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Original article

Cities vs countryside: An example of a science-based peri-urban landscape features rehabilitation in Milan (Italy)

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ABSTRACT

Urban-rural boundaries are often abrupt and unmitigated, a trait that significantly enhances their ecological vulnerability. Nonetheless, such fringe systems enclose a high potential in furnishing buffering and resilience functions and services towards the city. Our study intends to give a contribution on the understanding of the ecological behaviour of peri-urban landscape features (PLFs) systems, showing how floristic-vegetational and landscape ecology studies can inform their multi-functional phytocoenoses ecological reconfiguring. Analyses were led among a fringe context of Milan city. An agri-environmental extra-local scale analysis framed the forthcoming finer scale results. Landscape mosaic structural and functional main traits were interpreted, outlining a current impairment of the landscape system capacity to support ecological functions across the area. In parallel, floristic traits were studied through chorological, life forms and Ellenberg's ecogram analysis (total flora and single sub-areas values). The main phytocoenoses types were qualitatively described and related to the dynamic patterns of reference vegetation series. Results highlighted a significant deterioration of floristic-vegetational traits, if compared to the local potential. Recurrent anthropic disturbances, open space conditions were identified as the major impact factor on phytoconoeses evolution towards higher diversity, complexity and stability traits. Spontaneous recolonization processes were acknowledged as currently unable to change these trends, while past reforestation interventions showed positive effects. These results informed the building of a functional-dynamic interpretative approach, focused on the ecological roles and physical habitat conditions currently influencing phytocoenoses dynamics, and on which to intervene. Accordingly, the current and potential ecological functions of 9 key PLFs categories were inspected. Consequently, design criterions for corrective interventions were outlined. This brought to the identification of the optimal structural and functional patterns of PLFs to be integrated throughout the urban-rural boundary, as well as their floristic-vegetational design specificities, by pursuing a rebalancing effect on the peri-urban agroecosystem inner complexity and environmental stability parameters.

1. Introduction

Peri-urban rural belts are currently suffering from the functional separation of anthropic and environmental functions derived from decades of rapid and city-centred urban sprawl: the urban-rural boundary is often abrupt, disrupting the interactions between city and countryside and weakening the overall urban territorial system ecological functioning and balance (Donadieu and Dalla Santa, 1998). These territorial ecological gaps are easily paired to socio-cultural issues. Such fringe systems need to be re-considered as strategic metropolitan landscape system components, in both functional and planning terms (Simon, 2008). Planning strategies should be adequately informed by robust ecological intervention tools paired to bottom-up local socio-cultural initiatives. Multi-level, integrated approaches are needed for recovering the high potential of urban-rural fringes in furnishing buffering and resilience functions and services towards the city (Cueva et al., 2022; Frantzeskaki, 2019; Kabisch et al., 2017; Lee et al., 2015; Maheshwari et al., 2016; Mcdonnell et al., 1997; Sylla et al., 2020).

In detail, several significant threats, entailing reciprocal trade-offs, can be recognised both on the biotic and a-biotic urban-rural fringe dynamics, acting on different spatial scales, influencing both ecological and socio-cultural processes, issues and challenges.

Abbreviations: PLFs, peri-urban landscape features; WBCS, Worldwide Bioclimatic Classification System.

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From a landscape ecology perspective, peri-urbanization and urban sprawl typical traits strongly affect the capability of the existing semi-natural peri-urban landscape features (PLFs) to behave as an integrated and interconnected matrix (network of small woody areas, hedgerows and tree-lines, wetlands, vegetated ditches). PLFs spatial perturbation and fragmentation undermine their structural and organisational patterns, by keeping their biotic communities to simplified and low-developed organisational levels, entailing higher vulnerabilities (Higgins et al., 2003; Honnay et al., 2002; Opdam and Wascher, 2004; Su et al., 2014; With, 2002). Moreover, the chaotic urbanization trends (low urbanistic quality, lack of socio-cultural services, spread social diseases) implies cascade effects on PLFs environmental degradation processes (mismanaged, polluted, and unsafe semi-natural areas).

On the biotic side, these high disturbance traits entail: highly variable species richness values (spread gradient of habitat conditions) (Rebele, 1994); relatively simplified and instable communities structuring (McKinney and Lockwood, 1999); an overall imbalance between biological interactions (competitive, predatory, parasitic, mutualistic and commensal roles). These traits weaken the peri-urban agro-ecosystem auto-regulation processes through time (Loreau and de Mazancourt, 2013; Rebele, 1994) and its resistance and resilience capabilities [according to Oliver et al. (2015) definition] (Casula et al., 2006; Gilbert, 1989; Godefroid and Koedam, 2003a; Higgins et al., 2003; Honnay et al., 2002; Hooper et al., 2006; Hooper et al., 2005; Kowarik, 1990; Loreau et al., 2001; With, 2002).

Specifically, evidences underline that the urbanised matrix strongly influences the floristic-vegetational structural and qualitative diversification of the biocoenoses composing PLFs (Deutschewitz et al., 2003; Godefroid and Koedam, 2003a; Pyšek et al., 2004; Sukopp et al., 1990). Their trend towards higher complexity is constantly interrupted by recurrent disturbance (promotion of pioneer behaviours) and physical isolation (Kowarik, 1990; Rebele, 1994), promoting generalist and invasive alien species (Chytry et al., 2008; Fanelli et al., 2006; Godefroid and Koedam, 2003a; Kowarik, 1990; McCollin et al., 2000; Roy et al., 1999; Seabloom et al., 2003; Stapanian et al., 1998; Viciani et al., 2020; Walter et al., 2005). These traits enhance PLFs vulnerability and instability (Grime et al., 2000).

In its turn, the peri-urban agricultural land management easily adds further simplification determinants. High productivity is generally supported by constant external inputs: the agroecosystem regulation processes are kept under control through outside drivers and the system is kept at low level of complexity and diversification, enhancing its vulnerability and lack of self-sufficiency (Clergue et al., 2005; Gliessman, 2007; Grime et al., 2000; Odum and Barrett, 2004). Generalist, invasive alien species behaviours are favoured (Viciani et al., 2020), consequently lowering biodiversity values and facilitating allochthonous pests and diseases outbreak, which in their turn imply major concerns and challenges for the agricultural sector (Chamberlain et al., 2000; Donald, 2004; Donald and Evans, 2006; Gliessman, 2007; Krebs et al., 1999; McKinney and Lockwood, 1999). On the other side, urban sprawl dynamics easily affect peri-urban agriculture quality (degraded agri-environmental matrix, soil and air pollution, social diseases).

On the a-biotic side, the peri-urban landscape structural and functional configuration easily undermines the potential contribution of PLFs to the urban metabolism balance (Catalano, 2021; Franco, 2000; Franco, 2004; Goulding, 1997; Hernández-Morcillo et al., 2018; Udawatta and Jose, 2021; Wolton et al., 2014), by influencing and regulating the hydrological, hydraulic (Carroll et al., 2004; Gascuel-Odoux et al., 2009; Udawatta, 2021), water and soil quality (Lowrance et al., 1984; Ryszkowski et al., 1999) and micro-climate dynamics (Burel, 1996).

If considering all these patterns on an opposite perspective (ecological functions impairment versus ecological functions rehabilitation), it becomes evident that PLFs can potentially acquire a guiding role in restoring a territorial cohesion of urban, natural and agricultural matrices, supporting an effective implementation of the most recent trends in urban planning strategies (Contin, 2021; Mahmoud et al., 2022; Pamukcu-Albers et al., 2021; Piorr et al., 2011). PLFs coherent integration could rehabilitate the ecological exchanges, flows and buffering functions throughout these different systems, and enhance their environmental stability patterns. Parallelly, peri-urban landscape rehabilitation through PLFs could also help in recovering the aesthetic, cultural and social value of urban fringes (agreeability, accessibility, leisure, recreation, soft mobility). This would facilitate the development of peri-urban multifunctional agriculture activities and short supply chains, delivering important socio-ecological functions and services in their turn (Fanfani et al., 2022; Zasada, 2011).

To reach this aim, multi-perspective assessment and intervention approaches are needed. Reference experiences on the investigation of the socio-ecological behaviour of peri-urban rural landscapes and its PLFs components could usefully support their organic, effective and coherent agroecological rehabilitation and positively inform urban-rural fringe planning strategies, reducing the risk of unsuccessful interventions (Kleijn et al., 2001; Kleijn et al., 2004; Luken, 1990).

According to these needs, our study focuses on the ecological traits and behaviour of peri-urban landscape and phytocoenoses. The aim is to identify some reference analytical and interpretative tools useful for orienting PLFs ecological rehabilitation. The identified approach summarizes several literature experiences, and it specifically fits peri-urban rural systems peculiarities, intending to drive them towards higher environmental stability and resilience values. Such analyses are part of a wider multidisciplinary study focused on the assessment of the socio-ecological functions and services that can be activated among rural-urban fringes (Fig. 1) (Dal Borgo et al., 2023). The final aim of to identify some newly adapted, effective, science-based assessment tools that may inform and strategically orient the implementation of urban planning strategies, parallelly encompassing the ecological and socio-cultural issues of urban-rural fringes.

The study is applied on a pilot area of the city of Milan (Lombardy Region, North of Italy), a metropolis which already adopted several strategic policies and agreements for rural-urban integrated development (Città Metropolitana di Milano, 2021; Comune di Milano, 2018a; Pedrana et al., 2015; Comune di Milano, 2018b). This first application showed our approach to be suitable for: interprete and evaluate the ecological behaviour of the landscape matrix components; consequently identify some key intervention strategies on PLFs (which could be a reference for urban planning strategies implementation); build awareness on the potentially enabled ecological functions (a synthetic reference for other case studies), which could complement wider assessments also embedding socio-cultural functions and services.

Our study methodology is synthetized in Fig. 1 and is composed of 4 main steps, as follows (Chiaffarelli and Vagge, 2020, 2021; Dal Borgo et al., 2023). 1. Characterization: multi-scale preliminary analyses (with a specific ecological focus on landscape eco-mosaic patterns and floristic-vegetational traits; and a cultural focus on the human community and cultural landscape processes). 2. Assessment: evaluation of the ecological and cultural functions related to PLFs, based on the vulnerability and resilience properties analysis (Gibelli et al., 2021b). 3. Design: reference multifunctional interventions criteria identification. 4. Accounting: functional evaluation comparing the contributions given by current state and the designed scenarios (Ecosystem Services assessment) (Dal Borgo et al., 2023). We here present a detail on the landscape ecology and floristic-vegetational analyses, displaying how they oriented the PLFs design set-up (Chiaffarelli and Vagge, 2020; Chiaffarelli and Vagge, 2021). The following steps are presented (Fig. 1, asterisk boxes): i. extra-local scale (Vettabbia Valley system) agri-environmental and climatic context framing; ii. local scale (study area) landscape ecological traits featuring; iii. floristic and vegetational ecological, chorological, structural and dynamic featuring for the most significant existing phytocoenoses types (extra-local scale; field scale); iv. theoretical framing of the adopted functional-dynamic interpretative approach; v. synthesis on intrinsic PLFs ecological functions impairment level and

