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Agricultural Landscapes: A Pattern-Process-Design Approach to Enhance Their Ecological Quality and Ecosystem Services through Agroforestry

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Abstract: Agricultural landscapes are currently suffering and generating severe ecological issues. This is especially true in intensively managed alluvial contexts, where biodiversity is declining and ecosystem services (ES) delivery capacity is being depleted. The aim of our study is to set up and test a synthetic analytical methodology that allows us to: understand current agricultural landscape ecological quality drivers (structural and functional traits); identify context-specific strategies to correct current negative trends (landscape ecology design approach); and assess the changes in the landscape ecological behavior provided by design scenarios. The applied methodology is low-cost and low-time-demanding and is based on multi-scale landscape ecology and land-use-based ES assessment; it implements a *pattern-process-design* approach. Analyses are applied to four northern Italian alluvial agricultural landscape systems. We specifically address landscape biodiversity support functions (landscape ecology indicators) and landscape multifunctionality (ES spatial assessment). We test the agroforestry approach (landscape feature insertions and crop diversification) as a key strategy to enhance ecological quality and ES, and we account for its contributions to context-specific design scenarios. This analytical toolkit might serve for future applications on similar case studies.

Keywords: agroforestry; landscape features; landscape ecology; ecosystem services; Po Plain; Italy

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1. Introduction

Changes in agricultural management since the 1950s have significantly shaped agricultural landscapes, resulting in widespread ecological impacts and, from a landscape ecology perspective, multi-scale ecological imbalances [1]. This is particularly evident in alluvial agricultural areas, where intensive agriculture has easily prevailed, depleting the ecological infrastructure of the landscape. In such contexts, the progressive removal of landscape features, coupled with the biogeochemical impacts of intensive agriculture, has led to a diffuse trend in biodiversity loss [2–6], landscape oversimplification and mono-functionally [7], and the depletion of landscape ecosystem services [8,9]. The conservation of landscape features and their integration into agricultural landscapes and agroforestry-based agricultural management are key strategies to address such impacts (restoration of life-supporting, regulating, and cultural ecosystem services), while ensuring food provisioning services, and also thanks to crop diversification practices often associated with agroforestry approaches [10–14]. The composition of the agro-landscape ecomosaic and the spatial configuration of its components (agricultural vs. natural and semi-natural vs. artificial) influence the provision of ecosystem services [15]. Hence, the ecological effectiveness of landscape features and agroforestry practices depends on proper multi-scale landscape assessment, planning, and design. Indeed, the induced change in landscape structure might support, to different degrees, the delivery of ecosystem services [16], which depend on the multi-scale structural and functional configuration of the landscape.

The landscape ecology approach provides several analytical tools to consider such patterns and processes. Landscape ecology analyses can directly complement the assessment of some life-supporting, regulating, provisioning, and cultural ecosystem services by assessing the ecological functioning and quality of a landscape. [17]. In addition, landscape ecology multi-scale analyses can guide landscape ecological planning, design, and strategic management, thus promoting its cross-scale multifunctionality, i.e., its capacity to deliver multiple ES [18]. Several experiences have already tested the potential of landscape ecology in bridging the gaps between the assessment, design, and monitoring phases in relation to the ecosystem services framework [19]. Nassauer and Opdam proposed the evolution of the landscape ecology paradigm towards *pattern-process-design* [20]. In particular, the concept of landscape services helped to bridge the landscape ecology approach to sustainable landscape management by recognising landscape metrics as appropriate indicators to assess spatial-qualitative changes for spatial planning purposes [21]. However, the use of landscape metrics to assess landscape ecosystem services is limited to those services that depend on landscape structural aspects [22] and to those landscape metrics that are appropriately selected for the specific landscape type under assessment [21]. Depending on the required accuracy of ES assessment, landscape ecology metrics may need to be coupled with other indicators [21], and caution is needed as their ecological interpretation significantly differs between landscape types [23]; quantifying the ecological inferences of landscape metric values and transferring them to ES assessment could be misleading.

Accordingly, we can cautiously state that landscape ecology analyses can serve as a complement to land-use-based ecosystem services assessments. A viable, cautious strategy might be to use landscape ecology analyses to assess the ecological functioning and balance of a landscape system (mainly, biodiversity-support functions) and to guide strategic landscape ecological planning and design, and then couple such assessments with validated land-use-based ES assessment tools (iterative assessment on current state and landscape ecology-based design scenarios). The methodology of Burkhard et al. provides a viable synthesis of land-use-based ES assessment [24]. Specifically, Burkhard et al.'s work estimates ES delivery capacity through equal interval classification methods applied to data derived from statistics, expert knowledge, interview results, monitoring, and other literature data sources [24]. The outputs are ES matrices and maps, specifically built for specific scales of analysis, and can be easily applied to different design scenarios.

The aim of our study is to test a synthetic analytical methodology to address the need for:

- quantitative and spatialized information on the drivers of ecological balance in agricultural landscapes;
- available, low-cost, and low-time-consuming analytical tool kits suitable for application in similar agricultural contexts for their assessment and for guiding targeted management strategies to maximise the ES delivery capacity.

Our study focuses on the main drivers of agricultural landscape ecological quality and balance by investigating:

- their structural and functional traits—landscape ecology approach, focusing on the assessment of landscape structure and composition and on the consequent identification of landscape resilience and vulnerability drivers [25], with a specific focus on biodiversity support functions;
- their degree of multi-functionality or specialisation by addressing their relationship with the capacity to provide ecosystem services—application of a land-use-based approach.

Both analytical approaches are suitable for local and extra-local landscape unit assessments; they both rely on land use maps as entry data and are hence suitable for synthetic, cost-efficient assessments. Their spatialized outputs (landscape indices maps, maps of the drivers of landscape vulnerability and resilience, ecosystem services maps) also allow the identification of specific strategies and interventions to improve the ecological quality and multifunctionality of agricultural landscapes by intervening on landscape structure. In our study, we address landscape structure improvement through the agroforestry approach (management and insertion of linear and areal landscape features) and crop diversification through polyculture. This leads to the building of landscape ecological design scenarios, which can be assessed for their contributions to biodiversity and ES delivery by reapplying the landscape ecology and land-use-based ES assessment methodologies. This allows the agroforestry approach to be assessed for its contributions to local-scale landscape ecological balance and multi-functionality.

In this study, we present the application of the methodology to a series of alluvial agricultural landscapes (Western Po Plain, Northern Italy) dominated by conventional agricultural practices, which differ slightly in their landscape structure and composition. The sites were chosen because in each of them there is a local farm experience of agroforestry-based crop production that differs from the locally widespread conventional agricultural management. In each study site, the current ecological characteristics of the landscape system are investigated through multi-scale analyses, and then an agroforestry-based design scenario is built and assessed on the local-scale landscape system, taking inspiration from existing agroforestry farm experiences.

2. Materials and Methods

2.1. Overview of the Applied Methodology

The agricultural landscape assessment is built on a pattern-process-design approach [20] and is based on multi-scale landscape ecology tools and an ecosystem services (ES) spatial assessment (Figure 1). Specifically, the different agricultural contexts under study are investigated based on their landscape ecological traits by identifying two main scales of analysis: the extra-local scale (E_La) and the local scale (La) landscape system, which are identified according to the landscape unit and ecotope concepts [26–28].

Landscape ecology analyses (E_La; La) focus on biodiversity support functions in agricultural landscapes and are led both at extra-local and local scales of analysis (current state). They focus on the structural and functional traits of the landscape systems (*pattern* and *process*) (Figure 1; Section 2.2).

The landscape ES delivering capacity assessment (*process*) focuses on agricultural landscape multifunctionality and is investigated on the local scale using a current landscape system through a land-use-based approach [24] (Figure 1; Section 2.3).

Their results allow synthesis on the current drivers of vulnerability and resilience of the E_La and La landscape systems (*process*) [25,29–32], as already tested in previous experiences [33,34]. This positions the identification of landscape ecological re-design scenarios (*design*) (Figure 1; Section 2.4). In this specific study, the design scenarios were based on the agroforestry approach (i.e., landscape features and nature-based solutions) [35] and diversified crop management through polyculture. This allowed us to assess their contributions compared to conventional agricultural management (the absence or reduced presence of landscape feature management, i.e., the current state local-scale agricultural landscape). The design scenario is assessed by re-applying the landscape ecology and ES assessment tools (Figure 1).

2.2. Landscape Ecology Analyses

We collected and analysed, through GIS software (QGIS Desktop 3.26.0), the following data: geomorphology, pedology, hydrology, phyto-climate, regional land cover, historical land use, vegetation, protected areas, regional ecological network, and other in-force land-planning tools [36,37]. At the extra-local scale, land use patch boundaries were based on regional land cover maps (vector layers), whereas at the local scale, they were re-adapted from regional land cover maps based on satellite images [38] and quick field checks (vector layers). Land use types were classified into four landscape subsystems, according to the Corine Land Cover classification [39]: the forest and semi-natural subsystem (FSN); the agricultural subsystem (AGR); and the artificial subsystem (ART).

