figure 5). According to the results of the correlation analysis between the PCoA coordinates and all the analyzed indices on TOT data (Figure 5, bottom-left side), we can state that:

- POLY farms are mainly distinguished from CV farms by lower values of coordinate 1 (higher forest and semi-natural components (FSN), higher farm diversity (DIV1A), higher mean biological territorial capacity (MBTC), higher connectivity and circuitry across farmland (CON, WCON, CIR, L/N, WL/N, EQC1_2)).
- A portion of CV farms (mainly belonging to D, P, and C sites) is clearly distinguished from POLY farms by higher coordinate 2 values (lower forest and semi-natural components (FSN), lower dominance (DOM1), biological territorial capacity values (MBTC), and lower link/nodes ratio (L/N, WL/N)).
- Coordinate 3 does not clearly distinguish between the two management models, and it is also less informative (13.5% of the total variance, only positively correlated to the WCIR index).

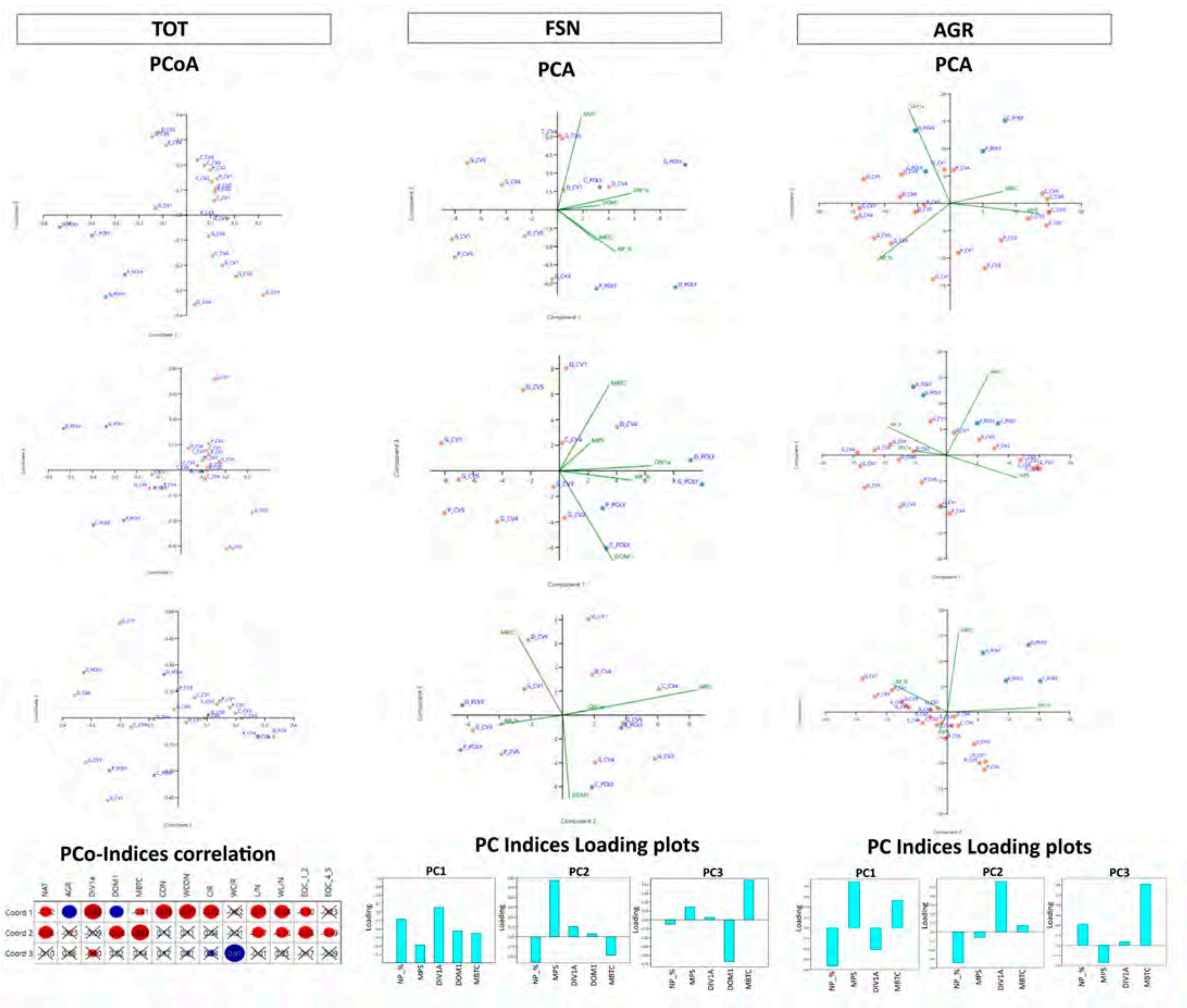

Figure 5. Ordination multivariate analysis results: PCoA on TOT farm systems' data set (left side, non-normally distributed data); PCA on FSN and AGR subsystems' datasets (middle and right side, normally distributed data); in green: POLY farms; in orange: CV farms. On the bottom side is reported the PCoA coordinates' correlation coefficients with landscape ecology indices for TOT data (Spearman's rs; $p < 0.05$ crossed); landscape ecology indices' loading plots on PC1-2-3 for FSN and AGR data.

For the FSN and AGR farm subsystems, data were normally distributed: principal component analysis was run (PCA), based on Euclidean distance.

For FSN data, PC1 and PC2 represent 59.8% of the total variance, their PCA biplot shows a separation of POLY farms from CV ones, except for one CV farm (belonging to the D site). The results highlight the following patterns:

- The main driver of farm models' separation is PC1 (37.6% of total variance), which is positively related to (in order of importance, see loadings plot in Figure 5) FSN component diversity (DIV1A), the relative amount of FSN patches (NP_%), dominance (DOM1), FSN mean biological territorial capacity values (MBTC), and their mean patch size (MPS).
- PC2 (22.2% of total variance) separates C-G POLY farms from P-D POLY farms and is mainly related to FSN mean patch size (MPS), which is higher in C-G POLY farms'

FSN components; secondly, PC2 is related to NP_% and MBTC values (slightly higher in P and D POLY farms' FSN components).

- PC3 mainly distinguishes farms on the MBTC values of FSN components, and the PC1-PC3 biplot (56.6% of total variance) clearly separates POLY farms from CV ones. The PC2-3 biplot (41.1% of total variance) still separates POLY farms into two subgroups (mixed with CV farms): C-G and P-D.

For AGR data, PC1 and PC2 represent 75.7% of the total variance, and their PCA biplot shows a prevalent (but non-unique) separation between POLY and CV farms, mainly driven by PC2 (27.7% of total variance). Results highlight the following patterns:

- PC2 higher values in POLY farms are related to higher AGR patch diversity (DIV1A) and lower relative amount of AGR patches (NP_%).
- PC1 (48.0% of total variance) separates POLY farms into two subgroups: C-P farms (higher AGR mean patch size -MPS-) and D-G sites (lower AGR MPS).
- PC3 distinguishes POLY farms from CV ones; it has low representativeness (19.4% of total variance) and its higher values in POLY farms are mainly influenced by higher MBTC values.