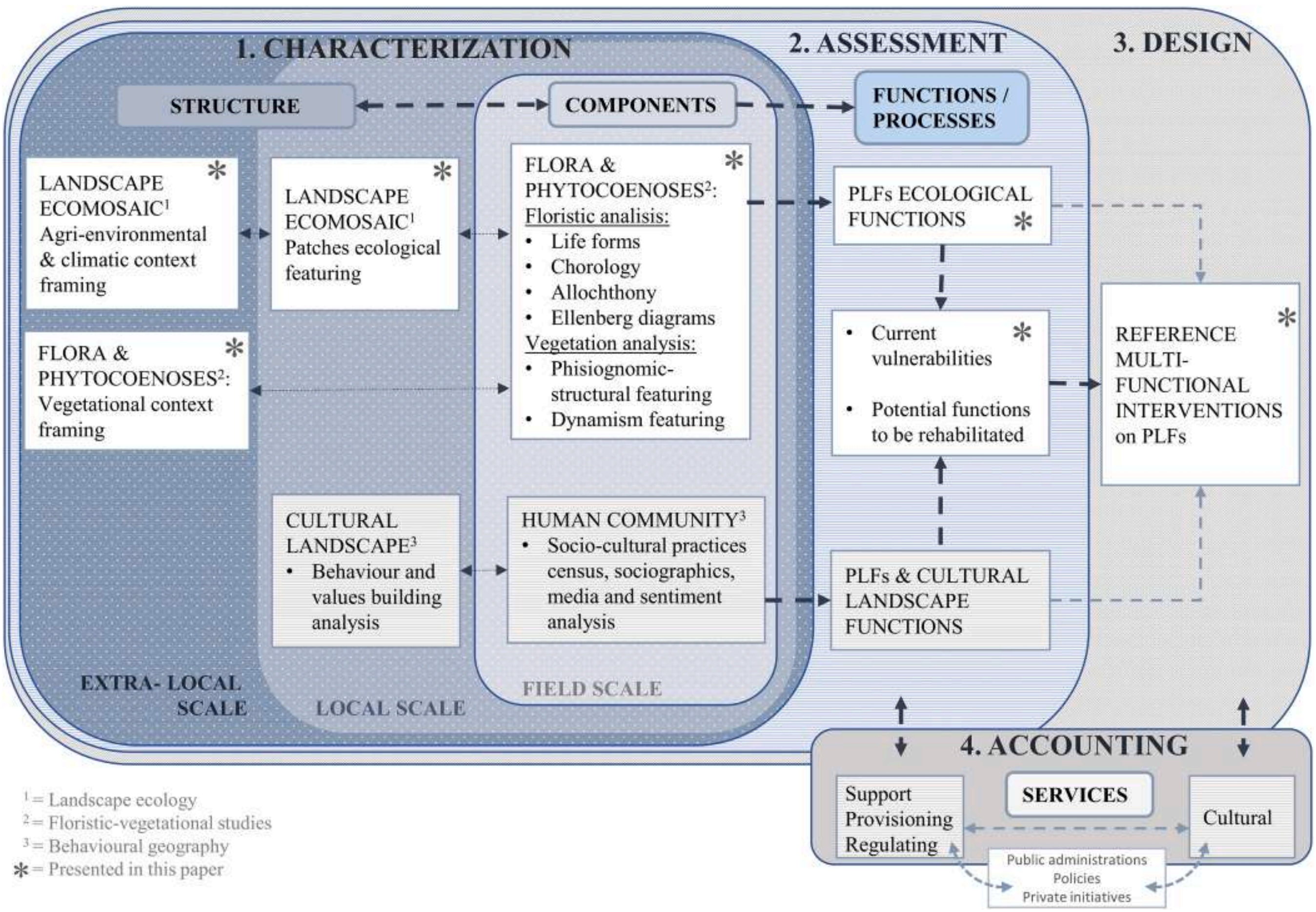

Fig. 1. The 4 main steps composing the applied multiscale and multidisciplinary methodology: here presented analyses and results (white boxes with asterisk); other analytical and assessment components not presented here (grey-striped boxes) (Dal Borgo et al., 2023).

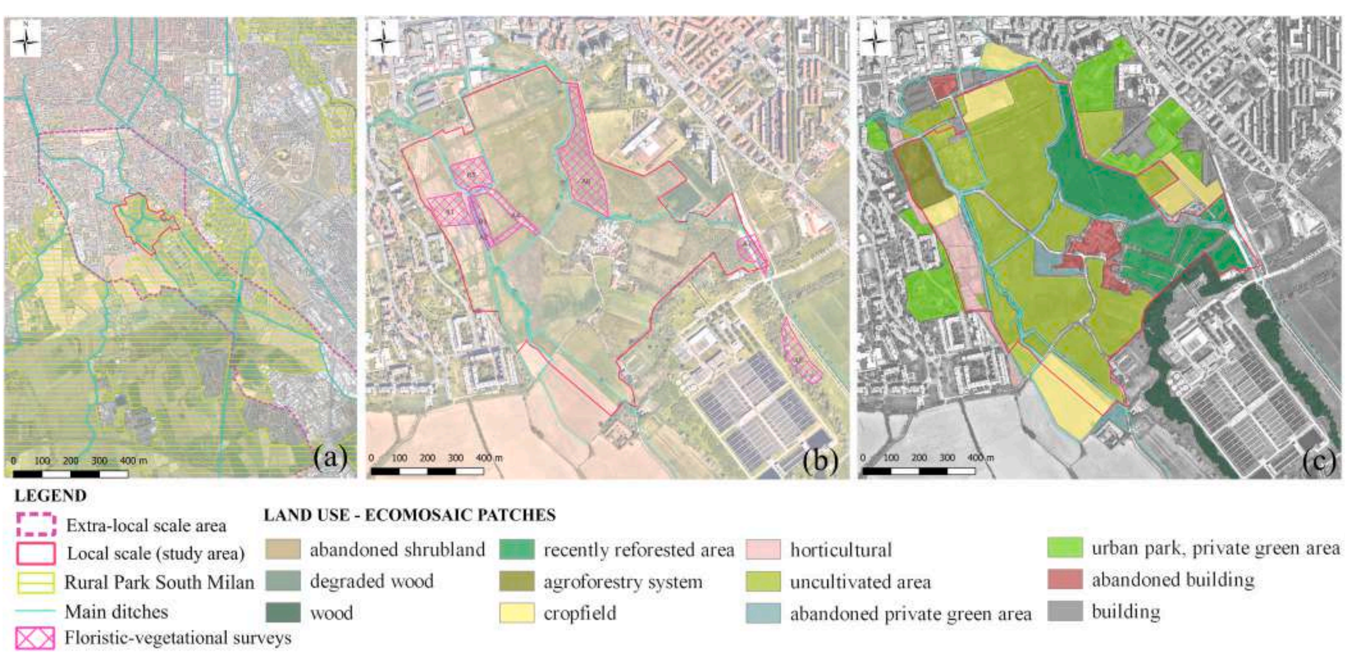

Fig. 2. (a) Study area location among the Milan South-Eastern urban-rural fringe (Geoportale Regione Lombardia, 2022); (b) A detail on the study area (current state), showing the sub-areas (in violet) where floristic-vegetational surveys were led: R1 (uncultivated area); R5 (mature uncultivated area); R3 (ditch margin and uncultivated area); A4 (road margin and uncultivated area); A7 (abandoned area and young reforestation); A2 (ditch margin); A8 (mature riparian belt); (c) land use categories of the landscape eco-mosaic patches.

consequent possible functions to be rehabilitated; vi. consequent identification of the design criteria for linear and areal PLFs to be integrated into the agricultural peri-urban landscape system (floristic-vegetational design specificities).

2. Material and methods

2.1. Study area

The study area is located among the south-eastern urban-rural fringe of Milan, inside the Rural Park South Milan (Lombardy region, North of Italy) (Fig. 2 A). It consists of an agricultural area of about 85 ha, wedged between the last city buildings, crossed by the historical Vettabbia ditch (Fig. 2 B). The area is currently mainly composed by uncultivated fields, croplands (mainly: corn, wheat and soyabean), abandoned areas with spontaneous phytocoenoses recolonizations, recently artificially inserted woody patches (with low to medium development degrees), spontaneous and artificially inserted young hedgerows systems, newly inserted tree-lines and recent in-field highly diversified productive agroforestry systems (Fig. 2C). Minor non-permanent irrigation ditches cross the area, no lentic water basins are present. Anthropic buildings, besides the encircling residential and industrial urban buildings, are limited to a central, low density and degraded small-sized hamlet. An ancient rural road crosses the area North-South. Thanks to the Vettabbia ditch, this area had historically a strategic connection role between the urban needs and its rural surroundings. During last century, these exchanges and mutualisms were gradually lost. Nowadays, new permeability, buffering, connective and protective functions may be envisioned and re-activated. Several urban planning tools and agreements already identified the Vettabbia valley as a strategic, multifunctional, green and blue infrastructure to be restored, by recovering its environmental, cultural and historical legacies (Bogliani et al., 2008; IReR Lombardia, 1995; Parco Agricolo Sud Milano, 2007; Pedrana et al., 2015). Specifically, the AQST strategic scenario recognises the study area as part of a wider ecological and recreational-cultural axis, envisaging an expansion of its natural and semi-natural habitats (Pedrana et al., 2015); the Milan Metropolitan city planning tools bound this area to multi-purpose environmental regeneration prescriptions (Città Metropolitana di Milano, 2021, 2022; Comune Di Milano, 2019). Several local studies already addressed such guiding principles (Caputo et al., 2020; Chiaffarelli and Vagge, 2020; Chiaffarelli and Vagge, 2021; Dal Borgo et al., 2022; Dezio, 2019; Longo, 2018; Liason, 2020; Prusicki, 2006; Tzortzi et al., 2022; Zanzi et al., 2021). Despite this, their coherent, effective and spread implementation is still delaying: except for some localized agri-environmental projects, most of the area in currently mismanaged. To let it run, multi-stakeholder approaches would be needed, directly involving public agencies, municipalities, park authorities, research institutes, local non-profit organizations and enterprises, citizens. Specific science-based tools supporting the ecological coherence of interventions and the accounting of their socio-ecological contributions may help in reaching these regeneration goals.

2.2. 1-Characterization: extra-local scale agri-environmental and climatic context framing

Extra-local scale boundaries were identified according to the landscape unit and ecotope concepts, as developed by Ingegnoli (Ingegnoli, 2002; Ingegnoli, 2015). GIS data were collected and processed at extra-local scale (Vettabbia Valley landscape system), featuring the environmental and landscape context (geomorphology, pedology, hydrology, protected areas and regional ecological network), as well as the anthropic uses and functions (land use, land use change) (Geoportale Regione Lombardia, 2022). Land planning in force and historical tools and strategies were collected and analysed (regional, district and urban SIT) (Chiaffarelli and Vagge, 2020, 2021; Geoportale Regione Lombardia, 2022; Milan Municipality, 2019).

Climate context was framed using the meteorological data of the closest regional ARPA station (Regional Agency for Environment): temperature, rain and air humidity; 21 years time series [1988–2018] (ARPA-Lombardia, 2022). Bioclimatic classification was based on the *Worldwide Bioclimatic Classification System* (WBCS) (Rivas-Martínez, 2004; Globalbioclimatics, 2022; Rivas-Martínez et al., 2011) using the online software *Global BioClimatics Belts Application* (Globalbioclimatics, 2022). The ombrothermic diagram (Walter & Lieth diagram) (Walter and Lieth, 1960) and the Thornthwaite water balance diagram (Thornthwaite, 1948) were built (Globalbioclimatics, 2022).