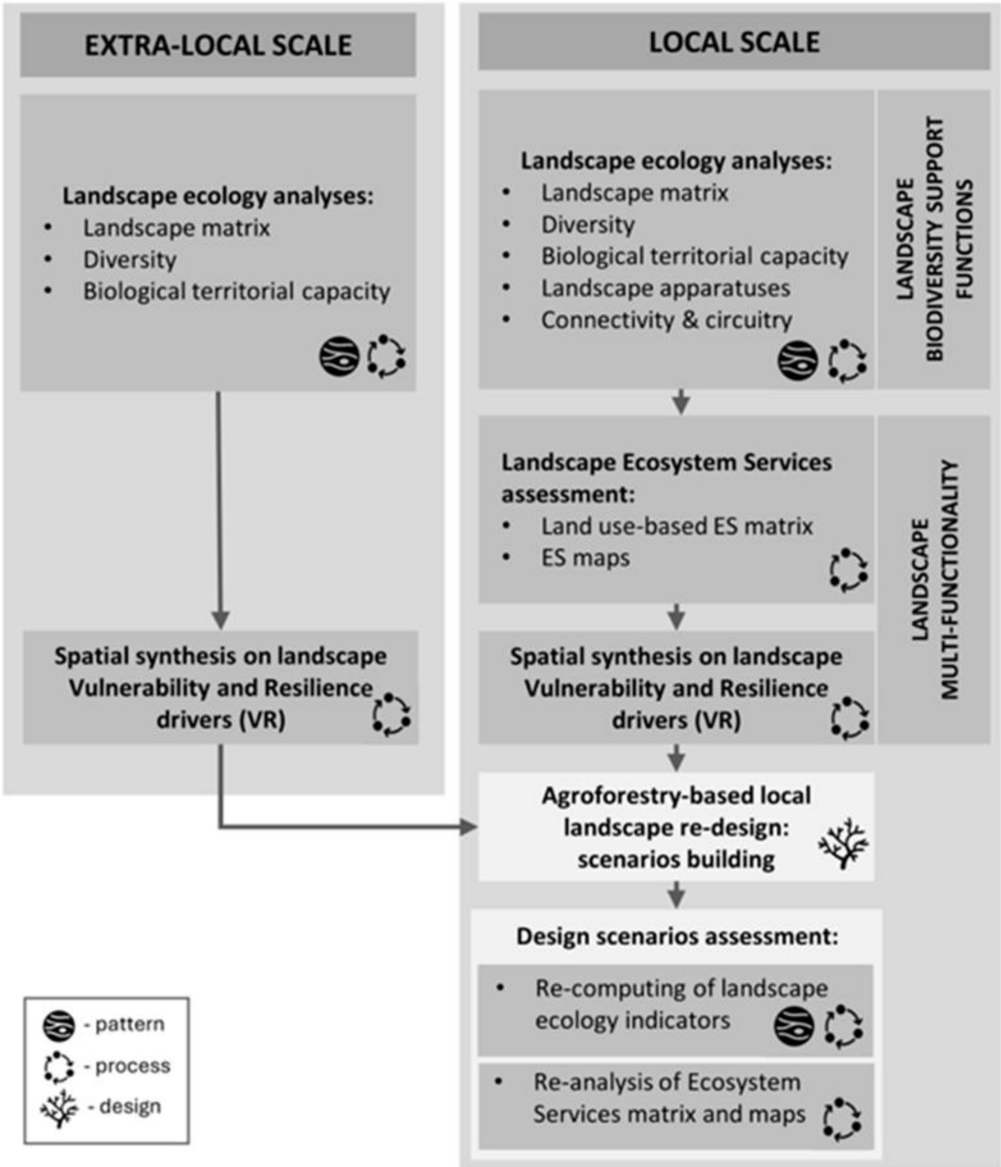

Figure 1. The applied multi-scale methodology for assessing the ecological quality and ES-delivering capacity of agricultural landscapes, with a specific focus on agroforestry contributions. Its *pattern-process-design* components are highlighted.

At the extra-local (E_La) scale, a set of landscape ecology indices was applied according to previous studies on the same territorial context [33,34,40]. Details on the applied indices are reported in Appendix A, Table A1. We investigated: the landscape eco-mosaic composition and matrix (MTX: FSN, AGR, and ART components ratio); the landscape diversity for the total landscape system (TOT) and for the FSN and AGR subsystems; and the landscape mean biological territorial capacity (MBTC), an indicator that synthetically represents the metastability degree of the landscape eco-mosaic [26,28,41]. BTC unitary values (ranges associated with different land use types) are reported in the literature for the northern Italy context [28,41].

Indices application allowed a first investigation of the main ecological traits of the territorial contexts of the different sites under study. The interpretation of thematic layers and landscape ecology analyses brought about a spatialized synthesis of the main drivers of vulnerability and/or resilience of each E_La landscape system (VR analysis) [25,29–32]. VR maps are conceived as synthetic graphic tools that help in identifying targeted planning strategies and priorities to balance landscape unit ecological criticalities [33,34].

At local scale (La), a wider set of landscape ecology indices was applied: the landscape eco-mosaic composition and matrix (MTX: FSN, AGR, and ART components ratio); landscape diversity for the total landscape system (TOT) and for the FSN and AGR subsystems; the landscape mean biological territorial capacity (MBTC); the landscape physiological apparatuses [connective AP_CN; excretory (AP_EX); productive (AP_PD); resilient (AP_RSL); stabilisation (AP_STB)]; and the connectivity and circuitry indices (CON; CIR), with their variants weighted on the links ecological quality classes (WCON, WCIR) [33]. The landscape apparatuses represent the landscape physiological traits (eco-tissue model) [26,28,42]. Details on the applied indices are reported in Appendix A, Table A1. The application of indices allowed for a quantitative and spatialized comparison of the different sites under study. These analyses, coupled with ecosystem service spatial assessment (see Section 2.3), allowed us to detect specific drivers of vulnerability and resilience of each landscape unit under study, which were synthesised in VR maps, as for the E_La scale. VR maps served as synthetic, interpretative tools to guide the identification of site-specific landscape ecological re-design strategies (see Section 2.4).

2.3. Landscape Ecosystem Services Assessment

We built a reference ES matrix based on land use types, which was conceived as a model to possibly be applied to alluvial temperate agricultural landscapes. We started with the methodology of Burkhard et al. to set up the first version of the reference ES matrix, focusing on ES potential assessment [24]. Provisioning, regulating, and cultural ES types were taken from Burckhard's work. To better link the ES assessment (with a focus on landscape multifunctionality) with the landscape ecological quality assessment (with a focus on landscape biodiversity), we also included the support ES category, according to TEEB classifications [43]. Our ES matrix included: 1 support ES, 10 provisioning ES, 10 regulating ES, and 4 cultural ES [43–45]. The Burkhard matrix refers to 'normal' European landscape land uses based on Corine Land Cover Level 3 classes [39]; we updated it with higher resolution in local land use type categories (Figure 8) to deepen our investigation on agricultural landscape peculiarities. Like Burkhard's work, the degree to which each land use type contributes to each ES delivery is estimated through an ordinal, discrete scale of values ranging from 0 (no relevant potential supply) to 5 (maximum relevant potential supply). ES estimates for each land use type were made according to the following steps:

- coupling of Burkhard's work land cover types to our study site land use categories;
- assignment of provisioning, regulating, and cultural ES delivery values to each land use type (Burkhard's work values);
- assignment of support ES delivery values according to the references in the literature (European and/or global meta-analyses and local studies (northern Italy));
- decrease and/or removal of single provisioning ES delivery, which were not relevant to the represented local case histories;
- correction of the support, regulating and cultural ES delivering values based on the ratio (BTC%) between biological territorial capacity (actual BTC) unitary values for each land use type and their maximum BTC values, according to literature ranges [26,28,41]. Like support ES, regulating ES and (partly) cultural ES, BTC values are positively related to phytocoenoses biomass, maturity and dynamism and are inversely related to human and natural disturbance. In this case, we used BTC% values to weight the effective ES contributions of actual land use types, to better reflect the typical alluvial agricultural landscapes components ecological quality, which differ from the Burkhard's normal European landscape traits because of the influence of the medium-to-long term human disturbances.

The obtained reference ES matrix was then applied to each site's actual local land use types. To transfer the results into a spatial representation, for each land use type, we considered the degree of potential delivery of each ESy macro-category (Esy = support (ES_SUPP), provisioning (ES_PROV), regulating (ES_REG), and cultural (ES_CULT)) compared to the maximum theoretical values (5 in our scoring system), similar to the authors' previous experiences [40]. For each land use category, we calculated the cumulated ES supply for each of the 4 ES macro-categories; then, each cumulated y-ES category scoring was normalised to 100 as follows:

$$ES_y = \frac{\sum_i^{n_y} ES_{yi}}{\sum_i^{n_y} MAX(ES_{yi})} \times 100 \; with: \; MAX(ES_{yi}) = 4; \; ES_{yi} = [1, 4]; \; ES_y = [0, 100],$$

where ESyi represents single i-ES supply values belonging to the y-ES category, and ESyi numerosity [1, ny] depends on the y-ES category. Consequently, the normalised values of the total ES supply (ES_TOT; cumulation of the four y-ES category scorings) were obtained for each land use category as follows:

$$ES_{tot} = \frac{\sum_1^4 ES_y}{\sum_1^4 MAX(ES_y)} \times 100 \; with: \; MAX(ES_y) = 100$$

In this way, for each land use type, we obtained normalised potential ES delivery values for each of the 4 ES macro-categories (SUPP; PROV; REG; CULT) and for the total ES (ES_TOT) gathering all ES types. These values were then added together with land-use geospatial layers for ES map building.

2.4. Agroforestry-Based Landscape Re-Design: Scenarios Building

According to the extra-local- and local-scale analyses results interpretation (Sections 2.2 and 2.3), we identified specific intervention strategies (types and localisation) on the local landscape ecological infrastructure for each site under study, according to the landscape ecology principles [19,20,46–50]. Intervention types were based on nature-based farming solutions and a landscape features approach, focusing on the implementation of an agroforestry-based diversified agricultural landscape (interspersed hedgerows, treelines, small woody areas, woody belts, woods, wetlands, crop diversification), targeted to reduce the current vulnerabilities of each local and extra-local landscape system and foster its resilience traits [10,12,51–54]. Within each local landscape system, design interventions were identified, taking inspiration from the already-existing agroforestry-based farm systems, which represent workable local case histories. We set up a design scenario for each local-scale landscape system, which was built on GIS software by modifying the landscape eco-mosaic (patches and linear components; vector layers) and forecasting the insertion of linear and areal landscape features according to the highlighted priorities on the VR map. Landscape ecology analyses are then re-applied to each design scenario (see Section 2.2); indicator values are compared to the current state through percentage gaps, as follows:

$$\%gap = \frac{scenario - current\ state}{current\ state} \times 100$$

Then, the ES matrix and maps are also built for each design scenario (see Section 2.3).

2.5. Case Studies

To test the methodology, we applied the landscape ecology and ES analyses among 4 sites representing agricultural landscape systems (C, D, G, P) located in the temperate alluvial western Po Plain district (Piedmont and Lombardy region, Northern Italy) (Figure 2A). Figure 2B shows, for each site, extra-local- and local-scale boundaries. As mentioned, an agroforestry-based farm is represented within each local landscape system (Figure 2B), which is characterised by in-field and between-field landscape features management and crop diversification through polyculture. These agroforestry farms are clearly distinguished from the most widespread local conventional crop farms, based on monoculture, with no active landscape feature management. Sites belong to the same macro-bioclimate (temperate continental) but show slight differences in their climatic and bioclimatic traits (Table 1) [55–57]. They all belong to alluvial deposits of different ages and pedogenesis degrees (Table 1; Figure 2C) [36,37], with a long history of agricultural management. Their main in-force planning tools and constraints are reported in Figure 2D.