3.2.2. Indices Significance Analysis

According to multivariate analysis results, which highlighted a generally separated behavior of POLY and CV farms, we further checked the significance of differences between the two management models by comparing each landscape ecology index value for the TOT farm system and for the FSN and AGR landscape subsystems. POLY and CV landscape ecology indices summary statistics are reported in Table 2 and the results are shown in Figure 6.

Considering the TOT farm system, POLY and CV farms' total surface (SURFACE) are equally distributed, according to landscape ecology analyses' requirements. POLY farms show significantly higher values than CV farms for (Figure 6; Table 2): forest and seminatural components' relative surface (FSN), diversity (DIV1A), mean total biological territorial capacity (MBTC), connectivity (CON), weighted connectivity (WCON), circuitry (CIR), links/nodes ratio (L/N), weighted links/nodes ratio (WL/N), links belonging to 1 and 2 ecological quality classes (EQC1_2). Links belonging to higher ecological quality classes (EQC4_5) show high variability among POLY farms. Generally, POLY farms show lower relative agricultural component surfaces compared to CV farms; however, the differences are insignificant.

Considering the forest and seminatural farm landscape subsystem (FSN), POLY farms show significantly higher values than CV farms for (Figure 6; Table 2) the number of FSN patches (NP_%), FSN component diversity (DIV1A), and dominance (DOM1). No significant differences were detected in the FSN components' biological territorial capacity (MBTC), and the CV FSN components generally showed a higher mean patch size (MPS), even though differences were not significant.

Considering the agricultural farm landscape subsystem (AGR), POLY farms' agricultural patches showed significantly higher values than the CV farms for (Figure 6; Table 2) diversity (DIV1A; DIV1B) and mean biological territorial capacity (MBTC). CV farms have a slightly higher proportion of AGR patches compared to POLY farms (NP_%) and show slightly higher variability in agricultural patches' mean patch size (MPS), even though differences were not significant.

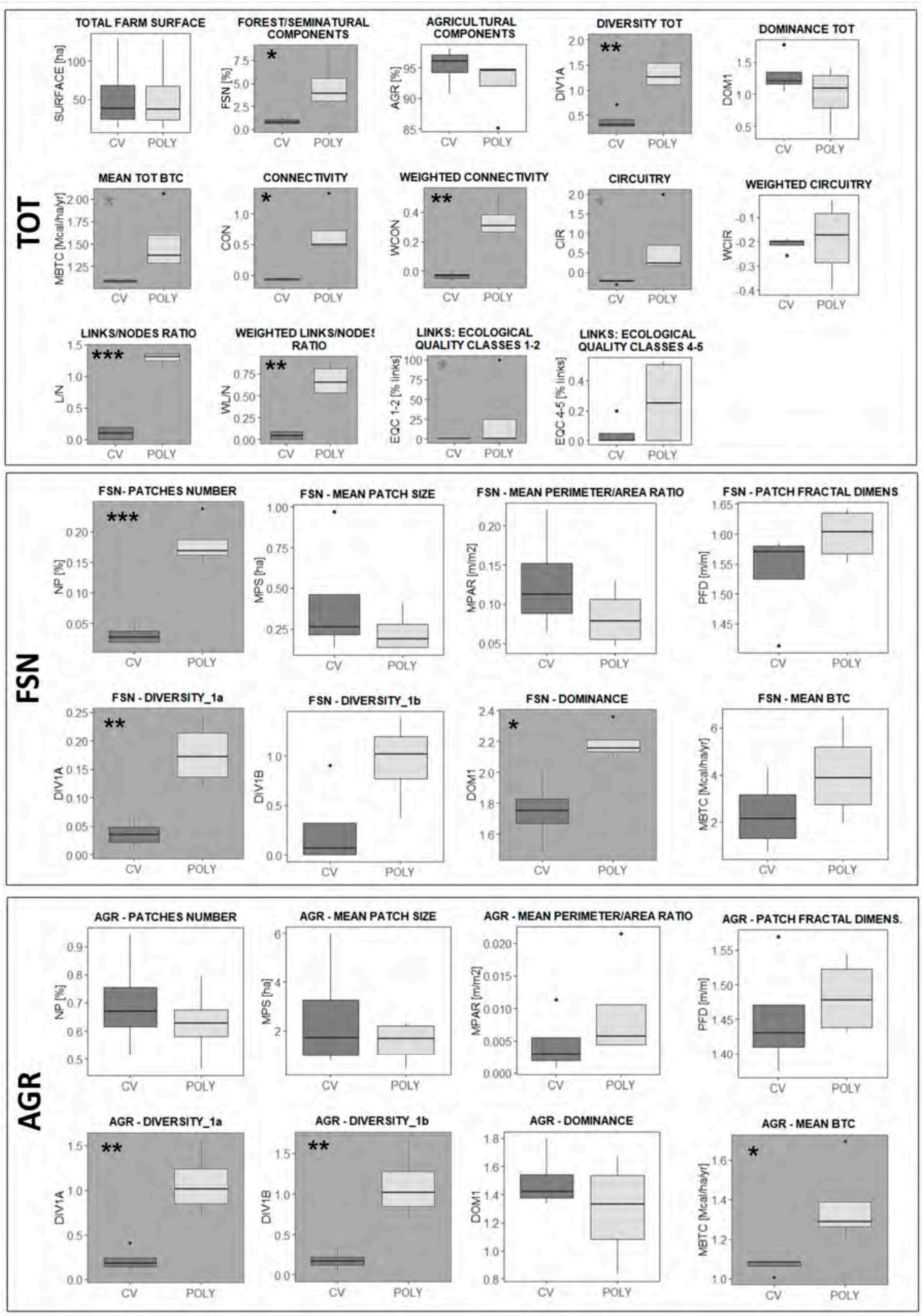

Figure 6. Comparison between the landscape ecology indices applied to the total farm system (TOT), the forest and semi-natural farm subsystem (FSN), and the agricultural subsystem (AGR) on POLY and CV farms (mean between 5 CV farms of each case study). Dark grey boxes highlight significantly differing indices: * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$; if gray *: only one of Montecarlo permutation non-parametric test or Welch test for unequal variance shows significant differences. See Table A1 for details on the applied indices.

Table 2. POLY and CV farms' mean values and standard deviation of the landscape ecology indices applied to the total farm system (TOT), the forest and semi-natural farm subsystem (FSN), and the agricultural subsystem (AGR), showing T-test results on differences between POLY and CV sites. Significant means differences are highlighted in bold.