Vegetational extra-local and local scale context featuring was based on the Italian vegetational series map and the *Prodromo della Vegetazione Italiana* (Biondi et al., 2015a,a,b,b,c; Prodromo della Vegetazione Italiana, 2022; Geoportale Nazionale, 2022; Verde et al., 2010), making reference to the phytosociological approach (Braun-Blanquet, 1964; Géhu, 1988; Géhu and Rivas-Martínez, 1981; Pirola, 1970; Rivas-Martínez, 1987). Merging different bibliographic sources, crossed with GIS and bioclimate analyses results, the reference vegetational series were identified: the climacic one, the substitution series (referred to the dynamics of substitution post anthropic disturbance) and the riparian a-zonal systems (Angelucci, 2011; Baietto et al., 2008; Banfi and Galasso, 1998; Biondi et al., 2004; Brusa and Rovelli, 2010; Prodromo della Vegetazione Italiana, 2022; Geoportale Nazionale, 2022; Ricotti et al., 2003; Seabloom et al., 2003; Verde et al., 2010). A reference scheme was built, illustrating the most plausible dynamic patterns occurring between the different stages of the identified reference vegetational series.

2.3. 1-Characterization: local scale landscape ecological featuring

Local scale boundaries (corresponding to the study area) were identified making reference to pre-existing studies experiences (Longo, 2018; Liason, 2020). Landscape analyses were based on the landscape ecology approach (Dover and Bunce, 1998; Dramstad et al., 1996; Forman, 1995; Forman and Godron, 1986; Turner and Gardner, 2015; Urban et al., 1987). Current landscape eco-mosaic elements (matrix, patches, corridors, stepping stones) were mapped, quantified and qualified (physiognomic, structural and dynamic traits), interpreting their role on the ecological fluxes dynamics (Dramstad et al., 1996). Patches were typified in relation to their different behavioural traits: i. disturbance; ii. environmental resources; iii. introduced (Dramstad et al., 1996). The results of these analyses allowed to interpret the landscape ecological structure and functions (vulnerability and resilience properties) (Chiaffarelli and Vagge, 2020; Chiaffarelli and Vagge, 2021).

2.4. 1-Characterization: field scale floristic-vegetational ecological, chorological, structural and dynamic featuring

Floristic data were collected among 7 sub-areas (Fig. 2 B) representing the most significant habitats surrounding the cultivated fields (uncultivated fields with different maturity degrees, field margins, irrigation ditches and surrounding hygrophilous phytocoenoses, road margins, recent and more developed reforested areas, abandoned areas with ongoing spontaneous recolonization processes). Only angiosperms were listed, also including possible cultivated species, when occurring spontaneously outside cultivated fields. Algae, mosses and crops were not included. Gymnosperms and pteridophytes were not observed. Species were determined *in loco* and, when necessary, through binocular microscope; taxonomy and scientific nomenclature make reference to the *Italian Flora* (Pignatti, 1982; Pignatti et al., 2017–2019; FloraItaliaeActaPlantarum, 2022; Dryades, 2022). For most taxa, the species level was identified; in some cases, the sub-species level; genus level only for a minority of taxa.

The resulting floristic list was integrated with taxonomic and ecological information [Raunkiær plant life forms, chorotype and macro-chorotype (Pignatti et al., 2017–2019; FloraItaliaeActaPlantarum, 2022); Ellenberg's indicators values (Domina et al., 2018; Guarino et al., 2012; Pignatti, 1982; Pignatti et al., 2017–2019; Pignatti et al., 2005)] allowing the analysis of: systematic and chorological traits, Raunkiaier biological spectrum, Ellenberg's ecograms. Alien, invasive alien and autochthonous species data were analysed both jointly and separately.

We qualitatively described the most relevant vegetational types on their main physiognomic-structural traits (Angelucci, 2011; Baietto et al., 2008; Banfi and Galasso, 1998; Biondi et al., 2004; Brusa and Rovelli, 2010; Prodromo della Vegetazione Italiana, 2022; Geoportale Nazionale, 2022; Ricotti et al., 2003; Seabloom et al., 2003; Verde et al., 2010) and on their dynamic behaviour. The observed phytocoenoses were located into the above-cited reference scheme (expected vegetational dynamics for the studied context) (see par. 2.2). Phytosociological associations were not classified, as phytosociological surveys could not be performed homogeneously among the different significant eco-topes (limited available surfaces), according to the Zurich-Montpellier School methodology (Braun-Blanquet, 1964; Géhu, 1988; Géhu and Rivas-Martínez, 1981).

2.5. 2-Assessment: theoretical framing of the adopted functional-dynamic approach

In order to reach the aim of rehabilitating the landscape features agri-environmental functions, a reference theoretical framework was identified, which was built on multiple bibliographic experiences related to the agroecological functional and dynamic interpretation of the agroecosystem phytocoenoses behaviour. The aim was to synthetize the rationale which sustained each subsequent design interventions setting.

2.6. 2-Assessment/3-design: landscape features current and potential ecological functions analysis and design criterions setting

In coherence with the identified interpretative approach, the landscape and floristic-vegetational analyses results informed the identification of the key agri-environmental features categories on which to intervene, synthetizing for each of them: i. the current ecological state; ii. the related impaired agroecological functions impacting on the overall environmental stability levels of the study area; iii. the consequent identified corrective actions; iv. the resulting agroecological functions which are expected to be rehabilitated.

This evaluation oriented the identification of the intervention categories (linear and areal phytocoenoses). Their design criteria were informed by the landscape scale analyses and by field scale floristic and vegetational vulnerabilities screening (see par. 2.4).

For species selection, the auto-ecological and physiological traits and management guidelines were collected from national and regional bibliography (Domina et al., 2018; Dume et al., 2018; FloraItaliaeActaPlantarum, 2022; Guarino et al., 2012; Malcevschi et al., 1996; Pignatti, 1982; Pignatti et al., 2017–2019; Pignatti et al., 2005; Toccolini, 2015; Viggiani and Tabacchi, 2017). For invasive alien species, regional and local prescriptions were collected (Banfi and Galasso, 1998; Brusa and Rovelli, 2010; Regione Lombardia, 2008; Regione Lombardia, 2010a; Regione Lombardia, 2010b). This brought to a final data set which oriented PLFs modules design.

3. Results and discussion

3.1. 1-Characterization: extra-local scale agri-environmental and climatic context framing

The study area is located on fluvial and fluvioglacial sediments belonging to the geomorphological system of the middle hydromorphic alluvial plain (Wurm), among the belt of plain springs (loamy-sand soils, with a finer texture and lower permeability if compared to the northern ones) (Fig. 3 A-B). Here, Cambisols with a high suitability for agricultural use are prevailing. The area is also partly crossed by a Holocene alluvial valley (ancient stream then replaced by the current Vettabbia ditch), with dominant Gleysols and a higher level of hydric saturation. The Vettabbia channel, coming out from the city, crosses the eastern part of the study area, supplying water to the southern irrigation ditches system (Fig. 3 B).

The area is included in the South Milan Rural Park. It is not part of the Regional Ecological Network (RER) (Fig. 3 C). In-force land planning tools describe it as a highly urbanised context, compromised on its ecological connectivity, with strong impacts derived from major linear infrastructures (highways, railways) and the neighbouring industrial areas (Bogliani et al., 2008) (Fig. 3 C). Historical aerial images [1954 GAI flight (Geoportale Regione Lombardia, 2022)] and orthophotos (1975) (Geoportale Regione Lombardia, 2022) show intensive land use changes from the 50's, gradually passing from a rural landscape with diffused interconnected hedgerows systems and riparian vegetated belts, to the current fragmented mixture of urbanised, industrialised, cultivated and abandoned patches. Consequently, semi-natural patches are currently strongly influenced by anthropic dynamics. They are isolated, size-limited, and marginal to the agricultural landscape matrix and urban patches. Only the recent reforestation interventions among the Vettabbia Park make exception (diffused new small-sized woodlands and hedgerows systems, locally recovering the landscape connectivity and heterogeneity values).

Climate is characterized by an equinoctial rainfall regime (annual mean: 871 mm/year; November is the most rainy month and July the least one). Mean relative humidity goes from 63,9% (July; minimum) to 90,8% (December; maximum). The area belongs to the temperate continental bioclimate, upper meso-temperate thermo-type and upper subhumid ombro-type, according to the WBCS (Rivas-Martínez, 2004; Globalbioclimatics, 2022; Rivas-Martínez et al., 2011) [Supplementary materials (Fig. S1B)]. The ombrothermic Walter & Lieth diagram [Supplementary materials (Fig. S1A)] doesn't show significant aridity periods, but there is a boundary condition in July ($p \approx 2 \times T$) (Gaussen index) (Gaussen and Bagnouls, 1952). Freezes are certain in January. The Thornthwaite water balance diagram [Supplementary materials (Fig. S1B)] shows the beginning of a hydric deficit in July (hydric stress conditions), after the winter and spring reserve has been used. From October onwards, soil re-starts imbibing (saturation in November).

In line with bioclimate and pedological conditions, the vegetational context of the study area belongs to the *Western neutron-acidophilus Po Plain series of higher and lower plain oak-hornbeam forests* (*Carpinion betuli* Isler 1931 alliance), climacic series of the second fluvial terraces of the low alluvial plain (Fig. 4) (Prodromo della Vegetazione Italiana, 2022).

Its mature stage is represented by woods with *Quercus robur* L., *Carpinus betulus* L. and *Fraxinus excelsior* L. subsp. *excelsior* as predominant species, and companion *Acer pseudoplatanus* L. and *Acer campestre* L. Intermediate, pre-forest, stage (soil building functions) is represented by associations with *Corylus avellana* L. and *Prunus avium* (L.) L. as characteristic species and companion *Fraxinus excelsior* L. and *Carpinus betulus*. The shrub stage (soil and micro-climate preparatory functions) is represented by mesophilic associations belonging to *Prunetalia-spinosae* Tuxen 1952 order, *Rhamno catharticae-Prunetea spinosae* Rivas Goday & Borja Ex Tuxen 1962 class, with *Crataegus monogyna* Jacq., *Euonymus europaeus* L., *Prunus spinosa* L., *Cornus mas* L., *Rosa canina* L., *Ligustrum vulgare* L. Initial stages with natural grasslands is currently absent in Po Plain context, due to the secular anthropic disturbance conditions: the theoretical herbaceous stage belongs to the *Festuco valesiacae-Brometea erecti* Br.-Bl. & Tuxen Ex Br.-Bl. 1949 class (Prodromo della Vegetazione Italiana, 2022).

Secondary substitution series derived from anthropic disturbance (Fig. 4) are characterized by woody coenoses dominated by *Robinia pseudoacacia* L., often monospecific. Pre-forest stages are also dominated by *R. pseudoacacia,* and are the most spread one in Po Plain context.