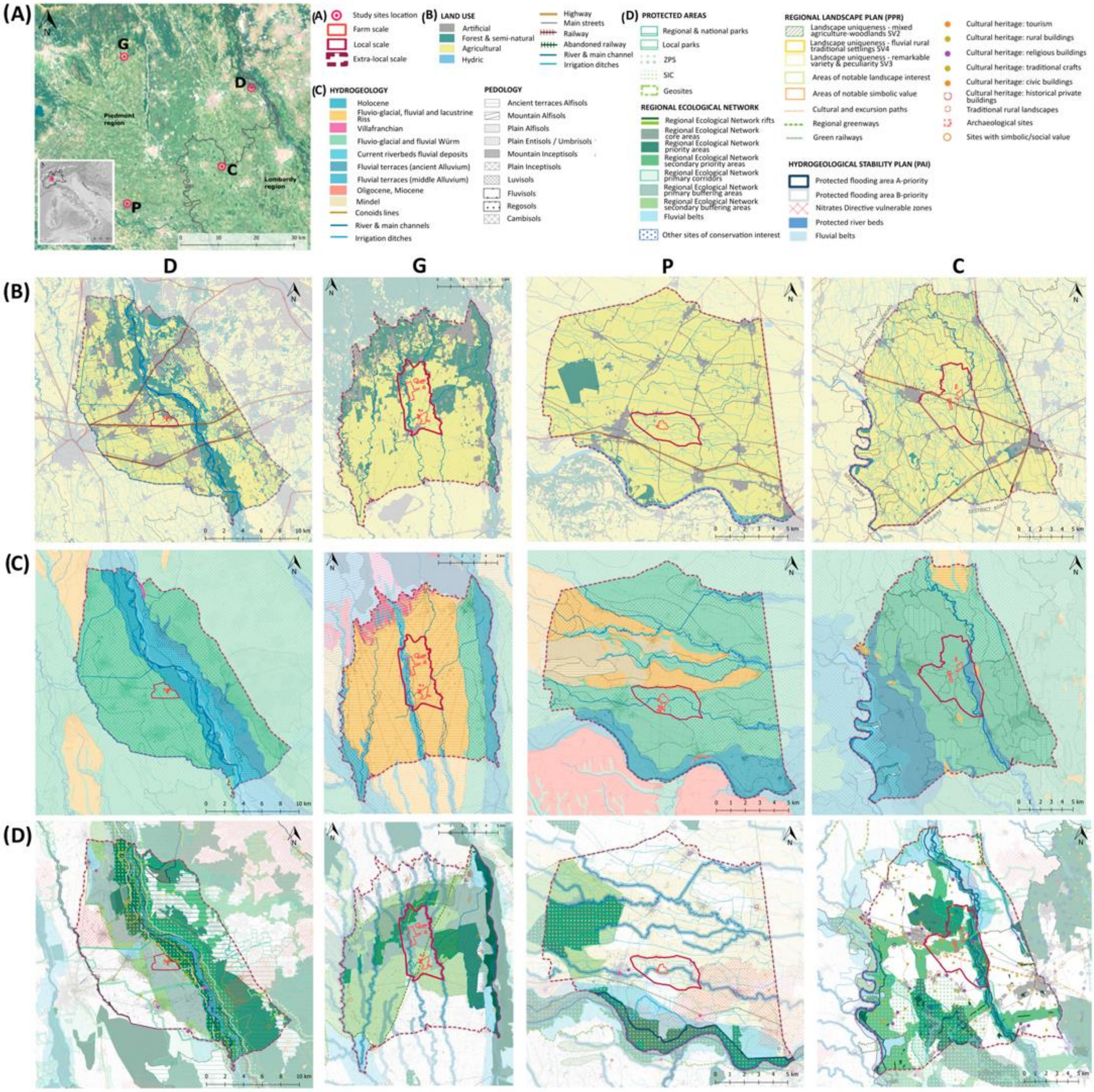

Figure 2. (**A**) The four site locations in western Po Plain (C, D, G, P); (**B**) the main land use categories, showing extra-local and local landscape systems boundaries, as well as agroforestry-based farm boundaries; (**C**) the main geomorphological and pedological traits of the four sites; (**D**) the protected areas and planning tool restraints binding the four site landscape systems. The legend above shows all the entries on each map.

Table 1. The main pedological, climatic, and bioclimatic traits of the four local scale sites (World Reference Base (WRB) and Soil Taxonomy (ST) pedological groups).

		C	G	P	D
PEDOLOGY	ST /WRB CLASSES	Luvisols; Arenosols	Alfisols (ancient terraces); Inceptisols	Inceptisols; Entisols	Inceptisols
	Geomorphology	Fluvial terrace	Riss alluvial terrace	Fluvial deposits	Fluvial terrace
	Main soil texture	Loamy-sand; Sandy-loam	Fine silty	Loamy-coarse; Loamy-sand	Loamy-skeletal
	Development	Medium pedogenesis	Intense pedogenesis	Low pedogenesis	Low pedogenesis
	Permeability	Medium-low permeability	Surface hydromorphy	Medium permeability	High permeability
	pH	Sub-Acid	Acid	Sub-alkaline to alkaline	Acid to Sub-acid
	Land-use capacity	IIw (waterlog)	III (Oxygen availability)	II (Oxygen availability)	III (stoniness)
	Specific traits				Dark epipedon
CLIMATE [1990–2022 data]	Annual rainfall [mm]	668	872	737	973
	Annual mean Temperature [°C]	13.1	12.3	13.2	11.8
	Average Maximum Temperature [°C]	18.6	18.9	18.8	17.9
	Average Minimum Temperature [°C]	8.19	7.0	8.5	6.4
BIOCLIMATE [1990–2022 data]	Bioclimate (variant)	Temperate oceanic (submediter-ranean)	Temperate continental (steppic)	Temperate continental (steppic)	Temperate continental
	Bioclimatic belt	Upper mesotemperate Low humid	Upper mesotemperate Upper subhumid	Upper mesotemperate Low subhumid	Upper mesotemperate Low humid

3. Results and Discussion

3.1. Extra-Local-Scale Landscape Ecological Assessment

3.1.1. Landscape Ecology Analyses: Biodiversity Support Functions

Table 2 reports the results of the landscape ecology indicator application on the extra-local landscape systems.

All sites' extra-local landscape eco-mosaics are characterised by an agricultural matrix (AGR), which is highly stable in sites P and C; it is significantly higher than 60% of the total surface [47], showing high landscape functional specialisation on productive functions. G and D show more mixed patterns, with a greater presence of forest and semi-natural components (FSN), which are almost depleted in P and C. Site D also shows greater artificial surface presence (ART), which has a minor influence on the other sites. Concerning extra-local landscape diversity, G and D show greater total landscape diversification compared to P and C (DIV_TOT), with the highest values in D. Furthermore, the FSN and AGR subsystems are more diversified in G and D. In line with this, G and D also have higher overall landscape metastability values (MBTC_TOT), which are mostly sustained by the main ecological corridors associated with river belts. The FSN components also show greater maturity and stability in G and D (MBTC_FSN) thanks to the persistence of ancient wood patches, absent in P and C, where FSN components are mostly made of spontaneous tree-shrub phytocoenoses of lower ecological quality and BTC values. The agricultural components do not show clear BTC differences between sites (MBTC_AGR), with conventional crop systems prevailing in all AGR matrices. P and C extra-local landscape systems show general higher instability, influenced by the higher landscape simplification and specialisation; the conventional agricultural management impacts are supposed to be less mitigated by the landscape ecological infrastructure.

Table 2. Main differences between the four extra-local-scale landscape system ecological traits (structural and functional metrics). See Appendix A, Table A1, for details on the applied indices.

			SITE			
	INDEX	**U.o.M.**	**D**	**G**	**P**	**C**
MATRIX	FSN	%	27.22	30.58	6.67	5.18
	AGR	%	54.96	60.14	86.67	88.56
	ART	%	17.83	9.28	6.66	6.26
DIVERSITY	DIV_TOT	-	2.13	1.70	1.11	1.09
	DIV_FSN	-	0.59	0.51	0.25	0.23
	DIV_AGR	-	0.92	0.80	0.56	0.60
BIOLOGICAL TERRITORIAL CAPACITY	MBTC_TOT	Mcal/ha/yr	1.88	2.39	1.26	1.17
	MBTC_FSN	Mcal/ha/yr	4.51	5.32	3.48	2.52
	MBTC_AGR	Mcal/ha/yr	1.01	1.14	1.14	1.14

3.1.2. Synthesis of Extra-Local Landscape Vulnerability and Resilience Drivers

Figure 3 shows the vulnerability and resilience maps (VR), which synthetise the ecological interpretation of the extra-local-scale main traits derived from the study of their land use, geomorphology, pedology, planning tools, and landscape ecological traits.