		Mean		**St. dev.**		**Shapiro-Wilk W**	***p* (Normal)**	**Levene's Test (Homoskedasticity) *p* (Same)**	**t**	**Critical t Value (*p* = 0.05)**	***p* (Same Mean)**	***p* (Same Mean) Unequal Variance Welch Test**	***p* (Same Mean) Montecarlo Permutation**
		POLY	**CV**	**POLY**	**CV**								
TOT	FSN	4.76	0.87	2.77	0.71	0.87	0.14	0.1158	2.72	2.45	**0.0348**		
	AGR	92.33	95.24	4.75	3.27	0.85	0.09	0.4438	1.01	2.45	0.3521		
	DIV1a	1.37	0.39	0.47	0.22	0.92	0.43	0.3215	3.83	2.45	**0.0086**		
	DOM1	0.99	1.30	0.46	0.32	0.95	0.68	0.5062	1.12	2.45	0.3074		
	MBTC	1.51	1.08	0.38	0.02	0.74	0.01	0.0421	2.26	2.45		0.1082	**0.0327**
	CON	0.70	−0.07	0.42	0.05	0.83	0.06	0.0396	3.59	2.45		**0.0352**	**0.0288**
	WCON	0.34	−0.04	0.13	0.03	0.89	0.25	0.1196	5.53	2.45	**0.0015**		
	CIR	0.65	−0.24	0.90	0.05	0.67	0.00	0.0309	1.98	2.45		0.1415	**0.0299**
	WCIR	−0.19	−0.21	0.16	0.03	0.96	0.76	0.0249	0.20	2.45		0.8525	
	L/N	1.29	0.10	0.13	0.12	0.80	0.03	0.8369	13.51	2.45	**1.02E-05**		**0.0281**
	WL/N	0.69	0.05	0.19	0.06	0.87	0.14	0.0084	6.55	2.45		**0.00395**	
	EQC_1_2	25.30	0.08	49.80	0.10	0.42	0.00	0.0242	1.01	2.45		0.38555	**0.0261**
	EQC_4_5	0.26	0.05	0.30	0.10	0.69	0.002	0.0004	1.32	2.45		0.26278	0.4229
FSN	FSN												
	NP_%	0.18	0.03	0.04	0.02	0.88	0.19	0.2059	6.99	2.45	**0.0004**		
	MPS	0.23	0.41	0.13	0.38	0.70	0.00	0.1257	0.89	2.45			0.5711
	MPAR	0.08	0.13	0.04	0.07	0.89	0.23	0.4715	1.13	2.45	0.3012		
	PFD	1.60	1.53	0.04	0.08	0.82	0.05	0.3152	1.40	2.45			0.244
	DIV1a	0.18	0.04	0.06	0.03	0.94	0.59	0.0553	4.50	2.45	**0.0041**		
	DIV1b	0.95	0.26	0.43	0.43	0.89	0.24	0.9414	2.26	2.45	0.0647		
	DOM1	2.19	1.75	0.12	0.22	0.95	0.75	0.5045	3.52	2.45	**0.0125**		
	MBTC	4.05	2.32	2.01	1.57	0.97	0.88	0.533	1.35	2.45	0.2245		
AGR	AGR												
	NP_%	0.63	0.70	0.14	0.18	0.95	0.74	0.6414	0.63	2.45	0.5501		
	MPS	1.52	2.54	0.88	2.39	0.79	0.02	0.1901	0.80	2.45			0.5428
	MPAR	0.01	0.00	0.01	0.00	0.81	0.04	0.3207	1.02	2.45			0.3833
	PFD	1.48	1.45	0.06	0.08	0.91	0.38	0.6295	0.64	2.45	0.5438		
	DIV1a	1.08	0.21	0.37	0.15	0.93	0.53	0.1566	4.33	2.45	**0.0049**		
	DIV1b	1.10	0.17	0.43	0.15	0.93	0.50	0.1395	4.11	2.45	**0.0063**		
	DOM1	1.29	1.49	0.37	0.21	0.96	0.83	0.1974	0.97	2.45	0.3718		
	MBTC	1.37	1.07	0.22	0.04	0.83	0.05	0.0686	2.65	2.45	**0.0380**		

3.2.3. Polyculture Farms Classification: Gaps from the Local Conventional Baseline

POLY farm classification was based on the landscape ecology indices, which showed significant differences between POLY and CV farms (see Section 3.2.2). Figure 7A reports the gaps between the POLY farms and their related CV farms (differences in absolute values).