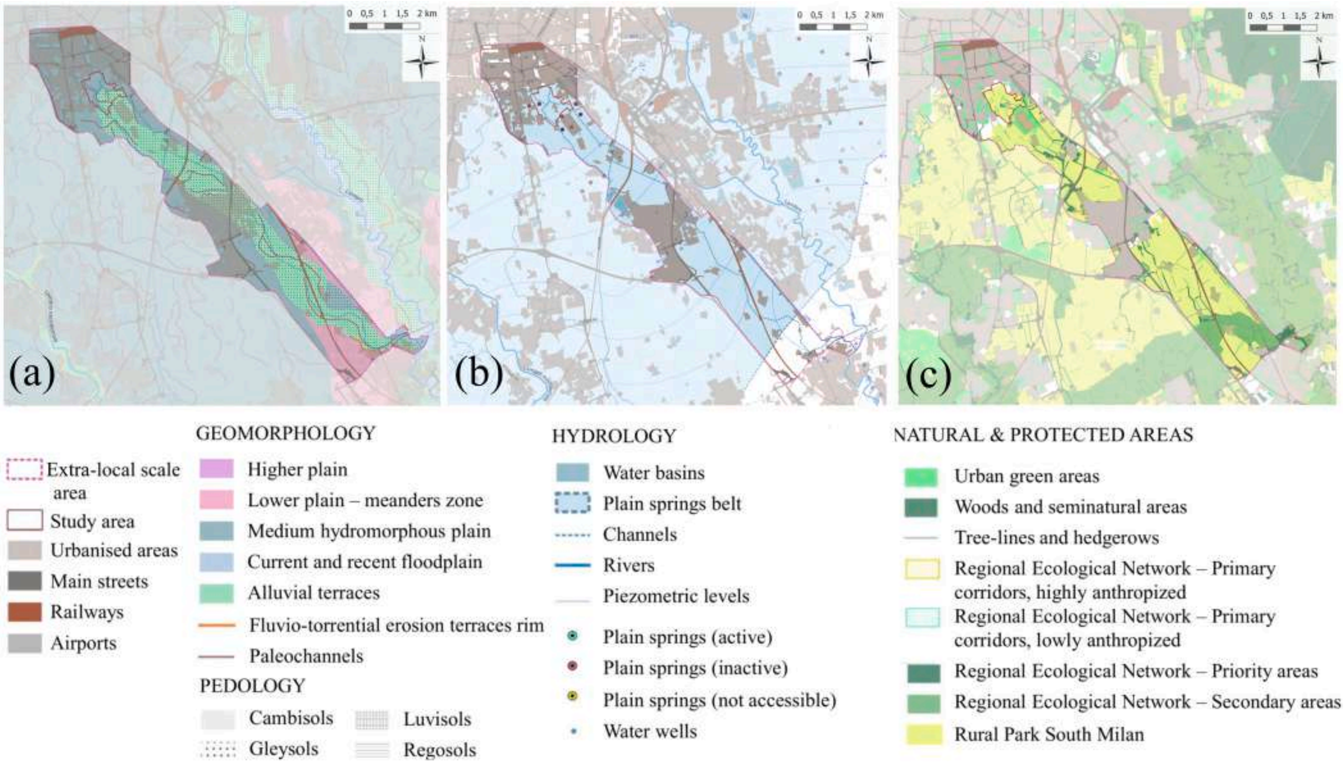

Fig. 3. (a) Pedological and geomorphological context; (b) hydric system context; (c) land-planning tools context.

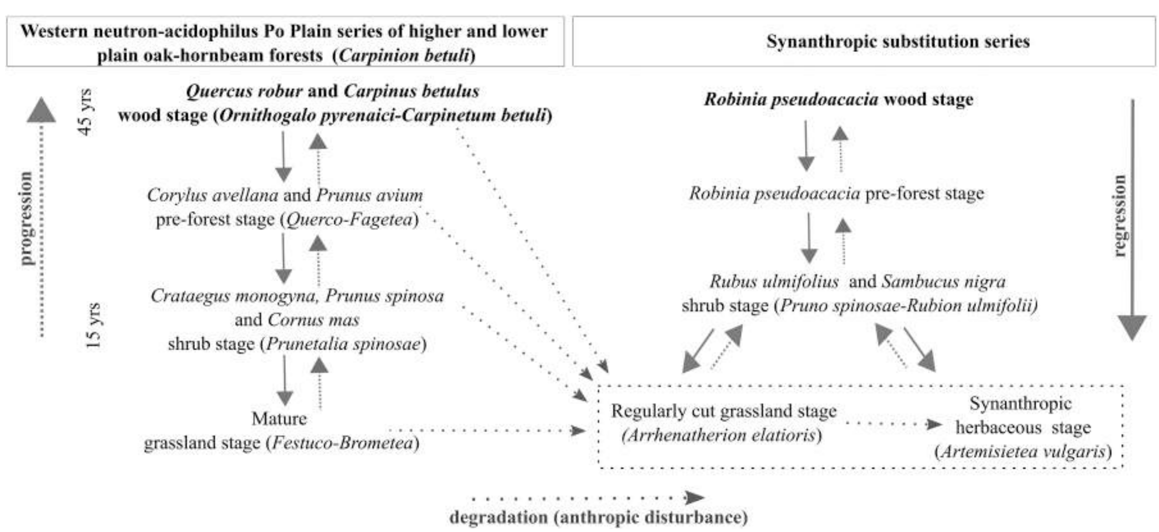

Fig. 4. Main stages of the climacic primary vegetational series (left side) and the secondary substitution series (right side) for the studied context, with a representation of the most common progressive and regressive dynamic trends, in relation to the currently widespread degradation processes.

Among more thermophilic and heliophilous sites, like peri-urban areas, other pioneer exotic invasive species accompany these coenoses, like: *Ailanthus altissima* (Mill.) Swingle, *Paulownia tomentosa* (Thunb.) Steud., *Buddleja davidii* Franch, *Acer negundo* L. Other relevant substitution woody coenoses, less spread than locust woods, are the one dominated by: *Prunus serotina* Ehrh., *Quercus rubra* L. (Verde et al., 2010). Shrub stages are represented by coenoses belonging to the *Pruno spinosae-Rubion ulmifolii* O. Bolòs 1954 alliance (Baietto et al., 2008), which often act as a regressive stage from mature woody coenoses [*Rubus ulmifolius* Schott and *Sambucus nigra* L. as dominant species, accompanied by young *R. pseudoacacia* and *Rubus caesius* L.; *Humulus lupulus* L. e *Clematis vitalba* L. among the climbing strata (Seabloom et al., 2003)]. The underbrush layer is dominated by nitrophilous species (with coenoses often referred to the classes: *Artemisietea vulgaris* Lohmeyer, Preising & Tüxen ex Von Rochow 1951; *Galio aparines-Urticetea dioicae* Passarge ex Kopecky 1969) among which, the following are widespread: *Urtica dioica* L., *Phytolacca americana* L., *Galium aparine* L., *Silene dioica* (L.) Clairv., *Parietaria officinalis* L. Initial herbaceous stages can be divided in: regularly cut grasslands coenoses (*Centaureo carniolicae-Arrhenatheretum elatioris* Oberdorfer 1964 corr. Poldini et Oriolo 1994, *Arrhenatherion elatioris* Koch 1926 alliance) (Angelucci, 2011); synanthropic coenoses, colonizing abandoned areas, dominated by *Artemisia verlotiorum* Lamotte and *Erigeron canadensis* L. (*Artemisietea vulgaris* Lohmeyer, Preising & Tüxen ex Von Rochow 1951 class), with abundant invasive alien species (e.g. *Reynoutria japonica* Houtt., *Solidago gigantea* Aiton, *Heliantus tuberosus* L., *Humulus japonicus* Siebold & Zucc.) (Verde et al., 2010).

Riparian phytocoenoses belong to the hygrophilic geo-sigmetum of low and high plain riverine and riparian vegetation and are characterized as follows (Banfi and Galasso, 1998; Biondi et al., 2004; Ricotti et al., 2003; Verde et al., 2010): in the ordinary floodplain, willow shrublands (*Salicion triandrae* Muller & Gors 1958 alliance, *Salicion incanae* Aichinger 1933 alliance), *Salix alba* L. and *Populus alba* L. woodlands (*Salicetum albae* Issler 1926 association), first alluvial terrace scarps *Populus nigra* L., *P. alba* L. and *Salix alba* L. woodlands, [*Salici albae-Populetum nigrae* (Tx. 1931) Meyer-Drees 1936 association]. At the level of the first alluvial terrace, there is *Alnus glutinosa* (L.) Gaertn. woodland referable to the association *Aro italici-Alnetum glutinosae* Gafta & Pedrotti 1995, with undergrowth consisting of *Cornus sanguinea* L., *Frangula alnus* Mill. *Humulus lupulus* L., *Rubus caesius* L., *R. ulmifolius* Schott. (Biondi et al., 2004). Often these shrub and tree coenoses are severely degraded by the presence of ruderal and synanthropic species or entirely replaced by thickets and shrublands of invasive exotic species such as *Robinia pseudoacacia*.

3.2. 1-Characterization: local scale landscape ecological featuring

The analysis on the landscape eco-mosaic (Table 1) highlighted:

- a stable agricultural matrix (62,8% of total patches surface), mainly composed by uncultivated areas (45,2%), whereas cultivated areas are relatively under-represented (17,6%);
- current agricultural patches are relatively over-sized (minimum: 0,09 ha; maximum: 9,07 ha; mean: 1,69 ha; median: 0,80 ha), low values are related to private horticulture patches;
- a significant presence of semi-natural components (31,5%), dominated by woody areas;
- anthropic components limited presence (5,7%), which reflects the low level of urban sprawl, notwithstanding the nestled shape amidst the last city buildings;
- linear corridors (6,1% of total area) are mainly composed by mixed discontinuous trees and shrubs phytocoenoses, mostly along irrigation ditches. Among them, connective functions are predominant, compared to buffering/filtering functions;
- stepping stones (3,7% of total area) are mostly composed by trees or shrubs phytocoenoses, mainly located inside uncultivated patches and urban parks.

Table 1
Relative surfaces of the different components of the local scale landscape eco-mosaic (patches, corridors, stepping stones).

PATCHES	**AREA**		→	**SUB-SYSTEM**	**AREA**
	ha	**%**			**%**
Cultivated field	9,08	11,3%		Agricultural	62,8%
Uncultivated field	36,36	45,2%			
In-field agroforestry	1,77	2,2%			
Horticultural	3,30	4,1%			
Wood	21,75	27,1%		Natural /	31,5%
Abandoned green area	3,55	4,4%		Semi-natural	
Urban green area	2,16	2,7%		Anthropic	5,7%
Urbanised	2,42	3,0%			
TOTAL	**80,38**				
CORRIDORS	**AREA**		→	**MAIN FUNCTION**	**AREA**
	ha	**%**			**%**
Trees and shrubs	3,31	63,1%		Connection	67,7%
Tree lines	0,13	2,6%			
Shrubs	0,11	2,0%			
Road margins	0,18	3,3%		Buffering / filtering	32,3%
Irrigation ditches	1,52	29,0%			
TOTAL	**5,24**				
STEPPING STONES	**AREA**		→	**STRUCTURE**	**AREA**
	ha	**%**			**%**
Along ditches	0,13	2,5%		Only trees	16,7%
Isolated	0,10	2,0%			
Inside other patches	2,52	48,2%		Trees and shrubs	82,4%
Along hedgerows	0,03	0,5%		Only shrubs	0,9%
Along roads	0,40	7,7%			
TOTAL	**3,19**				

Patches were clustered in 3 groups for interpreting their ecological behaviour: i. disturbance patches, ii. patches acting as environmental resources, iii. introduced patches.

i. Disturbance patches: patches whose phytocoenoses traits derive from secondary recolonization processes after anthropic uses abandonment:

- Uncultivated patches: they are mostly over-sized, with homogeneous shape (low interdigitation with the surrounding semi-natural patches) and predominant sink area traits, facilitating highly competitive generalist species predominance (Bruun, 2000; Dramstad et al., 1996). Nevertheless, the absence of recurrent anthropic disturbances make these patches potential refuge areas for micro and meso-fauna, contributing to the improvement of the matrix quality, pivotal to spatial permeability (Fahrig, 2001; Laurance et al., 2002).
- Abandoned shrublands and abandoned private green areas: little residual areas (from about 1000–3000 m^2) relatively simplified in their structure. They are evolving habitats, suitable as scattered source, transit and refuge areas, more likely for generalist species (Dramstad et al., 1996), supporting the matrix permeability.
- Degraded woody patches: they are instable contexts (secondary dynamisms), relatively simplified in their structure (lowered buffering functions). Located in marginal areas, often along the transition between anthropic and agricultural patches. Their frequent little size impairs their potential core area traits (Dramstad et al., 1996).