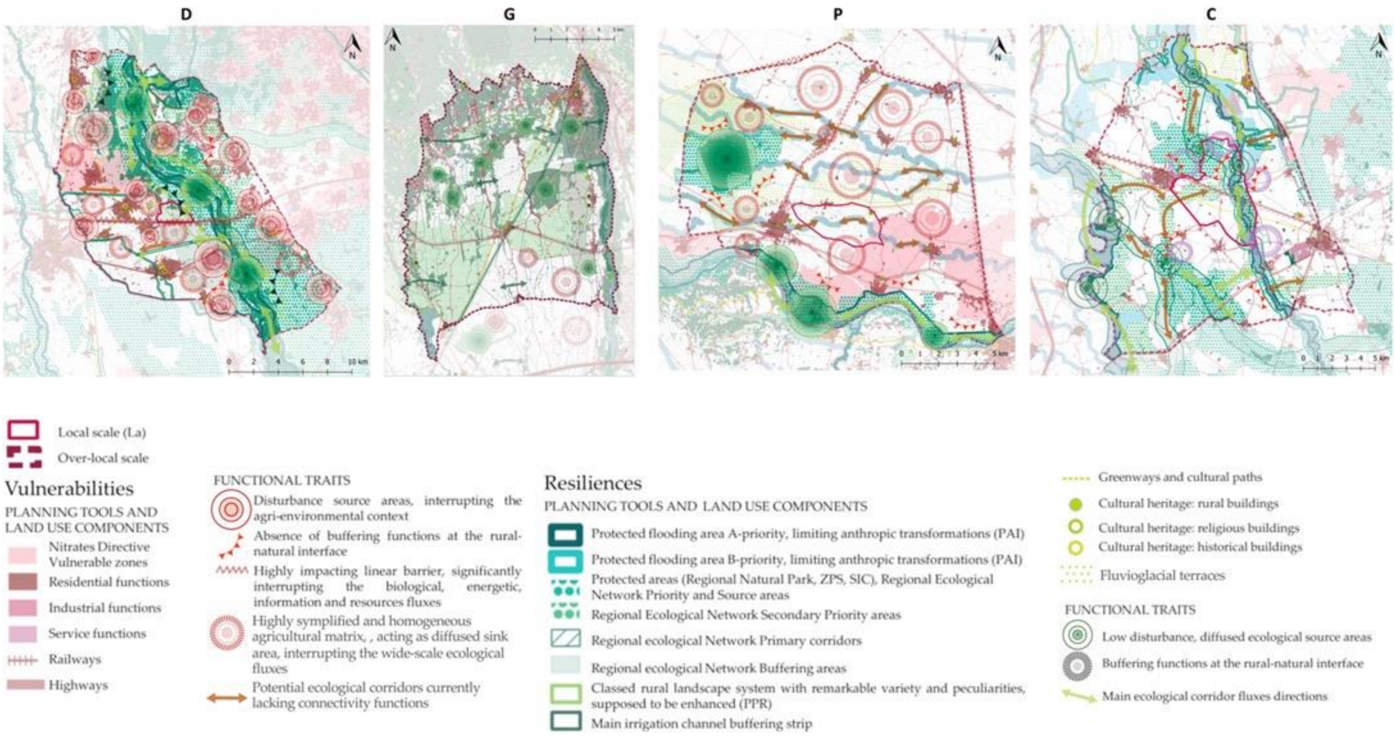

Figure 3. Maps synthesis for each extra-local-scale landscape system (D, G, P, C), the vulnerability and resilience drivers (VR analysis).

The pivotal role of the river belt axes as biodiversity source areas is highlighted in the D and G sites, where ecological buffering functions between the natural-agricultural interface might be better implemented, main ecological corridor source functions might be amplified, and the agricultural areas suffer from landscape over-simplification and are currently acting as sink areas [58]; they might be re-qualified through a targeted ecological infrastructure implementation. These last traits are predominant in the P and C sites, where biodiversity source areas are limited and fragmented, ecological corridor continuity is impaired, and its capacity to spread biotic, genetic, and information fluxes across the agricultural matrix is impaired [46]. In P and C, the extra-local landscape shows greater un-mitigated impacts resulting from intense agricultural landscape over-simplification (low buffering functions at the rural-natural interface, extensive sink areas reducing biodiversity, fragmented or absent ecological corridors, and un-mitigated barriers) [46,59,60].

3.2. Local-Scale Landscape Ecological Assessment

3.2.1. Landscape Ecology Analyses: Biodiversity Support Functions

As for the extra-local scale, also at the local scale, the four sites show two separated landscape ecological configurations between the P-C and D-G sites (Table 3).

Table 3. Landscape ecology indicators: main differences between the four local-scale landscape systems' ecological traits in their current state (structural and functional metrics). See Appendix A for details of the applied indices.

			SITE			
	INDEX	**U.o.M.**	**C**	**P**	**G**	**D**
	Area	ha	2276.15	692.64	1335.87	325.65
MATRIX	AGR	%	93.06	93.04	68.63	69.64
	FSN	%	4.23	4.40	26.45	23.53
	ART	%	2.71	2.56	4.92	6.83
DIVERSITY	DIV_TOT	-	0.79	0.74	1.81	1.55
	DIV_FSN	-	0.22	0.21	0.59	0.48
	DIV_AGR	-	0.45	0.42	1.03	0.84
BIOLOGICAL TERRITORIAL CAPACITY	MBTC	Mcal/ha/yr	1.18	1.16	2.56	2.22
LANDSCAPE APPARATUSES	AP_CN	%	0.821	0.983	1.441	1.575
	AP_EX	%	2.648	0.815	1.691	0.688
	AP_PD	%	89.495	91.650	67.357	69.060
	AP_RSL	%	0.846	1.963	3.601	2.384
	AP_STB	%	0.698	0.730	19.869	19.802
CONNECTIVITY AND CIRCUITRY	CON	-	0.24	0.36	0.39	0.33
	WCON	-	0.12	0.16	0.30	0.22
	CIR	-	−0.14	0.03	0.08	−0.01
	WCIR	-	−0.32	−0.28	−0.05	−0.18

- The P and C sites are strictly aligned with Po Plain typical agricultural landscape over-simplification traits (MATRIX and DIVERSITY indices, Table 3); the agricultural matrix (AGR) is strongly predominant; forest and semi-natural components (FSN) are consistently limited.
- The D and G case studies show greater land use diversification (DIVERSITY indices; Table 3) and a better ecological balance (MBTC values; Table 3) thanks to the presence

of river ecological corridors and pedological peculiarities, limiting agricultural and artificial land use intensity, as we already outlined in previous multi-scale studies on the same sites [33,34]. The G and D sites parallelly show greater artificial component presence (ART), which is supposed to be better mitigated by higher landscape diversity and BTC values (Table 3).

In detail, the G and D sites show: higher landscape diversity (DIV1A) for the total landscape system, the FSN systems, and the AGR system; higher mean biological territorial capacity (MBTC), accounting for the higher metastability degree of the landscape eco-mosaic (Table 3; Figure 4A); and higher connectivity functions (CON; WCON; LN; WLN) (Table 3; Figure 4C). The connectivity and circuitry indicator variants (WCON; WCIR), weighted on links ecological quality, show a greater decrease (compared to the original, un-weighted indicators: CON and CIR) in P and C due to the reduced presence of ecological link components of higher ecological quality (i.e., higher development, stratification, continuity, and autochthonous degree) [33].

Such traits are reflected by the landscape apparatus's relative proportions, a representation of the physiological balance of the landscape system according to the eco-tissue model [26,28,42]. The G and D sites show a higher proportion of the connectivity apparatus (AP_CN), the resilient (AP_RSL) and the stability ones (AP_STB), whereas the C and P sites are dominated by the productive apparatus (AP_PD), lacking in connectivity, resilience, and stability functions (Table 3; Figure 4B). This highlights the higher vulnerability and instability of the C and P local-scale landscape systems, even though the G and D sites also show the typical traits of agricultural landscapes, with the localised spatial segregation of anthropic and natural functions (dichotomic configuration), entailing ecological unbalances at the local landscape scale (Figure 4). For instance, G and D connectivity functions are mostly limited to the main ecological corridors, whereas connectivity functions within the agricultural matrix are almost absent (Figure 4C).

3.2.2. Ecosystem Services Assessment: A Reference Model for the ES Matrix Application in Temperate Agricultural Landscapes

To build the reference ES matrix for application in temperate alluvial agricultural landscapes, based on our sites' local-scale land-use types, we preliminary filled the ES matrix with Burkhard's reported values for provisioning, regulating, and cultural ES delivery capacity [24] (Supplementary Materials, Figure S1) and re-adapted it by adjusting the provisioning ES values that were not consistent with the specific local-scale land-use types (Supplementary Materials, Figure S2). Table A3 (Appendix C) reports the employed literature references used for assessing the support ES delivery values for each local land-use type to complement the ES assessment through habitat provisioning and biodiversity support functions. Then, support, regulation, and cultural ES delivery values were corrected based on BTC% values (the ratio between current and potential BTC values), and the final reference ES matrix was obtained (Figure 5). The BTC% value calculation is reported in Appendix B in Table A2. This reference matrix considers the real ecological quality of natural and agricultural land uses to better represent the typical traits of alluvial agricultural landscapes subjected to medium-to-long-term human disturbances.

3.2.3. Ecosystem Services Matrix Application: Current State Landscapes Multifunctionality

Figure 6 reports the ES maps for each site, resulting from the application of the reference ES matrix (see Section 3.2.2): support (ES_SUPP), provision (ES_PROV), regulation (ES_REG), culture (ES_CULT), and total (ES_TOT) ecosystem services. Each site ES matrix is reported in the Supplementary Materials (Figures S3–S6).