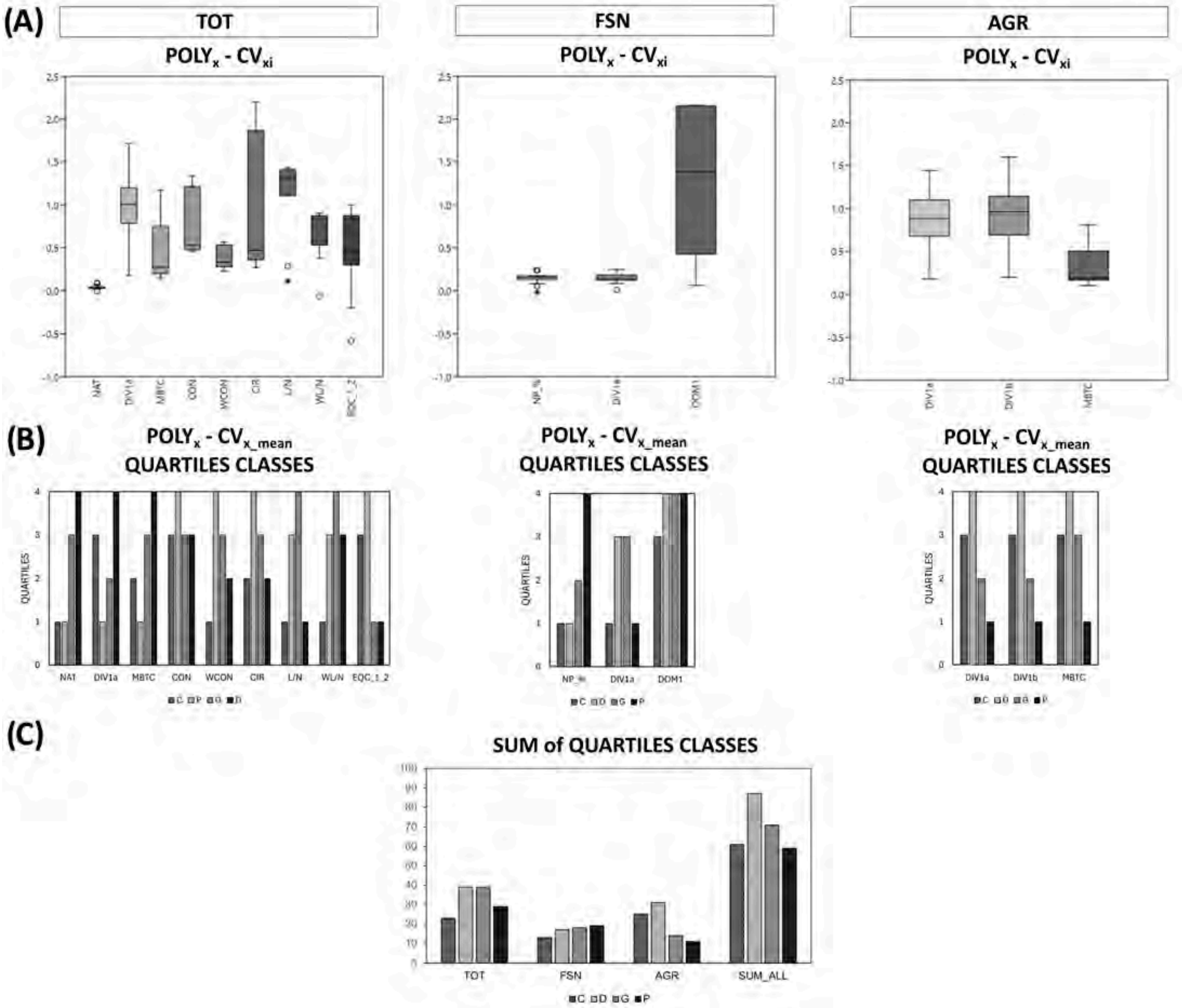

Figure 7. For the TOT farm system and the FSN and AGR subsystems are shown: (**A**) distribution of the differences between each POLY FARM and each corresponding CV farm (5 CV farms for each POLY farm); (**B**) classification of each of the 4 POLY farms under study into the 4 classes derived from quartile values, based on the difference between the POLY farm and the corresponding CV_MEAN; (**C**) classification of POLY farms based on the sum of the quartiles classes values for each POLY farm, for the TOT, FSN, and AGR subsystems, and for their sum (SUM_ALL). See Appendix A for details on the applied indices.

These gap values were used to identify thresholds for each index, based on quartile values, as detailed in Table A3 (Appendix A). Figure 7B shows the resulting classification of each POLY farm (C, P, G, D) through the scoring system based on the difference between each POLY farm and its local conventional baseline values (see Section 2.2.4) for the TOT, FSN, and AGR farm subsystems. An example of the interpretation that can be led on this scoring system is reported below.

Considering the total farm system (TOT), the D site shows the highest scores on FSN components, farm total diversity (DIV1A), and farm mean biological territorial capacity (MBTC). This reflects its significant contributions to biodiversity support functions, compared to its local conventionally managed context. Moreover, the G farm shows discrete contributions to the local biological territorial capacity balance (score 3). Considering connectivity functions, the highest contributions are shown by the P site: despite the limited presence of linear corridors and the high amount of low EQC links (EQC_1_2), relative contributions compared to the local conventional baseline are significantly high. Moreover, the G site shows particularly positive performances on connectivity indices. The C site's contributions are lowered when considering the ecological quality of links, which mainly depends on the young age of the recently inserted hedgerows and treelines in the farm. The highest ratio of low EQC links is indeed in the C site, joined by the P site.

Concerning the FSN farm subsystem, the highest relative contributions are given by the P site: this reflects the almost complete absence of FSN components in the local conventional baseline farms and the significant contributions produced by the P farm, despite its FSN components being quite limited in the farm surface. G and D sites are the ones that most contribute to the farm landscape diversification (DIV1A) compared to their local conventional baselines. Parallelly, all sites show significantly higher dominance values (DOM1).

Concerning the AGR farm subsystem, the highest relative contributions on farm diversification (DIV1A, DIV1B) and farm metastability (MBTC) come from the D site (which also has perennial cultivations, mixed to crop fields in rotation), then the C site, followed by the G site.

Figure 7C shows the resulting total farm score for the final classification and comparison of the POLY farms. The total farm scoring system (SUM_ALL) shows the highest performances in D farms, followed by G farms and then C and P farms. Considering the total farm system, G and D farms have the same score; however, they differ in AGR subsystem contributions, which are higher in D farms. This is influenced by the presence, in D, of perennial crops (see Table 1), which significantly raise the relative contributions of D farms compared to the local conventional farms based on annual crop field monocultures. In this regard, G, C, and P POLY farms' contributions to conventional farms can be considered more consistent in that they are based on annual crop productions, like their local CV farms. Considering these three farms, the C farm is the one that is most distinguished from its local CV baseline on the AGR subsystem; the G farm total farm system is the one which mostly differs from the local CV baseline; the P site shows the highest relative contribution on the FSN subsystem (despite the minor presence of FSN components in P, compared to the other POLY farms, this farm considerably differs from its local CV baseline). To complement the interpretation of the results, the spatial representation of the indices' values might help. We reported in Figure A1 (Appendix A) an example of the spatial representation of indices for the D and G sites—the ones that showed the best performances. For each site, diversity (DIV1A), mean biological territorial capacity (MBTC), and connectivity graphs maps are represented for the POLY farm and one local CV farm.

4. Discussion

The multivariate analyses on landscape ecology indices values of POLY and CV farms confirmed the different ecological behaviors, from a landscape ecology perspective, of the two farm management models (see Section 3.2.1). This is mostly influenced by the different farm eco-mosaic matrix composition, with higher forest and semi-natural (FSN) components in POLY farms, higher farm diversity values (DIV1A), and mean biological territorial capacity (MBTC). Moreover, connectivity functions have a clearly distinguished behavior in POLY farms, with higher connectivity functions (CON, CIR; L/N), also when considering the variants of connectivity and circuitry indices weighted on their ecological quality classes (WCON; WCIR, WL/N). When considering the FSN subsystem, POLY farms are distinguished by the higher amount and diversification of the forest and semi-natural components (DIV1A). The AGR subsystem shows higher diversification (DIV1A) and mean biological territorial capacity (MBTC) too. These differences were confirmed to be significant from a statistical point of view (see Section 3.2.2).

The classification of each POLY farm based on the scoring system allowed us to compare each farm's performance, in relation to their local CV baseline. D POLY farm showed the best performances, which are influenced by the different productive models (perennial crops are coupled to annual crops, differently from the local CV farms, which are all based on annual crops). Considering the other three POLY farms, based on annual crop production like their local CV baselines, the G POLY farm showed the best performance. This reflects the relevance of the contributions of this farm case history if we consider the better ecological quality (compared to C and P sites) of the local landscape context to which we compared the G POLY farm contributions. Indeed, G site extra-local and local landscape ecological traits (Table 1) show the best performances on forest and semi-natural equipment, landscape biological territorial capacity, and local landscape diversity values. Moreover, CV farms belonging to the G site local landscape system show a higher mean amount of forest and seminatural components and farm diversity values, if compared to C and P CV farms (see supplementary materials, Figure S1). Despite the positive local landscape ecological configuration, the G POLY farm clearly stands out.