ii. Patches acting as environmental resources: patches that were artificially rehabilitated to semi-natural features:

- Woody patches: more mature woody patches located at the southern edges of the study area. Relatively large-sized, they often have jagged edges, promoting their environmental permeability (cross-cutting movements through ecotonal areas; higher micro-habitat diversity) (Gehlhausen et al., 2000; Holland and Fahrig, 2000; Holland and Risser, 1991). They support core areas functions and currently act as source areas among the landscape mosaic (Battisti, 2004; Donald and Evans, 2006; Dramstad et al., 1996; Fabbri, 1997; Foppen et al., 2000).
- Recently reforested areas: differently sized patches (2 major ones - about 6 ha – and other minor ones – about 1,5-2 ha –), distributed along the Vettabbia ditch axis. Currently low developed, they potentially act as source and buffering axis among the landscape mosaic, where core areas functions will be safeguarded (Dramstad et al., 1996; Pysek et al., 2002).
- Multi-strata agroforestry systems patches: two agricultural patches (about 1 ha each) where diversification was recently implemented through the insertion of in-field high density linear multi-strata trees and shrubs systems (Ewel, 1999; Gliessman, 2007; Jackson, 2002; Soule and Piper, 1992). They support micro-habitat diversification among the agricultural matrix (higher matrix permeability), potentially playing both source and connective roles (Dramstad et al., 1996; Gliessman, 2007; Hernández-Morcillo et al., 2018; Jules and Shahani, 2003; McIntyre and Hobbs, 2001).

iii. Introduced patches: patches characterized by more intensive, regular anthropic uses:

- Horticultural patches: mainly located along the urban-rural transition belt, they represent highly disturbed patches (frequent management, interrupting spontaneous dynamisms). Nonetheless, due to their elongated shapes and the scattered presence of trees and shrubs species, they also act as medium-to-low quality stepping stones and urban-rural matrix permeating areas (refuge and trophic areas) (Dramstad et al., 1996; Jules and Shahani, 2003; Rodewald, 2003).

- Urban parks and private green areas: marginal patches, low ecological quality (highly controlled anthropogenic coenoses) easily hosting generalist species. Nonetheless, they have a key potential transition and permeating role among the urban-rural matrix fringe (Pysek et al., 2002).
- Residential buildings: disturbance source areas against the surrounding rural patches, they are often surrounded by spontaneous secondary recolonization strips, easily acting as generalist species source areas.
- Abandoned farmhouses: small-sized patches, huddled shape, their state of neglect facilitates generalist synanthropic species settlement.

3.3. 1-Characterization: floristic analyses results

Through floristic surveys, 82 species were identified (59 genera, 32 families), with low congeneric levels (1,4 species/genus on average). The most represented families are Poaceae (16%), followed by Asteraceae (11%), Rosaceae (9%), Fabaceae (7%), Salicaceae (6%), Polygonaceae (6%).

The Raunkiaier biological spectrum on life forms (Fig. 5 A) highlighted:

- a positive alignment with the temperate-continental macro-bioclimate [predominance of hemicryptophytes (36%), and good representation of phanerophytes (32%), which are mainly linked to the reforested areas and linear unstructured phytocoenoses along ditches and roads margins];
- a good occurrence of theropytes (17%), which in agricultural contexts are mainly related to repeated disturbance conditions facilitating ruderal short-cycle species, as it is confirmed by the biological spectrum calculated on the invasive alien species sub-set, where therophytes represent higher percentages (23%);
- a significant presence of geophytes (11%), normally related to stable, mature wood or grassland conditions (absent among the study area)

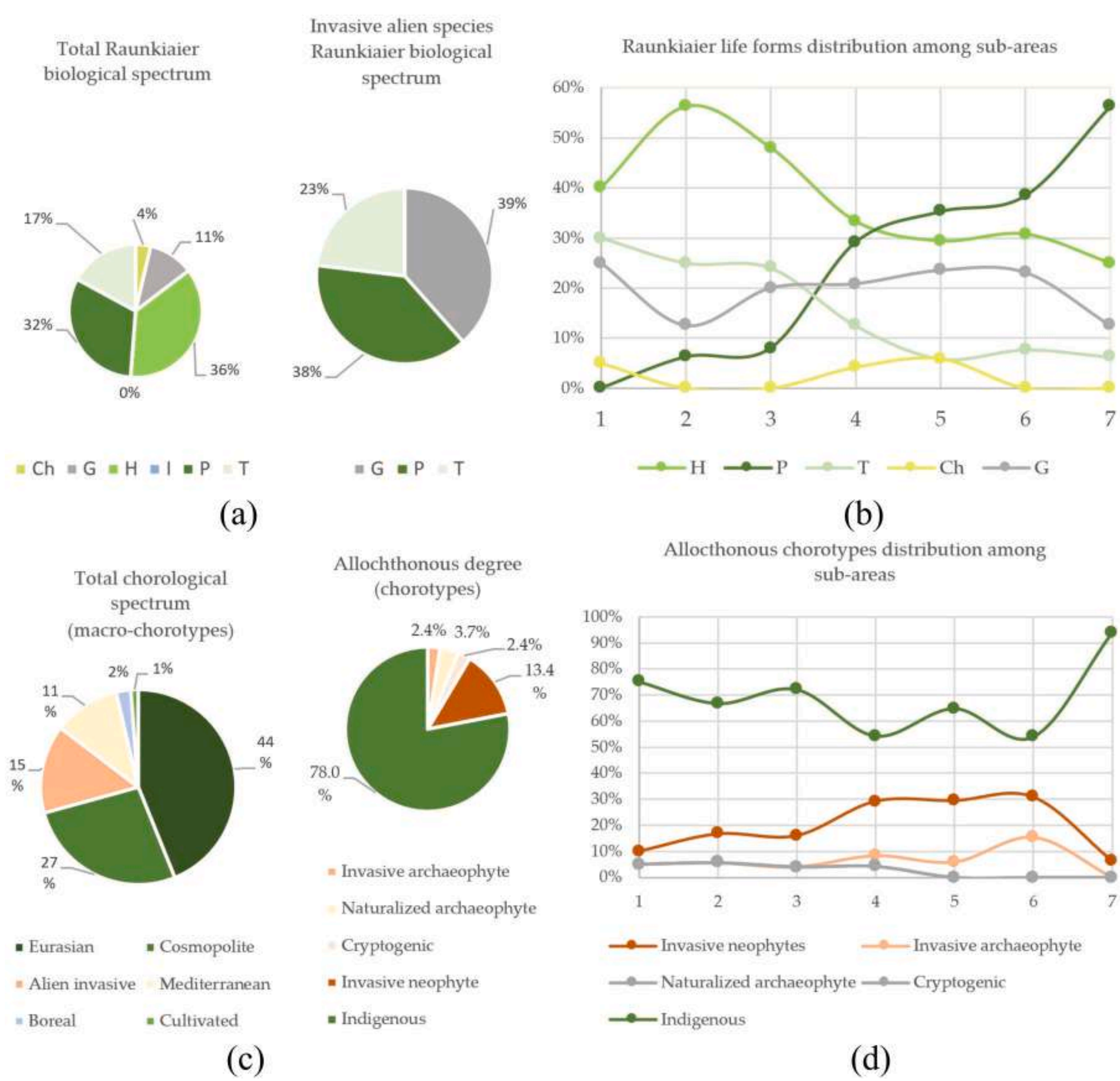

Fig. 5. (a) Raunkiaier biological spectrum for total area and for the invasive alien species sub-set (Ch = chamephytes; G = geophytes; H = hemicryptophytes; I = hydrophytes; P = phanerophytes; T = terophytes); (b) Raunkiaier life forms distribution among single sub-areas; (c) Total chorological spectrum (macro-chorotypes) and detail on allochthonous chorotypes; (d) Allochthonous chorotypes distribution among single sub-areas. [1 =R1 (uncultivated area); 2 =R5 (mature uncultivated area); 3 =R3 (ditch margin and uncultivated area); 4 =A4 (road margin and uncultivated area); 5 =A7 (abandoned area and young reforestation); 6 =A2 (ditch margin); 7 =A8 (mature riparian belt)].

but also, among agricultural contexts, promoted by soil management disturbances (agamic propagation of the fragmented bulbs and rhizomes); an interpretation that is supported by the invasive alien species biological spectrum, a significant proportion of which is constituted by geophytes (39%).

The distribution of life forms among the different sub-areas (Fig. 5 B) highlighted the following traits:

- hemicryptophytes are the most represented life form among all sub-areas, showing the highest percentage values among open field conditions (uncultivated areas (R1, R5, R3), with the highest values among the most mature one (R5)); lower values among road margins, partially reforested areas and ditch margins where also tree cover is present (A4, A7, A2), with the lowest values among the most mature wooded riparian belt (A8).
- Both hemicryptophytes and therophytes show opposite trend if compared to phanerophytes, highlighting the stabilization role of phytocoenoses stratification towards soil and micro-climatic conditions, disadvantaging shorter life cycles species.
- The distribution of geophytes confirms the hypothesis of their linkage with soil disturbance conditions, as no significant differences are highlighted between the different contexts, with lower values only among the mature uncultivated area (R5) and the more mature riparian belt (A8).

Chorological analyses (Fig. 5 C) highlighted the presence of 6 different macro-chorotypes: Eurasian is predominant (44%), in line with the biogeographical context in which the Po Valley is located, followed by Cosmopolitan macro-chorotype (27%), in relation to the heavy anthropization of the area. Allochthonous species presence degree is significant (22% of total species) and their chorotypes analysis highlighted how they are mainly composed by invasive species [invasive neophytes (13,4% of total species) and invasive archaeophytes (2,4% of total species)] (Fig. 5 C).

The distribution of chorotypes among the different sub-areas (Fig. 5 D) highlighted the following traits:

- Uncultivated areas (R1, R5, R3) showed lower invasive species (neophytes and archaeophytes) percentage values, mainly represented by geophytes (such as *Artemisia verlotiorum, Sorghum halepense* (L.) Pers.) and therophytes (such as *Erigeron canadensis*).
- Abandoned areas, road and ditch margins (A4, A7, A2) showed the highest percentage of invasive species (mainly represented by phanerophytes, such as *Robinia pseudoacacia, Ailanthus altissima, Parthenocissus quinquefolia* (L.) Planch.*, Acer negundo*; and geophytes, such as *Phytolacca americana, Artemisia verlotiorum, Reynoutria japonica, Sorghum halepense*), highlighting how current spontaneous re-colonization dynamic trends are related to secondary recolonization substitution series.
- The reforestation occurred among the more mature riparian belt (A8) positively contributed to lowering the susceptibility to invasive species insertion, registering the highest values of indigenous species (mainly: phanerophytes related to the pre-wood and mature stages of the climacic series and of the riparian a-zonal systems; hemicryptophytes such as *Calamagrostis epigejos* (L.) Roth*,* and many ruderal and synanthropic hemicryptophytes such as *Lactuca sativa* L.*, Rumex obtusifolius* L.*, Urtica dioica*).

The comparison of the Ellenberg's indicators values between allochthonous and autochthonous species (Fig. 6 A) shows clear gradients going from autochthonous to allochthonous and invasive allochthonous species, both for temperature, light, soil acidity and soil nutrients values. In detail, invasive alien species show a clear preference for higher temperature values, also in comparison of allochthonous non-invasive species. Both show higher light requirements, if compared to indigenous species. More acid and less fertile (lower nutrients values) soil conditions are preferred by allochthonous species.