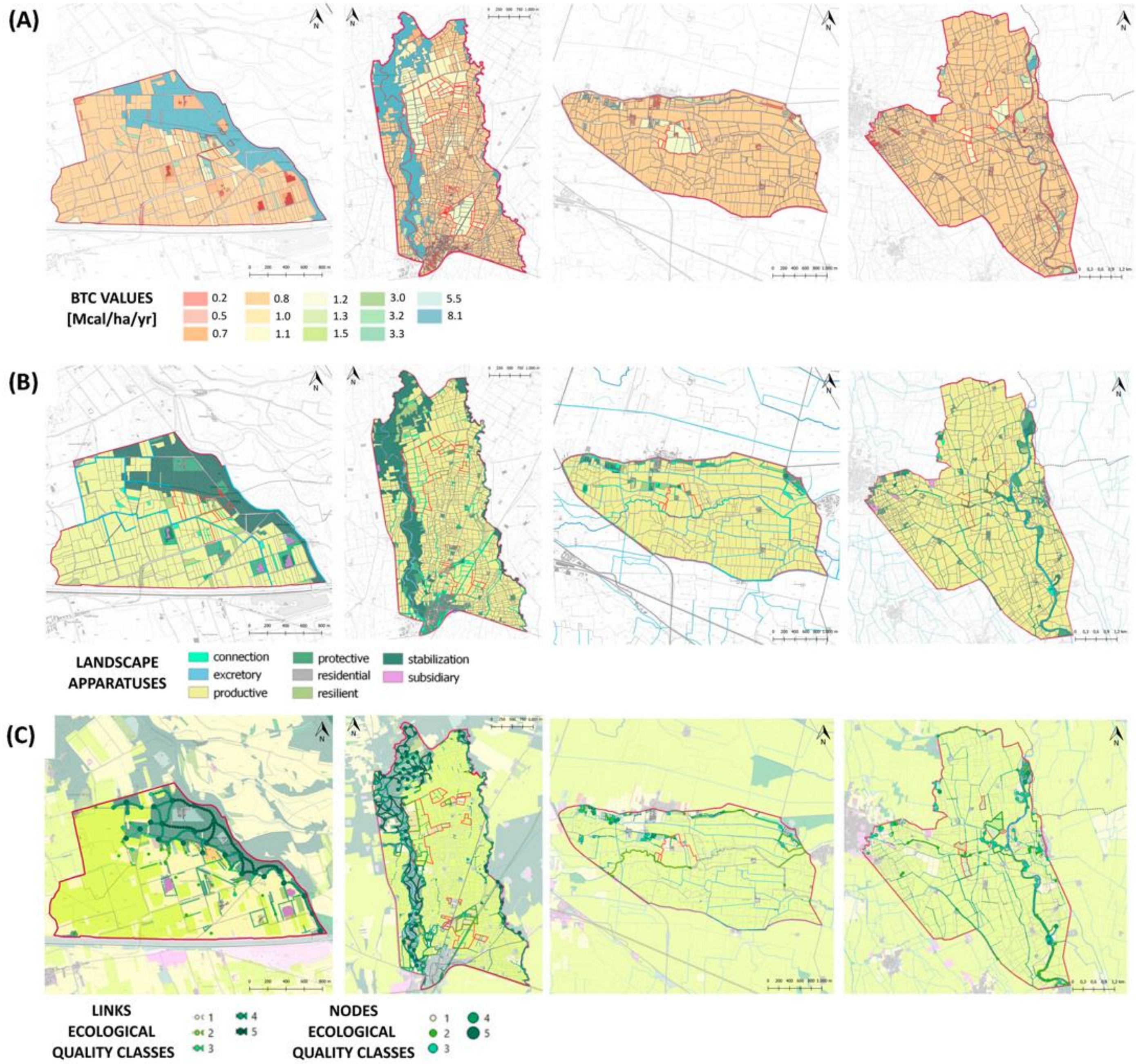

Figure 4. Maps synthesising the main differences between the four local-scale landscape systems regarding: (**A**) BTC values map, highlighting the spatial configuration of the different patch types, contributing differently to BTC values; (**B**) landscape physiological apparatus spatial configuration; (**C**) connectivity and circuitry graph analysis.

In line with landscape ecology analyses (see Section 3.2.1), the ES maps highlight the separated behaviour of the P-C and D-G sites, with the latter showing higher landscape multifunctionality, even though there is a dichotomic spatial configuration of areas with high and low ES-delivering capacity. That means, in the D and G sites, there are also areas that are underequipped, highlighting their capacity to deliver multiple ES. The main ecological corridors in D and G are pivotal for the delivery of support (ES_SUPP) and regulation (ES_REG) of ecosystem services in the agricultural landscape. The agricultural matrix lacks such functions; here, they are mostly supported by agroforestry farm land uses, whereas the widespread conventional crop systems cause extensive shortcomings. This is the predominant configuration in P and C, where life support and regulating ES are deficient; the small-sized and fragmented forest and semi-natural components provide limited and segregated contributions. The provisions in ES (ES_PROV) are higher in stable woody areas and in agricultural patches managed through polyculture and agroforestry approaches (higher product diversification). Green infrastructure components play a pivotal role in delivering cultural ecosystem services (ES_CULT), which are highly impaired in P and C. The maps of total ES (ES_TOT) reflect such patterns, highlighting the need for forest and semi-natural strategic implementation across the agricultural landscape (especially in P and C sites) to increase its multifunctionality (i.e., its capacity to counterbalance the impacts related to the predominant conventional agricultural matrix).

ES CLASSIFICATION	SUPPORT		REGULATING											PROVISIONING											CULTURAL					TOTAL
TEEB, 2011	x		x	x	x		x		x	x	x	x		x				x	x			x			x	x		x		
MEA, 2005			x		x	x	x		x	x	x	x		x				x				x			x	x		x		
CICES (Burkhard et al., 2014)			x	x	x	x	x	x	x	x	x	x		x				x	x			x			x	x	x	x		
POTENTIAL ES MATRIX BURKHARD ET AL. 2014 VALUES RE-ADAPTED FOR TEMPERATE ALLUVIAL AGRICULTURAL LANDSCAPES	Habitat & biodiversity	SUPPORT	Global climate regulation (C seq & stock)	Local climate regulation	Air quality regultion	Water flow reguation	Water purificatin	Nutrients regulaion	Erosion regulatin	Natural hazard rgulation	Pollination	Pest & disease cntrol	REGULATING	Food (crops, fruis, vegetables)	Biomass for enegy	Fodder	Food (livestock)	Fibre	Timber	Food (fish)	Wild foods & resources	Biochemicals & nedicine	Freshwater	PROVISIONING	Recreation & ecc-tourism	Landscape aesteichs & inspiration	Knowledge systems	Religious & spiriual experience	CULTURAL	TOTAL
LAND USE CATEGORIES																														
FOREST & SEMI-NATURAL		**40.6**											**33.6**											**19.4**					**34.9**	**32.1**
Grass strip	1	20.0	2	1	0	1	1	1	2	1	0	1	16.0	0	0	2	0	0	0	0	5	1	0	16.0	1	2	2	0	23.8	**18.9**
Grass strip with sparse trees and shrubs	1	25.7	1	1	0	0	0	1	0	0	1	1	12.9	0	0	1	0	1	1	0	1	1	0	10.0	1	1	2	0	21.4	**17.5**
Small woody area	2	46.1	3	3	3	2	3	3	3	2	2	2	51.8	0	1	1	0	1	5	0	3	2	0	26.0	1	2	2	1	28.8	**38.2**
Uncultivated area	2	30.0	2	1	0	1	1	1	2	1	0	1	16.0	0	1	2	0	0	0	0	5	1	0	18.0	1	2	2	0	23.8	**21.9**
Uncultivated area with spontaneous trees&shrubs ri-colonization	2	34.3	1	1	0	0	0	1	0	0	1	1	12.9	0	2	1	0	1	1	0	1	1	0	14.0	1	1	2	0	21.4	**20.6**
Wood	4	81.8	4	4	4	2	4	4	4	3	3	3	73.6	0	1	1	0	1	5	0	3	2	0	26.0	4	4	4	2	73.6	**63.8**
Woody belt	2	46.1	3	3	3	2	3	3	3	2	2	2	51.8	0	1	1	0	1	5	0	3	2	0	26.0	3	3	3	2	51.8	**43.9**
AGRICULTURAL		**40.5**											**23.1**											**20.5**					**23.2**	**26.8**
Apple	2	42.9	1	1	1	1	1	1	1	1	4	2	32.9	4	0	0	0	0	2	0	0	0	0	12.0	2	1	1	0	25.0	**28.2**
Arboriculture	1	23.3	2	2	2	1	2	2	2	2	2	2	34.9	0	1	1	0	1	5	0	0	0	0	16.0	2	2	2	1	34.9	**27.3**
Crop field	1	12.3	1	2	1	1	0	1	0	1	1	1	13.5	5	0	1	0	1	0	0	0	1	0	16.0	1	1	1	0	12.3	**13.5**
Crop field in rotation	2	33.8	1	3	1	1	0	1	0	1	1	2	18.6	5	1	2	0	2	0	0	1	1	0	24.0	1	1	2	0	16.9	**23.3**
Hazelnut	2	42.9	1	1	1	1	1	1	1	1	4	2	32.9	4	0	0	0	0	2	0	0	0	0	12.0	2	1	1	0	25.0	**28.2**
Horticoltural	2	36.9	1	2	1	2	0	1	0	1	1	2	20.3	5	5	5	0	5	0	0	1	2	0	46.0	1	1	2	0	18.5	**30.4**
Leguminous	2	40.0	1	3	1	1	0	1	0	1	1	2	22.0	5	1	2	0	2	0	0	1	1	0	24.0	1	1	2	0	20.0	**26.5**
Permanent grassland	4	74.3	3	1	0	1	1	2	3	1	0	1	29.7	0	1	5	5	0	0	0	2	0	0	26.0	2	3	3	0	44.1	**43.5**
Rice field	1	16.9	0	2	1	1	0	1	0	0	1	1	11.8	5	0	1	0	1	0	0	0	0	0	14.0	1	1	2	0	16.9	**14.9**
Rice field in rotation	3	60.0	0	2	1	1	0	1	0	0	1	1	14.0	5	1	2	0	2	0	0	0	1	0	22.0	1	1	2	0	20.0	**29.0**
Rice field organic	3	60.0	0	2	1	1	0	1	0	0	1	1	14.0	5	1	2	0	2	0	0	0	1	0	22.0	1	1	2	0	20.0	**29.0**
Walnut	2	42.9	1	1	1	1	1	1	1	1	4	2	32.9	4	0	0	0	0	2	0	0	0	0	12.0	2	1	1	0	25.0	**28.2**
HYDRIC		**77.9**											**30.4**											**16.0**					**63.4**	**46.9**
Water bodies	4	75.9	1	2	0	4	2	2	0	2	0	2	28.8	0	0	0	0	0	0	3	0	0	4	14.0	4	3	3	2	56.9	**43.9**
Riverbed	4	80.0	0	1	0	3	3	3	0	3	0	3	32.0	0	2	0	0	0	0	3	0	0	4	18.0	4	4	4	2	70.0	**50.0**
ARTIFICIAL		**8.5**											**4.5**											**0.8**					**13.0**	**6.7**
Agricultural buildings	1	12.8	0	0	0	0	0	0	1	0	1	1	3.8	1	0	0	0	0	0	0	0	0	0	2.0	2	1	1	1	28.8	**11.9**
Industrial	0	0.0	0	0	0	0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0.0	0	0	0	0	0.0	**0.0**
Other services	0	0.0	0	0	0	0	0	0	1	0	0	1	3.4	0	0	0	0	0	0	0	0	0	0	0.0	0	0	0	0	0.0	**0.9**
Private green areas	1	18.5	1	1	1	1	1	1	1	0	1	1	11.7	0	0	0	0	0	0	0	0	0	0	0.0	1	1	0	0	10.8	**10.2**
Residential buildings	1	11.2	0	0	0	0	0	0	1	0	1	1	3.4	1	0	0	0	0	0	0	0	0	0	2.0	2	1	1	1	25.2	**10.4**

Figure 5. The local scale reference ES matrix for temperate alluvial agricultural landscapes resulting from the re-adaptation of Burkhard's work [24] ES matrix (inclusion of support ES; correction on actual provisioning ES and on actual biological territorial capacity (BTC) values for each represented land use type: ratio between actual BTC and maximum BTC value for each land-use type). The links with the TEEB [43], MEA [44], and CICES [24] ES classifications are highlighted.