Figure 8 reports a reference matrix for the ecological interpretation of results obtained from the landscape ecology indices. We reported the indices that showed the most relevant differences between the two farm management models. It is conceived as a synthetic tool to interpret the results of the applied methodology, resuming the ecological interpretation (rows) of the lower (↓) or higher (↑) values of each index (columns) and the related references supporting such interpretations in agricultural contexts. The case histories detected in the present study are highlighted in grey boxes, distinguishing the ones that showed higher or lower values in POLY farms, compared to the CV ones (light grey boxes) and the ones in which these differences were significant from a statistical point of view (dark grey boxes).

As shown in the matrix in Figure 8, our study outlined an expected positive contribution of the POLY farms, compared to their local CV baseline, on biodiversity-support functions depending on landscape structure. Specifically, the obtained results on landscape ecology indices were related to a positive influence of POLY farm management on the reduction in agricultural landscape hyper-specialization and simplification impacts, higher agricultural matrix quality, source and buffer functions promotion among farmland, reduction in sink effects, promotion of ecological corridors functions, landscape multi-functionality and landscape stability, and self-maintenance capacity. Consequently, in POLY farms, the following traits are expected: more support for specialist and native species and disadvantage for generalist and alien species, higher pest control functions, field-scale biodiversity values, and, specifically, higher in-field biodiversity values. The farm assessment tool based on scorings provides a quick synthesis of such contributions, facilitating farm performance comparison.

The reported influences on ecological functions are identified based on landscape ecology theoretical references and should be complemented by field-scale biodiversity assessments to strengthen such ecological interpretations. In a recent study on G, D, and P sites, we found higher α-biodiversity values of spontaneous plant communities rising inside POLY rice fields, compared to the neighboring conventional ones [72]. This can be a consequence of both field-scale crop management practices and farm-scale landscape configuration. Nonetheless, higher allochthonous species amount were also found in POLY rice fields, and this raises important questions on the multi-scale implications of agricultural landscape management, where wide-scale over-simplification processes strongly impact the farm-scale ones, as we already outlined in recent studies on the same sites [64,66].

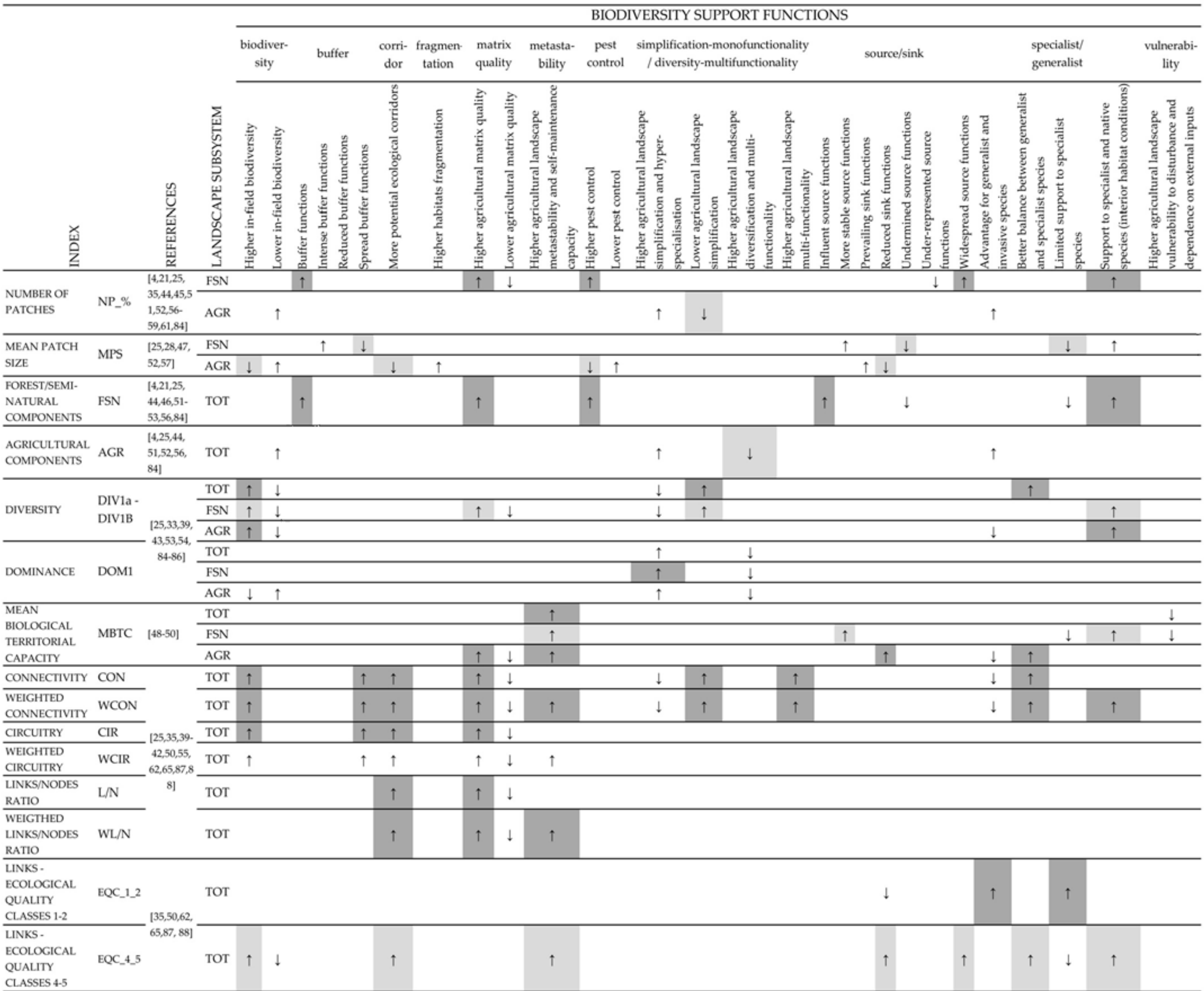

Figure 8. Reference matrix for the ecological interpretation (rows) of lower (↓) or higher (↑) values of the applied landscape ecology indices (columns) which showed relevant differences between the two farm management models (POLY and CV). Interpretations are referred to agricultural landscape peculiarities and are focused on biodiversity support functions. Grey boxes represent the POLY farms' case histories, according to our study results. The light grey ones represent the detection of higher/lower mean values in POLY farms, compared to their local CV baseline; the dark grey ones represent the detection of significantly higher/lower values in POLY farms (t-test results). References for each index: NP_% [4,21,25,35,44,45,51,52,56–59,61,84]; MPS [25,28,47,52,57]; FSN [4,21,25,44,46,51–53,56,84]; AGR [4,25,44,51,52,56,84]; DIV1A, DIV1B, DOM1 [25,33,39,43,53,54,84–86]; MBTC [48–50]; CON, WCON, CIR, WCIR, L/N, WL/N [25,35,39–42,50,55,62,65,87,88]; EQC_1_2, EQC_4_5 [35,50,62,65,87,88].