Species distribution among the different values of each Ellenberg's indicator (Fig. 6 B) highlighted the following traits, bringing some more information on Ellenberg's ecogram interpretation:

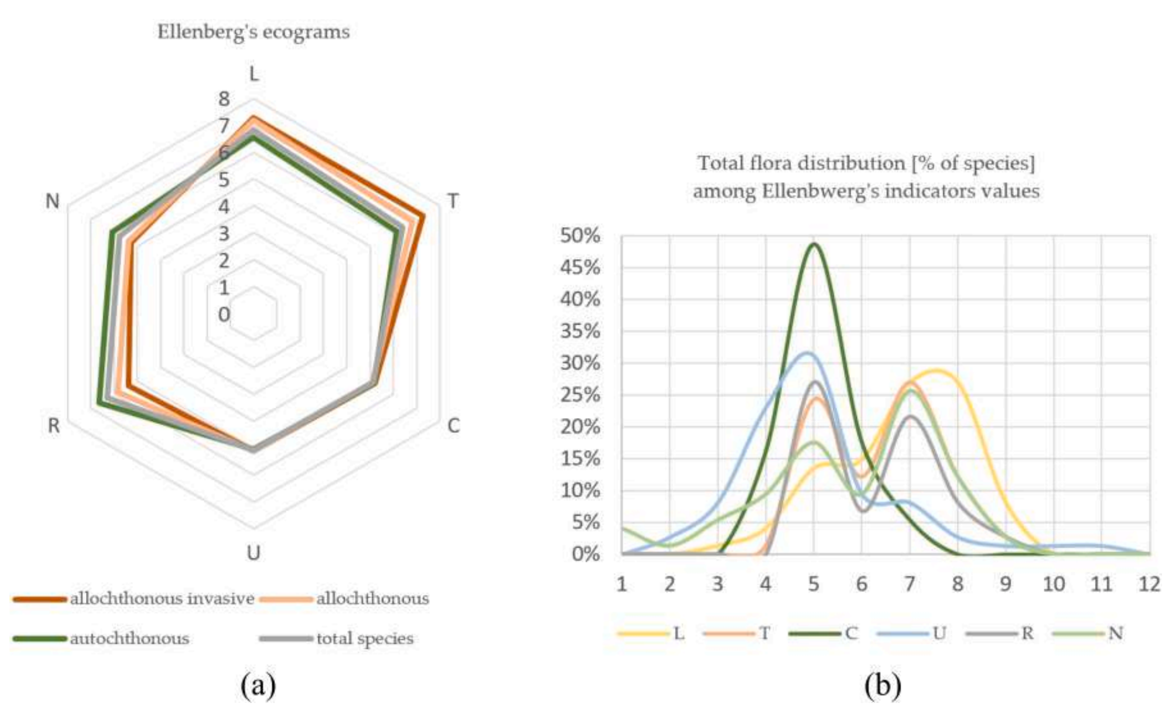

Fig. 6. (a) Ellenberg's ecogram comparing the allochthonous (total and invasive sub-set), authochthonous and total species ecological needs for the different ecological factors (L=light; T = temperature; C=climate continental degree; U=humidity; R=soil acidity; N = soil nutrients); (b) Total flora distribution among the different Ellenberg's indicators values (% of species for each Ellenberg's indicator value).

- continentality and soil humidity requirements show bell-shaped trends, with no significant clustering of species;
- light and soil nutrients requirements show one major peak on higher values, and a minor peak on medium values, partly reflecting the differences between allochthonous and indigenous species;
- temperature and soil acidity requirements show two clearly separated peaks, partly reflecting the separation between autochthonous and allochthonous species requirements, showing how these two ecological factors can significantly influence the floristic structure of phytocoenoses.

These data brought useful information for design and management criteria, highlighting how open air, low shadowed and highly disturbed soil conditions (low nutrients storage levels) would promote invasive alien species insertion, with pioneer behaviour, lowering the success rate of the interventions aimed at recovering the floristic-vegetational potential quality.

Table 2
Physiognomic, structural and dynamic traits of the most relevant phytocoenoses types among the study area (photo sources: authors).

Phytocoenosis type	Phisiognomic-structural traits	Iconic photo	Dynamic traits
Ditches margins – herbaceous	Mono-strata High aggregation levels for some guiding species (e.g. *Urtica dioica, Ambrosia artemisifolia* L., *Chenopodium album* L.)		SUBSTITUTION SERIES Synanthropic coenoses Initial stages Recolonization
Ditches margins – trees and shrubs	Bi-strata + creepers Highly discontinuous and degraded structure		SUBSTITUTION SERIES Shrub and pre-wood stages High instability and alternance of regressive and progressive trends
Road margins – herbaceous	Mono-strata Few species highly dominant (e.g. *Sorghum halepense, Parthenocissus quinquefolia, Phytolacca americana*)		SUBSTITUTION SERIES Synanthropic coenoses Initial stages Recolonization
Road margins - trees, shrubs, herbaceous	Bi-strata + creepers Highly discontinuous and degraded structure		SUBSTITUTION SERIES Shrub and pre-wood stages High instability and alternance of regressive and progressive trends
Field margins	Prevalent mono-strata (herbaceous), with sporadic insertion of recolonizing trees (e.g. *Robinia pseudoacacia, Ailanthus altissima*)		SUBSTITUTION SERIES Initial stages and initial shrub stages Recolonization
Uncultivated areas	Mono-strata Often significant dominance of few species (e.g. *Lactuca sativa* L. subsp. *serriola* (L.) Galasso, Banfi, Bartolucci & Ardeghi*, Avena fatua* L., *Chenopodium album*)		SUBSTITUTION SERIES Hay meadows coenoses Initial stages Highly disturbed recolonization
More mature uncultivated areas	Mono-strata Generally lower dominance values (cfr. previous one)		SUBSTITUTION SERIES Hay meadows coenoses Initial stages Medium disturbed recolonization
Spontaneous young woody areas	Bi-tri-strata + creepers Discontinuous and low-density structure Significant dominance of few species (e.g. *Robinia pseudoacacia, Parthenocissus quinquefolia, Rubus ulmifolius*)		SUBSTITUTION SERIES From pre-wood to wood stages Low to medium stability and spotted alternance of regressive and progressive trends
Young reforested woody areas	Bi-tri-strata Continuous low-density structure Low dominance values (shrub and tree species)		CLIMACIC SERIES From shrub to pre-wood stages Progression
More mature reforested woody areas	Bi-tri-strata Continuous medium to high-density structure Low dominance values (shrub and tree species)		CLIMACIC SERIES From pre-wood to wood stages Progression and stabilization

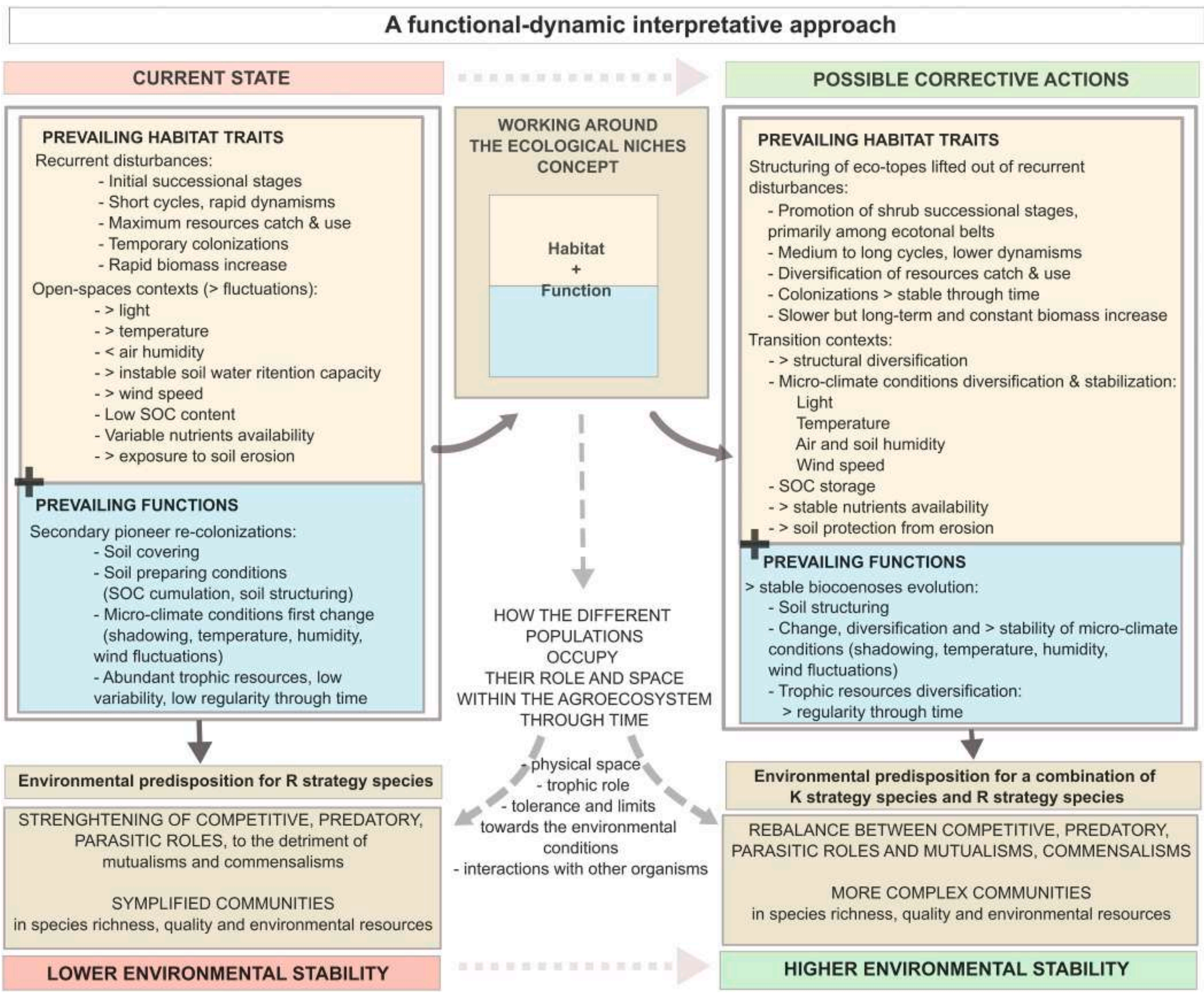

Fig. 7. The identified functional and dynamic approach for the correction of current ecological vulnerabilities and for a coherent ecological rehabilitation, aimed at sustaining the overall environmental stability of the agroecosystem.

3.4. 1-Characterization: phytocoenoses physiognomic-structural and dynamic main traits

The following table (Table 2) resumes the physiognomic, structural and dynamic traits of the most relevant phytocoenoses types currently characterizing PLFs in the study area, complementing the information coming from floristic analyses.

3.5. 2-Assessment: a functional-dynamic approach for the agroecosystem environmental stability recovery

The above presented analyses allowed us to frame the overall vulnerabilities related to current PLFs phytocoenoses. The predominant detected floristic-vegetational traits of spontaneous phytoceonoses are related to secondary successional stages (Fig. 4), where generalist, stress-tolerant, opportunist synanthropic species are facilitated (both the native and alien ones) in consequence to peri-urban and agricultural high disturbance conditions (Davis et al., 2000), as pre-existing studies on peri-urban phytocoenoses testify (Chytry et al., 2008; Fanelli et al., 2006; Godefroid and Koedam, 2003a; Godefroid and Koedam, 2003b; Kowarik, 1990; Pyšek et al., 2004; Seabloom et al., 2003; Stapanian et al., 1998). Marginal areas and riparian belts, where disturbance is moderately frequent, are currently the preferential contexts for medium stages spontaneous secondary re-colonization processes (shrub and pre-wood stages), which difficultly evolve towards wood stages.