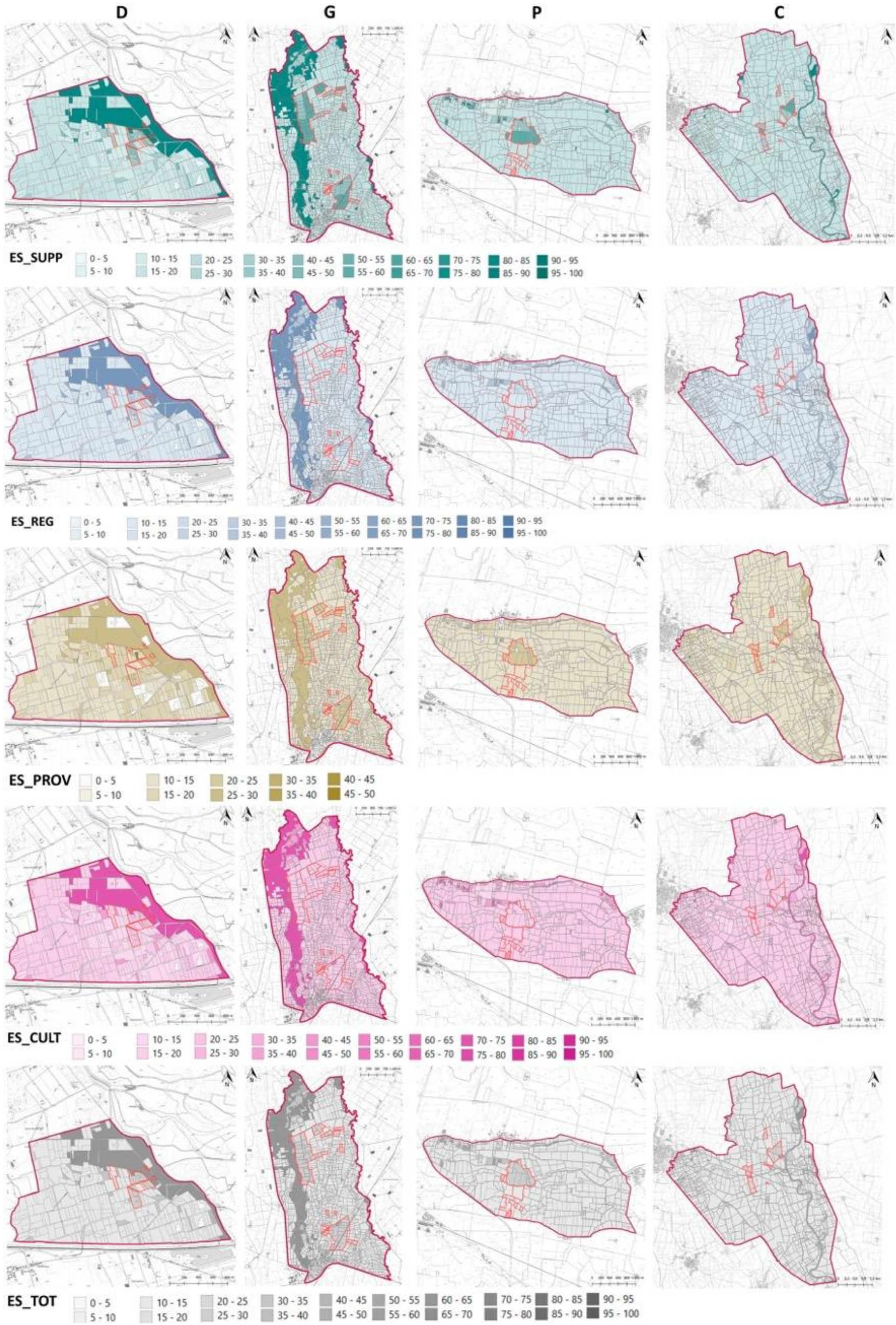

Figure 6. Maps representing the ES delivering capacity of current local scale patches of the four sites under study (D, G, P, C). From top side: support (ES_SUPP); regulating (ES_REG); provisioning (ES_PROV); cultural (ES_CULT); total (ES_TOT).

3.2.4. Synthesis of Local Landscape Vulnerability and Resilience Drivers

Figure 7 reports the vulnerability and resilience maps (VR) for local-scale landscape systems, synthesising the landscape ecology and ES analysis results.

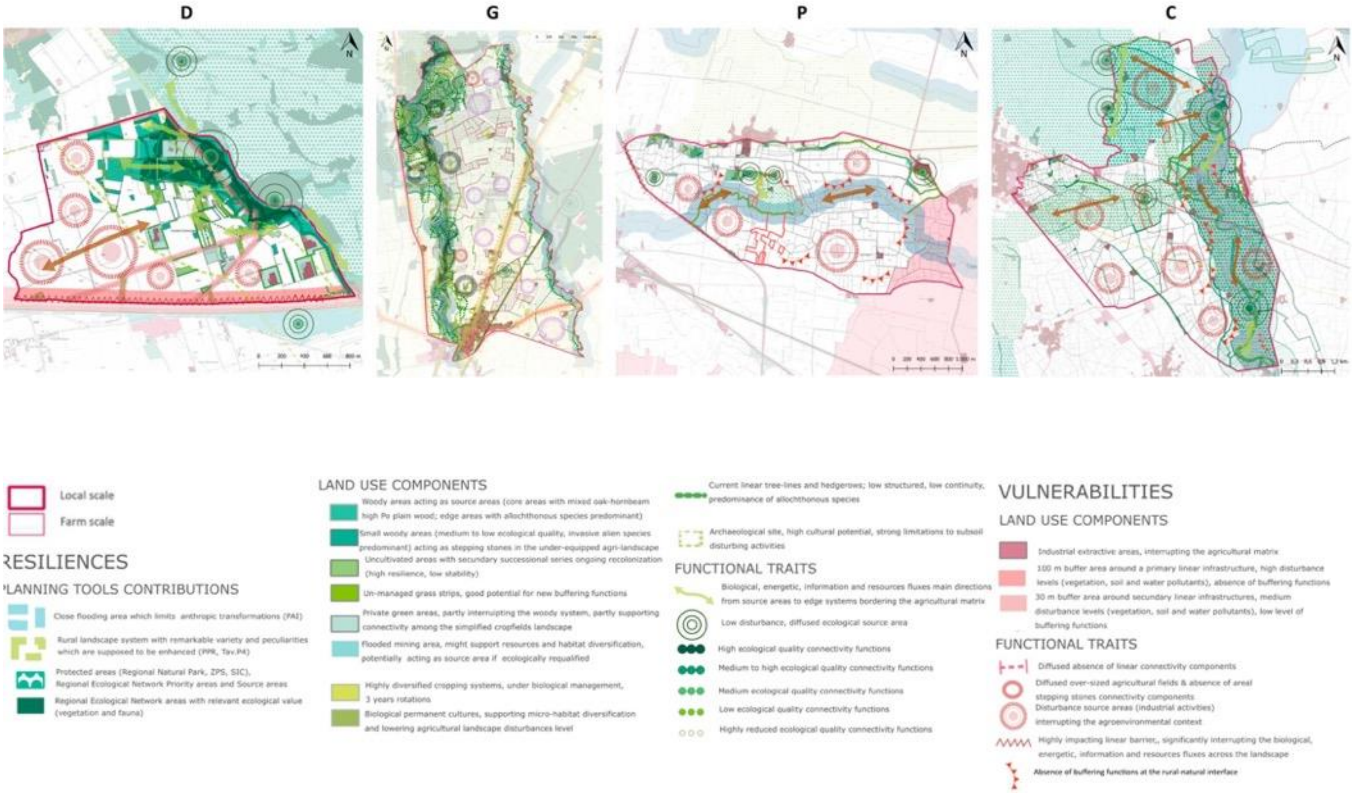

Figure 7. Maps synthesising, for each local-scale landscape system (D, G, P, C), the vulnerability and resilience drivers (VR analysis).

The areas most lacking in biodiversity support functions and multifunctionality are highlighted, thus allowing us to prioritise corrective intervention strategies. In D and G, the main issues are related to the spatial dichotomy between the agricultural matrix and FSN infrastructure; agricultural areas are currently acting as sink areas, lacking in connectivity components that might interlink them to the biotic, genetic, and information fluxes coming from the main biodiversity source areas. Buffering functions at the rural-natural interface are limited and might be strengthened through linear and spatial landscape feature strategic implementation. Furthermore, linear barriers related to grey infrastructure might be better mitigated through buffer strips. In the P and C sites, the potential ecological corridors are under-equipped, discontinuous, and consequently unable to behave as biodiversity source areas. Widespread sink areas are predominant; they significantly impact the ecological balance of the local landscape system, and there is no mitigation of the agricultural bio-geo-chemical impacts towards areas of higher ecological value (absence of buffering functions along the interface with woody areas and water courses). The main ecological corridors might be strategically implemented through interspersed, diffused landscape features.

3.3. *Agroforestry-Based Design Scenarios for Local-Scale Landscape Systems*

Figure 8 reports the maps representing the identified design scenarios for the local-scale landscape systems for each study site (D, G, P, C), where agroforestry-based solutions and crop diversification through polyculture are proposed. The scenarios aim at solving current criticalities by identifying some key agroforestry components (landscape features, crop diversification, and a nature-based solutions approach) and their strategic spatial configuration (a landscape ecology design approach). Specifically, the following landscape feature types are inserted: woody belt; small woody area; wood; wetland; hedgerows; and tree lines. Conventional cropping systems are partially converted to organic ones or to polyculture.