5. Conclusions

The results of our study demonstrate a distinct differentiation in landscape ecological behavior between two contrasting farm management models. The first is a POLY model, which incorporates principles of agroforestry, landscape feature management, and crop diversification. The second is a conventional crop monoculture (CV) model that exhibits minimal or no management of landscape features. The POLY model exhibited superior performance, with notable positive contributions to forest and semi-natural equipment (FSN) and diversification (DIV1A); agricultural components diversification (DIV1A, DIV1B), self-maintenance capacity and metastability (biological territorial capacity: MBTC); total farm diversity (DIV1A), metastability (MBTC), connectivity and circuitry (CON, WCON, CIR, L/N, WL/N).

The results were synthesized through the use of a farm assessment tool based on a scoring system, which provides a rapid synthesis of the contributions in question, with a particular focus on the relative contributions of each POLY farm in relation to a local conventional baseline. This allows for the consideration of site-specific advantages in relation to the localized disadvantages associated with conventional agricultural management practices.

The ecological interpretation of the applied landscape ecology indices relies on previous literature-based evidence; however, local context-specific and species-specific processes might occur, which might influence the ecological outcomes of the detected landscape patterns [89]. As we stated in the introduction paragraph, the employ of landscape ecology tools to assess farm management contributions to biodiversity values intends to complement field-scale assessments through indirect assessments, in a hybrid assessment scheme framework [22]. In light of the aforementioned premise, the provided results offer a valuable and cost-effective insight into the ongoing ecological processes resulting from specific farm management practices. Our study demonstrated that they facilitate the identification of significantly different structural and functional traits on farmlands under different management models. Such an assessment methodology might help in meeting the need for a partially outcome-based evaluation of the best farm practices [16] and would benefit from integration with field-scale biodiversity assessments, which we are currently leading in the studied sites through floristic-vegetational analyses, in view of multi-scale data comparison. The investigation of the diversity and ecological traits of plant communities growing in the different habitats that can be found among each farm may complement and help in better understanding the effectiveness of farm management models in supporting biodiversity once coupled with landscape ecology assessments. This might also lead to a context-specific update of the reference matrix for the ecological interpretation of landscape ecology indices (Figure 8). In addition, farm landscape ecological quality is also related to farm multi-functionality, in the Ecosystem Services perspective, and the here-presented farm-scale methodology might also be coupled to other field-scale evaluations, such as on soil health parameters linked to the farm agroforestry management. Currently, this is being developed on the studied sites through the monitoring of soil organic carbon turnover behavior in relation to the management of in-farm landscape features [90].

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land13101598/s1, Table S1: Main landscape ecology traits of the conventional farms (CV); Figure S1: Indices representing the main conventional farms (CV) ecological traits.

Author Contributions: Conceptualization, I.V., G.C. and N.S.; methodology, I.V., G.C. and N.S.; software, G.C. and N.S.; validation, I.V., G.C. and N.S.; formal analysis, G.C. and N.S.; investigation, I.V. and G.C.; resources, I.V. and G.C.; data curation, G.C.; writing—original draft preparation, I.V. and G.C.; writing—review and editing, G.C.; visualization, I.V., G.C. and N.S.; supervision, I.V.; project administration, I.V.; funding acquisition, I.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partly financed by Compagnia di San Paolo, project "BIODIVERSITAS—L'AGROBIODIVERSITÀ PARTECIPATA. Agrobiodiversity in the Polyculturae farms of Eastern Piedmont" in the "Call for proposals Re:azioni—Defend the environment, contribute to the well-being of tomorrow—2023".

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. The applied landscape ecology indices. For each index, the following information is provided: the employed acronym, the applied scale of analysis, the applied equation, and the related references.

	Indicator	Equation	References
BASIC STRUCTURAL TRAITS	Matrix (MTX) x = [FSN; AGR; ART]	$MTX_x = \frac{\sum_{i=1}^{n} A_{ix} \times 100}{A_{tot}}$ Ai = total area of each land use categories patch Atot = total area	[31]
	Medium patch size (MPS)	$MPS = \frac{\sum_{i=1}^{n} A_i}{N_i}$ Ai = area of each patch Ni = no. of patches	[31]
SHAPE COMPLEXITY INDICES	Mean Perimeter area ratio (MPAR)	$MPAR = \frac{\sum_{i=1}^{n} PAR_i}{NP}$ $PAR_i = \frac{P_i}{A_i}$ Pi = Perimeter of each land use category patches NP = total no. of patches	[82]
	Shape index (SI)	$SI = \frac{P_i}{2 \times \sqrt{\pi \times A_i}}$	[82]
	Mean Shape Index (MSI)	$MSI = \frac{\sum_{i=1}^{n} SI}{NP}$	[82]
	Area-weighted mean shape index (AWSI)	$AWSI = \frac{\sum_{i=1}^{n} SI \times A_i}{\sum_{i=1}^{n} A_i}$	[82]
	Patch fractal dimension (PFD)	$PFD = \frac{2 \times \ln P_i}{\ln A_i}$	[31,82]
	Mean patch fractal dimension (MPFD)	$MPFD = \frac{\sum_{i=1}^{n} PFD_i}{NP}$	[82]
	Area-weighted mean patch fractal dimension (AWPFD)	$AWPFD = \frac{\sum_{i=1}^{n} PFD_i \times A_i}{\sum_{i=1}^{n} A_i}$	[82]
DIVERSITY INDICES	Diversity_1a/tot (DIV1a)	$DIV_{1a} = -\sum_{i=1}^{n} \frac{A_i}{A_{tot}} \times \ln \frac{A_i}{A_{tot}}$	[31]
	Diversity_1b/landscape element (DIV1b)	$DIV_{1b} = -\sum_{i=1}^{n} \frac{A_i}{A_y} \times \ln \frac{A_i}{A_y}$ Ay = total area of each landscape system (FSN, AGR, ART)	[31]
	Diversity_2 (DIV2)	$DIV_2 = \frac{-\sum_{i=1}^{n} \frac{A_i}{A_{tot}} \times \ln \frac{A_i}{A_{tot}}}{\ln S}$ lnS = max(DIV) S = no. of land use categories	[31,91]
	Dominance_1 (DOM1)	$DOM_1 = \ln S + \sum_{i=1}^{n} \frac{A_i}{A_{tot}} \times \ln \frac{A_i}{A_{tot}}$	[50,92]
	Dominance_2 (DOM2)	$DOM_2 = \ln S + \frac{\sum_{i=1}^{n} \frac{A_i}{A_{tot}} \times \ln \frac{A_i}{A_{tot}}}{\ln S}$	[31]
	Landscape Structural Diversity_1 (LSD1)	$LSD_1 = DIV_1 \times (3 + DOM_1)$	[50,92]
	Landscape Structural Diversity_2 (LSD2)	$LSD_2 = DIV_2 \times (3 + DOM_2)$	[50,92]