The discreet allochthonous degree is related to higher temperature and light conditions (open air, instable contexts) as well as higher soil acidity conditions and lower soil nutrients levels (immature, low developed coenoses, related to recurrent disturbance conditions). This results are in line with literature evidences (Chytry et al., 2008; Walter et al., 2005), with the exception of soil nutrients levels, which are normally reported as higher for alien species, a difference which should be related to the influence of some highly rustic alien species among the study area flora, such as *Ambrosia artemisifolia* and *Erigeron annuus*.

Older reforestation contexts (the A8 riparian belt) positively represent more stable conditions (higher phanerophyte species percentage, lower therophytes and hemicryptophytes) with higher autochthonous species levels. Open space conditions (uncultivated areas) show opposite trends. Spontaneous multi-strata phytocoenoses and young reforestation contexts are in the middle of this gradient and show the highest invasive alien species levels, which were related to their more discontinuous and lower density cover conditions and to the closer in time anthropic disturbances (if compared to reforested contexts).

In synthesis, the environmental and human management contexts

Table 3
Synthesis on the PLFs current vulnerabilities and potential functions to be re-habilitated, in relation to their current state and the here-proposed corrective actions. References: [1]: (Burel, 1996; Carroll et al., 2004; Franco, 2000; Franco, 2004; Ryszkowski et al., 1999; Udawatta et al., 2021; Wolton et al., 2014); [2]: (Gascuel-Odoux et al., 2009; Hernández-Morcillo et al., 2018; Rivest et al., 2013; Ryszkowski et al., 1999; Wolton et al., 2014); [3]: (Hernández-Morcillo et al., 2018; Kremer, 2021; Lorenz and Lal, 2014; Rivest et al., 2013; Wolton et al., 2014); [4]: (Donald and Evans, 2006; Dramstad et al., 1996; Hernández-Morcillo et al., 2018; Tewksbury et al., 2002; With and Crist, 1995); [5]: (Bianchi et al., 2006; Précigout and Robert, 2022; Torralba et al., 2016; With, 2002; Wolton et al., 2014); [6]: (Bentrup et al., 2021; Nicholls and Altieri, 2013; Wolton et al., 2014); [7]: (Hernández-Morcillo et al., 2018); [8]: (Donald and Evans, 2006; Dramstad et al., 1996; Fahrig et al., 2011; Maskell et al., 2019; Morelli, 2013); [9]: (Burel, 1996; Catalano, 2021; Dzierżanowski et al., 2011; Franco, 2000; Franco, 2004; Ryszkowski et al., 1999; Udawatta, 2021; Wolton et al., 2014); [10]: (Falkowski and Diemont, 2021).

PLFs		CURRENT STATE	IMPAIRED AGROECOLOGICAL FUNCTIONS	PROPOSED CORRECTIVE ACTIONS	AGROECOLOGICAL FUNCTIONS TO BE RE-HABILITATED
LANDSCAPE FEATURES SYSTEM	Trees and shrubs hedgerows	Highly discontinuous, low structured Synanthropic biocoenoses Alien species dominant Instable environment Simplified habitats of low quality Simplified communities	MICROCLIMATIC AND HYDRIC FLUXES REGULATION [1]: > wind speed and turbulence > evapotranspiration > temperature changes < water infiltration > soil humidity changes < WATER FILTERING AND QUALITY PROTECTION [2] < SOIL FERTILITY [3] < ECOLOGICAL CORRIDOR [4] < SPECIES BALANCE [5]: Simplified communities > instable secondary dynamisms > sink areas < biological control systems (birds, mammals, insects, reptiles) < POLLINATORS [6] < BY-PRODUCTS [7]: Wood, woodchip, fruits	Insertion of diversified multi-functional habitats, with higher ecological quality Continuity recovery Phytocoenoses structuring (stratification and texture) > Floristic diversity High planting density Autochthonous species balance	MICROCLIMATIC AND HYDRIC FLUXES STABILISATION [1]: > wind quiet zones < evapotranspiration < temperature changes > water infiltration < soil humidity changes > WATER FILTERING AND QUALITY PROTECTION [2] > SOIL CONSERVATION [3] > ECOLOGICAL CORRIDOR [4] > SPECIES BALANCE [5]: > complex and structured communities Dynamisms reconducted towards climacic series > source areas > use options (movement, trophic uses, refuge, reproduction, …) > biological control systems (birds, mammals, insects, reptiles) > POLLINATORS [6] > BY-PRODUCTS [7]: Wood, woodchip, fruits
	Degraded, abandoned woodlands	Low structured phytocoenoses dominated by invasive alien species Poor floristic and faunal diversity Generalist species dominant		Progressive conversion to climacic series dynamisms through medium and pre-wood rapid-growth autochthonous species insertion under the pre-existing canopy Species with soil edification role, as a precondition to more diversified coenoses establishment	
	Recently reforested areas	Initial to medium pre-wood stage Good trees and shrubs species diversity, in line with climacic series Scarse distribution across the area		Marginal ecotonal belts re-structuring (insertion of high density shrub species) Strengthening of the interconnection with other landscape features	
	Isolated trees and shrubs	Uniform floristic traits Few generalist invasive alien species dominant Unstructured		Structure improvement through shrub autochthonous species insertion Insertion of new small-sized units for stepping stones functions enhancement	
	Tree-lines	Almost absent		Insertion of diffused, interconnected tree-lines Tree species diversification Movement and visual paths	
RIPARIAN SYSTEM	Spontaneous vegetation along irrigation ditches	Highly discontinuous, low structured Synanthropic biocoenoses Alien species dominant Instable environment Simplified habitats of low quality Simplified communities	MICRO-CLIMATIC AND HYDRIC FLUXES REGULATION [1]: > wind speed and turbulence > temperature changes > evapotranspiration < ditch shadowing > soil humidity changes < WATER FILTERING AND QUALITY PROTECTION [2]: > surface run-off < phytodepuration < soil pollutants filtering < SOIL CONSERVATION [3]: > ditch bank soil erosion < MICRO-HABITAT DIVERSIFICATION [8] < ECOLOGICAL CORRIDOR [4] < SPECIES BALANCE [5]: Simplified communities > instable secondary dynamisms < source areas < biological control systems (birds, amphibians and insects communities)	Reconversion of substitution series phytocoenoses Insertion of diversified multi-functional habitats, with higher ecological quality Continuity recovery Phytocoenoses structuring (stratification and texture) > Floristic diversity High planting density Autochthonous species balance	MICRO-CLIMATIC AND HYDRIC FLUXES STABILISATION [1]: < wind speed and turbulence < temperature changes < evapotranspiration > ditch shadowing < soil humidity changes > WATER FILTERING AND QUALITY PROTECTION [2]: < surface run-off > phytodepuration > soil pollutants filtering > SOIL CONSERVATION [3]: < ditch bank soil erosion > ditch bank stability > MICRO-HABITAT DIVERSIFICATION [8] > ECOLOGICAL CORRIDOR [4] > SPECIES BALANCE [5]: > complex and structured communities Dynamisms reconducted towards local catenal riparian phytocoenoses traits > source areas > use options (movement, trophic uses, refuge, reproduction, …) > biological control systems
	Woody buffering strips	Absent		Linear woody buffering strips insertion among the main hydric axes High continuity, well structured High floristic diversity High planting density	

(continued on next page)

Table 3 (*continued*)

PLFs		CURRENT STATE	IMPAIRED AGROECOLOGICAL FUNCTIONS	PROPOSED CORRECTIVE ACTIONS	AGROECOLOGICAL FUNCTIONS TO BE RE-HABILITATED
					(amphibians and insects communities)
FRINGE SYSTEM	Phytocoenoses among the urban-rural fringe	Low structured and highly discontinuous phytocoenoses dominated by invasive alien species Poor floristic and faunal diversity Generalist species dominant	< ENVIRONMENTAL BUFFERING FUNCTIONS [9]: Soil and air pollutants Noise Temperature (*heat island* effect) < HABITAT DIVERSIFICATION [8]: Absence of protective buffering belts	Ecological restructuring of different types of herbaceous, trees and shrubs linear coenoses Progressive insertion of rural phytocoenoses components at the interface with urban parks (also didactic purposes) Both parallel and orthogonal deployment with respect to the urban fringe	> ENVIRONMENTAL BUFFERING FUNCTIONS [9]: Soil and air pollutants Noise Temperature (*heat island* effect) > HABITAT DIVERSIFICATION [8]: > protective buffering belts
	Fields and paths margins	Spontaneous, homogeneous, herbaceous synanthropic phytocoenoses Generalist species dominant	> generalist species fluxes from the urban matrix > vulnerability of specialist species Simplified communities, impacting on the rural surroundings > sink areas > instable secondary dynamisms < ECOLOGICAL CORRIDOR [4] < DIDACTIC-DISSEMINATION FUNCTIONS [10]	Insertion of highly diversified herbaceous linear belts, with diversified functions (refuge, movement, trophic and reproduction areas, support to pollination, genetic exchanges, etc.) Making reference to stable grassland phytocoenoses	< generalist species fluxes from the urban matrix < vulnerability of specialist species > diversified communities Dynamisms reconducted towards climacic series < sink areas > use options (movement, trophic uses, refuge, reproduction, …) > ECOLOGICAL CORRIDOR [4] > DIDACTIC-DISSEMINATION FUNCTIONS [10]

(open and highly perturbed habitats, lowly structured and diversified, lowly connected) currently promote simplified, generalist communities, linked to instable initial dynamisms, as several theoretical frameworks confirm (Casula et al., 2006; Gliessman, 2007; Hooper et al., 2006; Hooper et al., 2005; Loreau et al., 2001; McKinney and Lockwood, 1999; Rebele, 1994; With, 2002; With and Crist, 1995).

These traits suggest that the floristic-vegetational quality of PLFs could be improved, getting closer to the local potential, by operating on the modification (diversification and stabilization) of the available ecological niches for species insertion (Shea and Chesson, 2002), namely by bringing changes on current predominant habitat and function characters through the insertion of targeted species and planting patterns through space and time (Bakker and Wilson, 2004), relying on the *initial floristic composition* concept (Egler, 1954), and balancing the *empty niches* effects (Rebele, 1994). Disturbance conditions and physical isolation impacts should be concurrently addressed, both working on phytocoenoses structuring drivers and on their spatial configuration (Seabloom et al., 2003). In-between fields belts, urban-rural transition areas and riparian belts were identified as the key contexts for the insertion of balancing vegetational dynamisms: their boundary conditions and ecotone behaviour (Boutin et al., 2002; Kark, 2017; Kark and Van Rensburg, 2006; Odum and Barrett, 2004; Risser, 1995) could have a leading role in guiding the agroecosystem towards diversity generation trends and buffering functions activation (Pysek et al., 2002). Hence, PLFs ecological rehabilitation should be targeted to the increase of higher complexity components (morphologically and functionally diversified, well structured, high-density new-insertion phytocoenoses, highly interconnected), aiming at: diversifying and balancing the eco-topes, micro-habitat conditions and ecological roles across the whole area (Bakker and Wilson, 2004; Battisti, 2004; Baum et al., 2004; Benton, 2007; Donald and Evans, 2006; Dramstad et al., 1996; Fabbri, 1997; Gliessman, 2007; Luken, 1990; McIntyre and Hobbs, 2001; Tewksbury et al., 2002); improving the quality of the overall agricultural matrix (Fahrig, 2001); supporting higher floristic quality and biodiversity values and a consequent overall increased environmental stability (Frank and McNaughton, 1991; Loreau and de Mazancourt, 2013; Loreau et al., 2001; Odum, 1969; Oliver et al., 2015). Fig. 7 illustrates the rationale underpinning this functional and dynamic approach (Fig. 7).