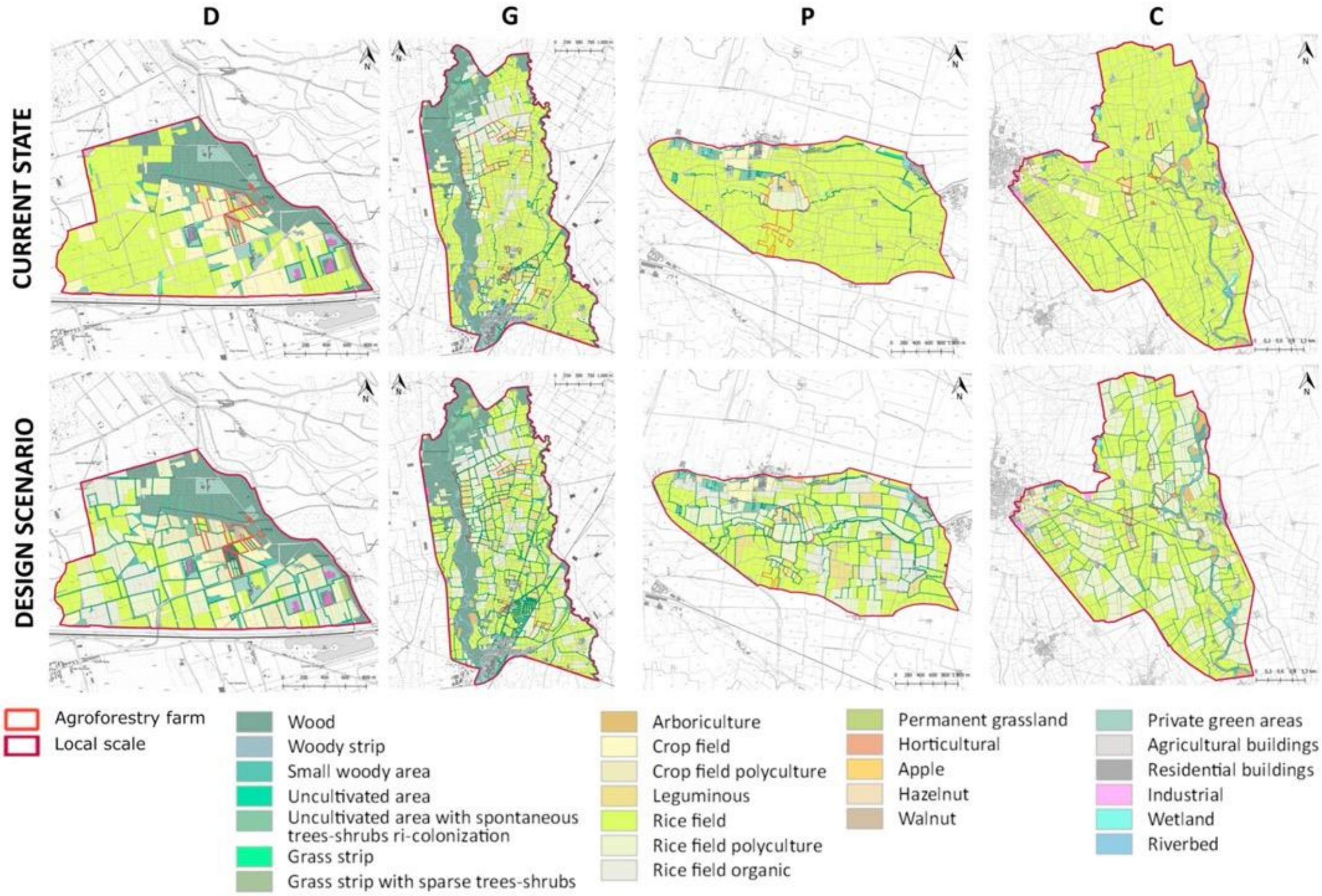

Figure 8. The local-scale agroforestry-based design scenarios (compared to the current state) for local-scale landscape systems, identified according to multi-scale analytical results.

In design scenarios, forest and semi-natural components rise +19.7% ± 15.7σ compared to the current state, whereas the AGR component decrease is minimised (−1.6% ± 0.1σ) thanks to the strategic spatial interspersion of FSN components within the agricultural matrix.

3.3.1. Scenarios Assessment: Landscape Ecology Analyses

Table 4 reports the results of landscape ecology indicators re-computed using local-scale design scenarios. The increase compared to the current state is reported as the % gap. The highest increase in FSN components is in the C and P sites (+36.2%; +34.7%), where they are currently mostly lacking. The results clearly show an increase in total landscape diversity (DIV_TOT) and in the FSN and AGR subsystem diversity; the highest increase is in the C and P sites. Higher agricultural landscape diversity is related to higher α and β diversity values and landscape multi-functionality [59,61–64]. Furthermore, MBTC shows the highest increase in C and P, accounting for the overall contributions given by the forecasted agroforestry components to the overall landscape ecological balance and metastability (i.e., its capacity to auto-regulate its ecological processes at a landscape scale) [65]. In G and D, the slight improvement in all indicators accounts for the strengthening and consolidation of the pre-existing ecological configuration of the local landscape systems. These data show the positive contributions of the agroforestry and crop diversification models, which might overcome landscape oversimplification impacts while only limitedly reducing productive functions thanks to the strategic spatial configuration of interventions.

Table 4. Main differences between the four local-scale landscape systems' ecological traits in the design scenario, also showing the percentage gap if compared to current state values (structural and functional metrics). See Appendix A, Table A1 for details on the applied indices.

SCENARIO vs. CURRENT STATE	INDEX	U.o.M.	SITE C		SITE P		SITE G		SITE D	
			Value	% Gap	Value	% Gap	Value	% Gap	Value	% Gap
MATRIX	AGR	%	91.53	−1.6%	91.51	−1.6%	67.53	−1.6%	68.73	−1.3%
	FSN	%	5.76	36.2%	5.92	34.7%	27.52	4.1%	24.44	3.9%
	ART	%	2.71	0.0%	2.57	0.1%	4.95	0.6%	6.83	0.0%
DIVERSITY	DIV_TOT	-	1.39	75.4%	1.70	128.0%	2.07	14.2%	2.14	38.7%
	DIV_FSN	-	0.27	25.9%	0.27	30.0%	0.63	6.5%	0.50	6.2%
	DIV_AGR	-	0.99	121.8%	1.31	213.1%	1.25	21.3%	1.41	67.5%
BIOLOGICAL TERRITORIAL CAPACITY	MBTC	Mcal/ha/yr	1.32	11.6%	1.30	12.6%	2.65	3.2%	2.38	7.5%

3.3.2. Scenarios Assessment: Ecosystem Services Matrix Application

Figure 9 reports the ES maps as recomputed using the local-scale design scenarios. The highest increases are highlighted for:

- support ES (ES_SUPP), related to wider and more diversified FSN habitat availability amongst the agricultural matrix, and to crop diversification through the forecasted adoption of polyculture and organic farming practices (see Figure 5 for details on each land-use type contribution to ES). The spatial configuration of the ES_SUPP delivering capacity answers the need for balancing sink functions amongst the agricultural matrix, as highlighted through VR analysis (Figures 3–7). The local-scale design scenario, if implemented, would significantly enhance biodiversity values sustained by the local agricultural landscapes under study.
- Provisioning ES (ES_PROV) related to crop diversification and the opportunity for secondary products potentially provided by the interspersed landscape features inserted among the agricultural matrix.

Regulating ES increase shows a spotted pattern; the interspersed FSN components provide a diffused re-activation of regulating functions, especially in belts of strategic importance (areas currently suffering from landscape oversimplification and sink effects; areas demanding buffering functions), according to the priority areas identified through VR analyses (Figures 3–7). Such patterns represent a viable compromise, in that they parallelly address the need for mitigating agricultural land use impacts and the need for preserving agriculturally productive areas.

- Cultural ES maps show the interspersed amelioration of the cultural values that can be sustained by an agricultural landscape; spotted areas delivering higher cultural values interrupt the agricultural landscape homogeneity and mono-functionality of current local landscapes.

Total ES maps (ES_TOT) highlight the overall landscape multifunctionality obtained through the design scenarios, overcoming the current state dichotomic functional configuration of D and G and the current mono-functionality of P and C local landscapes.

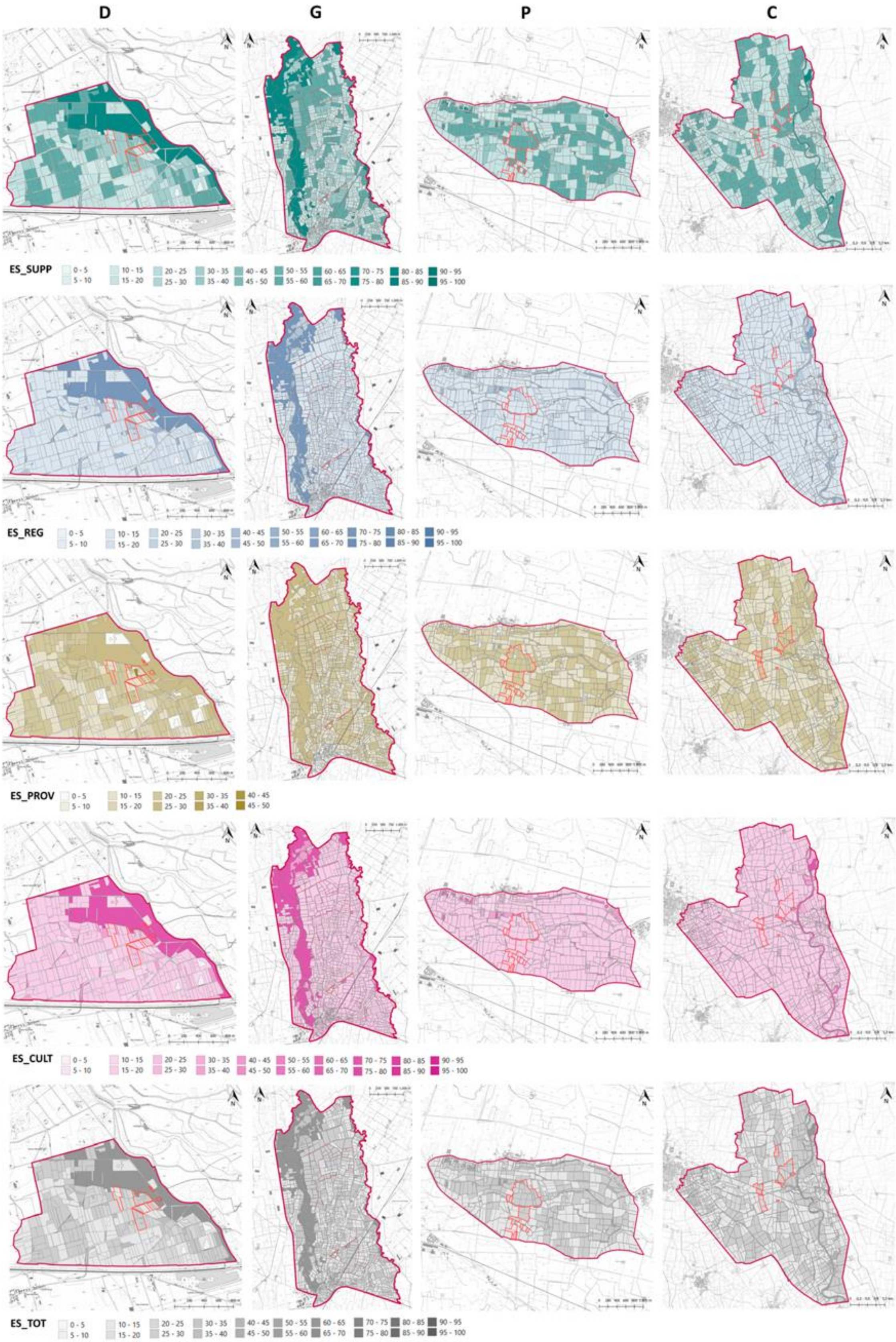

Figure 9. Maps representing the ES delivering capacity of local-scale patches of the four sites under study, as re-defined through the agroforestry-based design scenarios. From top side: support (ES_SUPP); regulating (ES_REG); provisioning (ES_PROV); cultural (ES_CULT); total (ES_TOT).