META-STABILITY INDICES	Mean Biological Territorial Capacity (MBTC)	$BTC = \frac{\sum_{i=1}^{m} BTC_i \times A_i}{A_{tot}}$	[48,49]
CONNECTIVITY INDICES	Connectivity (CON)	$CON = \frac{L}{[3 \times (N-2)]}$ L = no. of links N = no. of nodes	[93]
	Weighted connectivity (WCON)	$WCON = \frac{\sum_{i=1}^{5} L_i \times W_i}{[3 \times (N-2)]}$ Li = no. of links for each Ecological Quality Class (EQCi = [1–5]) Wi = EQCi weight: $W_i = \frac{EQC_i}{EQC_{max}}$	[65]
	Circuitry (CIR)	$CIR = \frac{(L-N+1)}{[2 \times (N-5)]}$	[93]
	Weighted circuitry (WCIR)	$WCIR = \frac{[(\sum_{i=1}^{5} L_i \times W_i) - N + 1)]}{[2 \times (N-5)]}$ Li = no. of links for each Ecological Quality Class (EQCi = [1–5]) Wi = EQCi weight (as above)	[65]
	Links/nodes ratio (L/N)	$L/N = \frac{L}{N}$ L= n. of links N= n. of nodes	[50,92]
	Weighted links/nodes ratio (WL/N)	$WL/N = \frac{WL}{N}$ $WL = \sum_{1}^{5} L_i * (\frac{i}{5})$ WL = weighted n. of links	[50,65,92]
	Links of 1st and 2nd Ecological Quality Class (EQC_1_2)	$EQC\_1\_2 = \frac{L_{1,2}}{L_{tot}}$ L1,2= n. of links with EQC=[1, 2] Ltot= total n. of link	[65]
	Links of 1st and 2nd Ecological Quality Class (EQC_4_5)	$EQC\_4\_5 = \frac{L_{4,5}}{L_{tot}}$ L4,5= n. of links with EQC = [4, 5] Ltot= total n. of link	[65]

Table A2. Summary statistics on farm-scale landscape ecology indices (entire dataset, including TOT farm system, AGR, and FSN subsystems values).

	N	Min	Max	Mean	Std. Error	Variance	Stand. Dev	Median	25 Prcntil	75 Prcntil	Skewness	Kurtosis
MPS	86	0.06	7.19	1.01	0.15	1.99	1.41	0.45	0.23	1.02	2.84	8.29
MTX	94	0.00	100.00	51.07	4.92	2272.65	47.67	86.32	2.34	99.99	−0.04	−2.02
FSN	24	0.00	8.71	1.52	0.45	4.86	2.21	0.34	0.00	3.06	1.81	3.61

AGR	24	85.21	98.94	94.75	0.77	14.05	3.75	95.38	92.85	97.46	−1.14	0.65
MPAR	86	0.00	0.22	0.05	0.01	0.00	0.05	0.04	0.01	0.09	1.04	0.64
SI2	86	1.14	18.14	5.55	0.45	17.17	4.14	4.09	3.32	5.33	1.85	2.28
MSI2	86	0.10	2.53	0.87	0.06	0.29	0.54	0.74	0.47	1.14	0.82	0.39
AWSI2	86	1.14	15.93	4.45	0.44	16.28	4.04	3.11	2.37	3.68	2.08	2.91
PFD	86	1.36	1.66	1.50	0.01	0.01	0.08	1.51	1.43	1.57	−0.02	−1.17
MPFD	86	0.01	1.58	0.59	0.05	0.20	0.45	0.45	0.22	0.89	0.72	−0.58
AWPFD	86	1.36	1.62	1.47	0.01	0.01	0.07	1.46	1.39	1.53	0.32	−1.16
DIV1a	96	0.00	2.02	0.28	0.04	0.14	0.37	0.14	0.06	0.31	2.38	6.31
DIV1b	92	0.00	2.71	0.66	0.06	0.30	0.54	0.65	0.02	1.00	0.69	0.95
DIV2	96	0.00	0.84	0.14	0.02	0.03	0.17	0.09	0.03	0.18	1.94	3.81
DOM1	86	0.37	2.51	1.53	0.04	0.17	0.41	1.48	1.25	1.78	0.05	0.03
DOM2	86	0.16	0.99	0.84	0.02	0.03	0.17	0.91	0.80	0.96	−1.86	3.30
LSD1	96	0.00	6.83	1.17	0.15	2.09	1.45	0.62	0.27	1.35	1.97	3.64
LSD2	96	0.00	2.66	0.51	0.06	0.32	0.57	0.33	0.11	0.69	1.67	2.45
MBTC	86	0.70	6.51	1.41	0.11	1.05	1.02	1.09	0.93	1.18	3.02	9.57
CON	24	−0.33	1.33	0.06	0.07	0.12	0.35	0.00	0.00	0.00	2.23	6.94
WCON	24	−0.23	0.53	0.03	0.03	0.03	0.17	0.00	0.00	0.00	1.43	2.93
CIR	24	−0.60	2.00	−0.09	0.10	0.24	0.49	−0.20	−0.20	−0.20	3.68	16.04
WCIR	24	−0.48	0.00	−0.21	0.02	0.01	0.10	−0.20	−0.20	−0.20	−0.78	2.28
L/N	24	0.00	1.43	0.30	0.11	0.29	0.53	0.00	0.00	0.75	1.33	−0.12
WL/N	24	0.00	0.90	0.16	0.06	0.08	0.29	0.00	0.00	0.30	1.57	1.05
EQC_1_2	24	0.00	1.00	0.15	0.06	0.10	0.31	0.00	0.00	0.23	2.01	3.20
EQC_4_5	24	0.00	0.53	0.08	0.04	0.04	0.19	0.00	0.00	0.00	1.91	1.81

Table A3. Distribution of the values of differences between POLY-CVx (absolute values, for each index), for the total farm system (TOT), the forest and semi-natural subsystem (FSN), and the agricultural subsystem (AGR). In bold: the quartile values employed to set the four classes.