3.6. 2-Assessment: PLFs ecological functions: current vulnerabilities and potential functions to be re-habilitated

In coherence with the above-presented interpretative approach, local scale landscape analysis results and field scale floristic-vegetational featuring brought to the identification of 9 key PLFs categories, whose current impairment level directly or indirectly impacts on the environmental stability levels of the study area. PLFs were attributed to 3 main functional systems: landscape features system, riparian system, fringe system. Table 3 resumes, for each of them: the current ecological state, the intrinsic compromised agroecological functions, the consequent proposed corrective actions; the resulting agroecological functions which are intended to be re-habilitated (Table 3). Fig. 8A synthetizes the vulnerability and resilience properties of the local scale ecological landscape system, influencing single PLFs behaviours and their effective contributions (Fig. 8 A).

3.7. 3-Design: a consequent set of multi-functional interventions on PLFs

We integrated the above illustrated principles and analytical results into a strategic ecological reconfiguring guidelines drafting, which was built around the following key topics: i. diversification; ii. support to the multi-functionality of the different sub-systems; iii. relations between the different sub-systems; iv. relation with the neighbouring urban system; v. new-insertion species selection criteria, in coherence with the current and dynamic agri-environmental context ecological status; vi. design solutions, interventions and management conditions for new coenoses insertion and establishment through time (Chiaffarelli and Vagge, 2020; Chiaffarelli and Vagge, 2021). A multiple set of intervention strategies was designed, in relation to the following agri-environmental sub-systems: 1. in-between fields linear landscape features; 2. riparian features; 3. woody components; 4. marginal belts

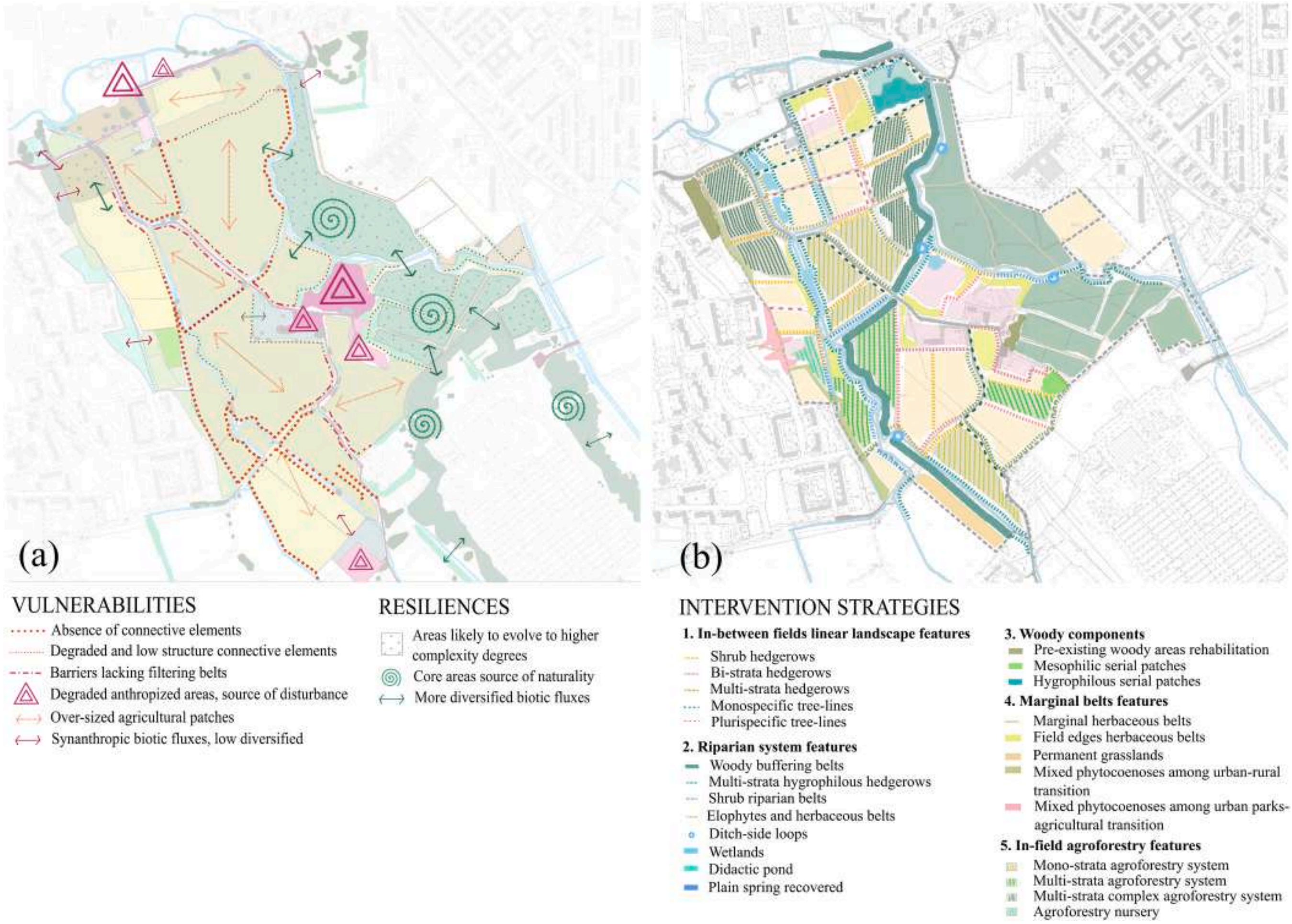

Fig. 8. (a) Synthesis map representing the vulnerability and resilience properties of the local scale ecological landscape system; (b) the multiple set of intervention strategies, grouped in 5 main agri-environmental sub-systems: 1. in-between fields linear landscape features; 2. riparian features; 3. woody components; 4. marginal belts features; 5. in-field agroforestry features.

features; 5. in-field agroforestry features (Fig. 8 B). Further functional qualitative evaluations on the multi-functional overall agroecological reconfiguring resulting from the here-presented analytical and interpretative approach were already described by the authors (Chiaffarelli and Vagge, 2020; Chiaffarelli and Vagge, 2021), illustrating the potential that this approach displays also for what concerns the showcasing of the attainable multi-functional benefits, in the Ecosystem Services perspective. Supplementary materials (Table S1) report some examples on design modules for the different intervention categories (1.; 2.; 3.), detailing the auto-ecological, physiological (Domina et al., 2018; Guarino et al., 2012; FloraItaliaeActaPlantarum, 2022) and dynamic traits (Blasi, 2010; FloraItaliaeActaPlantarum, 2022; Prodromo della Vegetazione Italiana, 2022; Verde et al., 2010) which oriented the selection of the species, their planting patterns [in some cases, re-adapting pre-existing experiences (Carchidi et al., 2001; Sartori, 1992; Sartori and Gallinaro, 2005)] and the targeting of their different expected major functions and dynamic roles, in coherence with the here-presented analytical results and with the here-outlined intervention approach [see Supplementary materials (Table S1)].

4. Conclusions

This study gives an example on how floristic-vegetational and landscape ecology studies can usefully inform the multi-functional phytocoenoses ecological reconfiguring of peri-urban rural areas, deepening the understanding of their ecological behaviour by taking into account their multi-scale ecological and dynamic functional traits. Such a perspective should be considered when intervening on highly disturbed and fragmented contexts. Indeed, the high impairment level of the agri-environmental matrices easily compromises the ecological effectiveness of requalification interventions. The adopted approach is aligned with some recent experiences in Italian urban territorial planning strategies, favouring multi-scale and multi-disciplinary assessment and intervention tools and strategies, where the structural and functional ecological patterns of the urban landscape system are considered and synthetized into vulnerability and resilience properties analyses (Bisogni et al., 2017; Gibelli et al., 2021a; Gibelli and Pinto, 2004). In detail, our study brings some reference analytical experiences for locally implementing urban planning strategies.

Landscape ecological featuring helped us in understanding the current impairment level of the landscape system capacity to support ecological functions across the study area. The following critical traits have been highlighted: low developed connectivity functions (degraded, discontinuous and low structured ecological corridor components); low presence of stable source areas (predominance of low developed instable source contexts); spread sink areas (over-sized fields, isolated low quality semi-natural components); under-expressed buffering functions towards the impacts coming from the urban matrix. In line with other experiences (Vagge and Chiaffarelli, 2023), a more detailed quantitative analysis on landscape indices (shape, heterogeneity and functional spatial configuration) would increase the informative potential of the landscape scale evaluation, also allowing to perform quantitative comparative analyses on current and transformation scenarios (Dal Borgo et al., 2023).

Similarly, floristic-vegetational analyses results were pivotal in interpreting the current phytocoenoses ecological and dynamic traits, and their consequent impairment level if compared to the local potential. The detected flora highlights the positive role of past reforestation interventions (lower invasive alien species rates, more stable conditions), showing how current spontaneous recolonization trends are dominated by substitution series dynamics (low maturity and stability levels), which are related to lower diversity values. In particular, trees and shrubs spontaneous phytocoenoses are highly depleted and degraded (highest invasive alien species values, discontinuous structure, often under alternate regressive and progressive trends which preclude these phytocoenoses to further evolve) and have been identified as key eco-topes for corrective interventions. Moreover, the auto-ecological traits of the detected flora bring key information on the environmental conditions that are currently facilitating alien species competition against the indigenous ones [open air conditions (higher temperature and light levels) of frequently perturbed and instable contexts promoting immature, low structured and low developed coenoses (lower soil nutrients levels)]. These issues should be addressed through corrective interventions design, by focusing on the adjustment of the ecological niches characters. To this aim, vegetational quantitative data (phytosociological surveys), representing the effective relative coverage of species, could bring further useful information for a coherent ecological interpretation of current phytocoenoses traits (weighted biological spectrums and ecograms). Moreover, the application of an equivalent analytical approach in post-intervention conditions could positively broaden the understanding of the ecological processes under study.

Multi-level landscape ecology and floristic vegetational approaches were a useful approach for delivering highly informative, synthetic and consistent ecological information, suitable for building models for design and monitoring protocols set up.

The obtained results could be a useful reference both for local public authorities (examples on how to coherently implement urban planning strategies, synthetizing the local and extra-local obtainable benefits) and local organizations and agricultural enterprises (detailed examples on how to coherently implement PLFs among the urban-rural interface, reducing ecological failures). Our approach might preferably be applied to strategic priority areas (as identified by planning tools, like the here-presented study area), to optimise assessment efforts versus the obtainable improvements. To summarize, the here-presented functional-dynamic interpretative approach could be a suitable reference tool for handling the multi-faceted peculiar vulnerabilities of peri-urban rural contexts, and driving them towards coherent and effective rehabilitating scenarios. The here-presented examples on targeted interventions may serve as design guidelines for implementing urban planning strategies and as a model to be adapted and replicated in other pedo-climatic contexts.

Finally, the performance of our approach is improved by the scheduled link between the assessment of the PLFs ecological functions and the ongoing evaluation of the cultural functions that PLFs might underpin (Fig. 1) (Dal Borgo et al., 2023). This could further deploy the positive and long-lasting effects of such science-based rehabilitating interventions, connecting multiple stakeholders needs. This also enables a direct interface with the Ecosystem Services assessment approach, which could be a useful tool to summarize assessment results and orient the coherent implementation of urban planning strategies, as well as the development of new metropolitan planning tools.

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CRediT authorship contribution statement

Vagge Ilda: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – review &editing. **Chiaffarelli Gemma:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources; Software; Validation; Visualization, Writing – original draft, Writing – review &editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2023.128002.

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