4. Conclusions

Our study aimed to contribute to the existing knowledge and experience related to agricultural landscape ecological quality and multifunctionality support through *science-to-practice approaches*. The applied *pattern-process-design* approach is a viable way to simultaneously understand agricultural landscape ecological quality, its vulnerability drivers, and the site-specific strategies to solve or at least mitigate them. Through this study, we developed a reference analytical toolkit to apply such an approach to real case studies and tested it on temperate alluvial agricultural contexts. This work could serve as a reference for application to similar case studies. The applied approach is low-cost and not time-consuming, and could positively complement more specific studies on biodiversity and ecosystem service valuation. Biodiversity support and multi-functionality are needed to respond to current ecological critiques of agricultural landscapes; our study showed that the agroforestry approach and crop diversification strategies can be viable solutions to respond to this need while maintaining the need for food production. Such benefits can be assessed at the landscape level (as we have done in the present study) as well as at the individual farm level. It might also be interesting to deepen the analytical results and the outcomes of such an approach through farm level assessments.

Furthermore, the methodology presented here has been applied to agricultural landscapes, but it could be positively adapted to the specificities of other types of landscapes, such as natural or urban landscapes, where a pattern-process-design multi-scale approach could positively support their strategic management.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d16070431/s1, Figure S1: The first version of the reference ES matrix built on local-scale land use types; Figure S2: The local-scale reference ES matrix corrected on actual provisioning ES; Figure S3: The local-scale reference ES matrix for temperate alluvial agricultural landscapes applied to the D site local scale; Figure S4: The local-scale reference ES matrix for temperate alluvial agricultural landscapes applied to the G site local scale; Figure S5: The local-scale reference ES matrix for temperate alluvial agricultural landscapes applied to the P site local scale; Figure S6: The local-scale reference ES matrix for temperate alluvial agricultural landscapes applied to the C site local scale.

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

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Data Availability Statement: The data presented in this study are available on 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[extra-local (E_La); local (La)], the applied equation and the related references.

	INDICATOR	SCALE	EQUATION	REFERENCES
BASIC STRUCTURAL TRAITS	Matrix (MTX) x = [FSN; AGR; ART]	E_La La	$MTX_x = \frac{\sum_{i=1}^{n} A_{ix} \times 100}{A_{tot}}$ A_i = total area of each land use categories patch A_{tot} = total area	[66]
DIVERSITY INDICES	Diversity (DIV) X = [DIV_TOT; FIV_FSN; DIV_AGR]	E_La La	$DIV_x = -\sum_{i=1}^{n} \frac{A_i}{A_{tot}} \times \ln \frac{A_i}{A_{tot}}$	[66]
LANDSCAPE APPARATUSES	Apparatuses' ratio (AP) X = [connective (AP_CN); excretory (AP_EX); productive ((AP_PD); resilient (AP_RSL); stabilisation (AP_STB)	La	$APP_x = \frac{\sum_{i=1}^{n} A_{ix} \times 100}{A_{tot}}$	[28]
CONNECTIVITY INDICES	Connectivity (CON)	La	$CON = \frac{L}{[3 \times (N-2)]}$ L = no. of links N = no. of nodes	[67]
	Weighted connectivity (WCON)	La	$WCON = \frac{\sum_{i=1}^{5} L_i \times W_i}{[3 \times (N-2)]}$ L_i = no. of links for each Ecological Quality Class (EQC_i = [1–5]) W_i = EQC_i weight: $W_i = \frac{EQC_i}{EQC_{max}}$	[33]
	Circuitry (CIR)	La	$CIR = \frac{(L-N+1)}{[2 \times (N-5)]}$	[67]
	Weighted circuitry (WCIR)	La	$WCIR = \frac{[(\sum_{i=1}^{5} L_i \times W_i) - N + 1)]}{[2 \times (N-5)]}$ L_i = no. of links for each Ecological Quality Class (EQC_i = [1–5]) W_i = EQC_i weight (as above)	[33]
INDICES ON ECOLOGICAL FUNCTIONALITY	Mean Biological Territorial Capacity (MBTC)	E_La La	$MBTC = \frac{\sum_{i=1}^{m} BTC_i \times A_i}{A_{tot}}$	[28,41,65]

Appendix B

Table A2. The biological territorial capacity unitary values (Actual BTC) and ratio (BTC%: actual BTC values [Mcal/ha/yr] vs. maximum BTC (BTC MAX; [Mcal/ha/yr]) of each land use type) applied for the local scale land use types to re-adjust support, regulating and cultural ES values in coherence with alluvial agricultural contexts typical traits. We reported the local land use types (study sites) and the associated Burkhard's CLC land cover types (on which we based ES delivering valuing) [24] and the Ingegnoli's land use types (on which we based the BTC values assignment) [28,41].

	LOCAL SCALE LAND USE TYPES	Burkhard LAND COVER TYPES (CLC) [24]	Ingegnoli's LAND USE TYPES [28,41]	Actual BTC	BTC MAX	BTC %
FORES ' AND SEM -NAT JRAL	Grass strip	MEAN (Pastures; Natural grassland: reg. + cult.); Natural grassland (prov.)	Meadows	0.70	1.40	0.50
	Grass strip with sparse trees and shrubs	Broad-leaved forest	Shrubs, hedgerows	1.50	3.50	0.43
	Small woody area	Broad-leaved forest	Temperate forest	4.75	8.25	0.58
	Uncultivated area	MEAN (Pastures; Natural grassland: reg. + cult.); Natural grassland (prov.)	Meadows	0.70	1.40	0.50
	Uncultivated area with spontaneous trees and shrubs re-colonization	Broad-leaved forest	Shrubs, hedgerows	1.50	3.50	0.43
	Wood	Broad-leaved forest	Temperate forest	6.75	8.25	0.82
	Woody belt	Broad-leaved forest	Temperate forest	4.75	8.25	0.58
AG ICULTURAL	Apple	Fruit trees and berries	Orchards and olive groves	2.50	3.50	0.71
	Arboriculture	Broad-leaved forest (see CLC)	Temperate forest	3.20	8.25	0.39
	Crop field	Permanently irrigated arable land	Crop fields	0.80	1.30	0.62
	Crop field in rotation	Permanently irrigated arable land	Crop fields	1.10	1.30	0.85
	Hazelnut	Fruit trees and berries	Orchards and olive groves	2.50	3.50	0.71
	Horticultural	Non-irrigated arable land (see CLC)	Crop fields	1.20	1.30	0.92
	Leguminous	Permanently irrigated arable land	Crop fields	1.30	1.30	1.00
	Permanent grassland	MEAN (Pastures; Natural grassland); Pastures (prov.)	Meadows	1.30	1.40	0.93
	Rice field	Rice fields	Crop fields	1.10	1.30	0.85
	Rice field in rotation	Rice fields	Crop fields	1.30	1.30	1.00
	Rice field organic	Rice fields	Crop fields	1.30	1.30	1.00
	Walnut	Fruit trees and berries	Orchards and olive groves	2.50	3.50	0.71

Table A2. *Cont.*

	LOCAL SCALE LAND USE TYPES	Burkhard LAND COVER TYPES (CLC) [24]	Ingegnoli's LAND USE TYPES [28,41]	Actual BTC	BTC MAX	BTC %
HYDRIC	Water bodies	Water bodies	Bogs and wetlands	5.50	7.25	0.76
	Riverbed	Water courses	Bogs and wetlands	0.50	0.50	1.00
ARTIFICIAL	Agricultural buildings	Discontinuous urban fabric	Scattered houses and gardens	0.80	1.25	0.64
	Industrial	Industrial or commercial units	Dense buildings	0.00	0.35	0.00
	Other services	Industrial or commercial units	Dense buildings	0.20	0.35	0.57
	Private green areas	Green urban areas	Urban parks	1.00	3.25	0.31
	Residential buildings	Discontinuous urban fabric	Scattered houses and gardens	0.70	1.25	0.56

Appendix C

Table A3. Literature references used for attributing the support ES delivering capacity to each local scale land use type.

	Habitat and Biodiversity Support ES
FOREST AND SEMI-NATURAL SUBSYSTEM	
Grass strip	[68–71]
Grass strip with sparse trees and shrubs	[63,72–76]
Small woody area	[63,72,73,75–77]
Uncultivated area	[68–70]
Uncultivated area with spontaneous trees-shrubs re-colonization	[63,72,73,75,76]
Wood	[63,72,75–77]
Woody belt	[63,72–78]
AGRICULTURAL SUBSYSTEM	
Apple	[79,80]
Arboriculture	[79,80]
Crop field	[69,70,79]
Crop field in rotation	[69,70,79]
Hazelnut	[79,80]
Horticultural	[69,70]
Leguminous	[79]
Permanent grassland	[69,70]
Rice field	[69,70,79]
Rice field in rotation	[69,70,79]
Rice field organic	[69,70,79]
Walnut	[79,80]

Table A3. *Cont.*

	Habitat and Biodiversity Support ES
HYDRIC SUBSYSTEM	
Water bodies	[81–83]
Riverbed	[82]
ARTIFICIAL SUBSYSTEM	
Agricultural buildings	[84]
Industrial	[85]
Other services	[85]
Private green areas	[85,86]
Residential buildings	[85]

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