t		TOT									FSN									AGR								
	N	Min	25 Prcntil	Median	75 Prcntil	Max	Mean	Std. Error	Variance	Stand. Dev	Min	25 Prcntil	Median	75 Prcntil	Max	Mean	Std. Error	Variance	Stand. Dev	Min	25 Prcntil	Median	75 Prcntil	Max	Mean	Std. Error	Variance	Stand. Dev
FSN	20	−0.01	**0.02**	**0.03**	**0.04**	0.09	0.04	0.01	0.00	0.02																		
AGR	20	−0.10	**−0.04**	**−0.03**	**−0.02**	0.02	−0.03	0.01	0.00	0.03																		
NP_%											−0.02	**0.13**	**0.15**	**0.17**	0.24	0.15	0.01	0.00	0.06	−0.17	**−0.14**	**−0.07**	**−0.02**	0.09	−0.07	0.02	0.01	0.07
MPS											−0.74	**0.00**	**0.13**	**0.23**	0.27	0.07	0.05	0.05	0.23	−5.04	**−2.40**	**−0.36**	**0.28**	0.66	−1.02	0.40	3.19	1.79
MPAR											−0.117	**−0.063**	**0.040**	**0.098**	0.131	0.023	0.020	0.008	0.088	−0.002	**0.003**	**0.004**	**0.006**	0.015	0.005	0.001	0.000	0.004
PFD											0.00	**0.07**	**0.87**	**1.57**	1.64	0.84	0.17	0.61	0.78	−0.07	**−0.03**	**0.04**	**0.08**	0.16	0.03	0.01	0.00	0.06
DIV1a	20	0.18	**0.79**	**1.01**	**1.20**	1.71	0.99	0.08	0.12	0.34	0.01	**0.12**	**0.14**	**0.18**	0.24	0.14	0.01	0.00	0.05	0.18	**0.68**	**0.89**	**1.10**	1.44	0.87	0.07	0.10	0.32
DIV1b											−0.27	**0.37**	**0.86**	**1.08**	1.13	0.69	0.09	0.18	0.42	0.19	**0.69**	**0.97**	**1.15**	1.60	0.93	0.08	0.14	0.37
DOM1	20	−1.07	**−0.41**	**−0.30**	**−0.17**	0.41	−0.31	0.07	0.10	0.32	0.06	**0.43**	**1.38**	**2.15**	2.16	1.26	0.20	0.80	0.89	−0.95	**−0.36**	**−0.17**	**0.09**	0.41	−0.21	0.08	0.12	0.34
MBTC	20	0.14	**0.19**	**0.28**	**0.75**	1.17	0.43	0.08	0.13	0.35	0.43	**1.77**	**2.12**	**3.00**	6.51	2.60	0.34	2.26	1.50	0.10	**0.17**	**0.19**	**0.50**	0.81	0.30	0.05	0.06	0.24
CON	20	0.46	**0.48**	**0.53**	**1.21**	1.33	0.77	0.08	0.13	0.36																		
WCON	20	0.23	**0.28**	**0.33**	**0.53**	0.57	0.38	0.03	0.02	0.13																		

CIR	20	0.27	**0.36**	**0.47**	**1.87**	2.20	0.89	0.18	0.62	0.79
WCIR	20	−0.20	**−0.16**	**−0.04**	**0.10**	0.45	0.02	0.04	0.03	0.18
L/N	20	0.11	**1.11**	**1.31**	**1.40**	1.43	1.19	0.08	0.13	0.36
WL/N	20	−0.07	**0.53**	**0.53**	**0.87**	0.90	0.64	0.05	0.06	0.24
EQC_1_2	20	−0.58	**0.30**	**0.46**	**0.88**	1.00	0.48	0.09	0.16	0.40
EQC_4_5	20	0.00	**0.00**	**0.00**	**0.52**	0.53	0.21	0.06	0.07	0.26

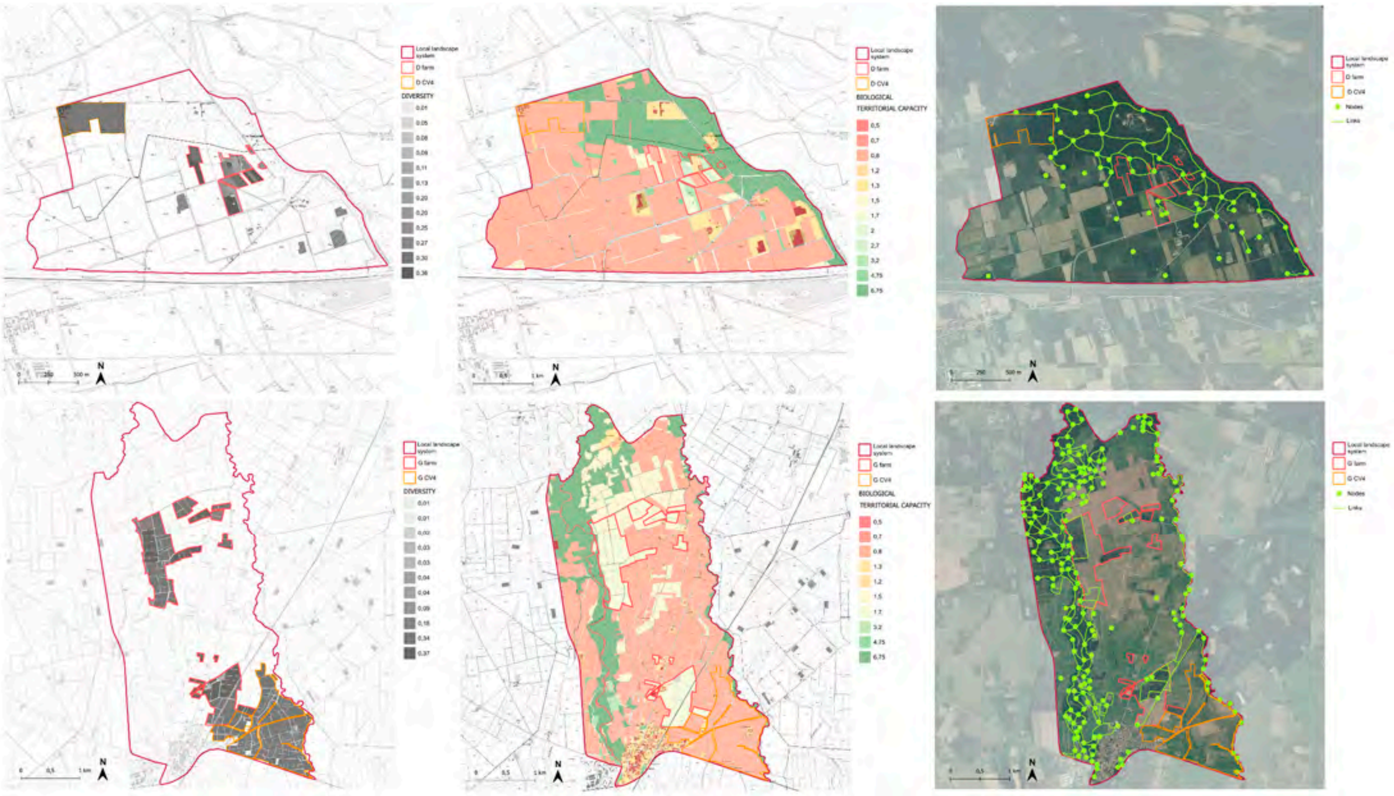

Figure A1. Example on the spatial representation of indices for D (**upper side**) and G (**bottom side**) sites, the ones which showed best performances. For each site, diversity (DIV1A), mean biological territorial capacity (MBTC), and connectivity graphs maps showing links and nodes are reported for the POLY farm (D and G) and an example on one local CV farm (D-CV4; C-CV4).

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