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Assessing social-ecological connectivity of agricultural landscapes in Spain: Resilience implications amid agricultural intensification trends and urbanization

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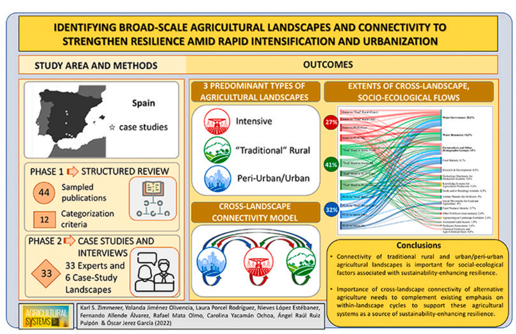
HIGHLIGHTS

- Global agricultural changes require innovative landscape and spatial approaches for resilient connectivity/networks
- The study identified three broad-scale agricultural landscapes in Spain: intensive, traditional rural, and peri-urban/urban
- Case studies showed connectivity variation among clusters of bipartite landscape interactions and social-ecological factors
- Landscape-level connectivity expanded the capacities of alternative agriculture for sustainability-enhancing resilience
- Adaptive multi-scale, cross-landscape connectivity benefitted alternative agriculture amid accelerating global changes

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Accelerated intensification/disintensification and urbanization are changing agricultural systems and propel the need for spatial approaches to understand sustainability-enhancing resilience. Landscapes are key to this understanding though little is known of the broad-scale, cross-landscape connectivity of social-ecological factors amid changing agricultural systems.

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Cross-landscape networks
Agricultural resilience
Agricultural changes
Cross-scale adaptive capacity

OBJECTIVE: This study's goals are to identify broad-scale types of agricultural landscapes in Spain that are associated with intensification/disintensification and urbanization and then to use case studies to assess the types and extent of cross-landscape connectivity. It examines the social-ecological connectivity of environmental resources, resource users, and governance. The overarching purpose is to improve the understanding of social-ecological connectivity in strengthening the sustainability-enhancing resilience of agricultural landscapes amid global agri-food changes.
METHODS: To pursue these goals, we conducted a structured literature review of publications to identify major types of agricultural landscapes in Spain that reflect intensification/disintensification and urbanization trends. Case studies of agricultural landscapes and connectivity were undertaken in the Madrid and Granada regions. These case studies used a structured interview with experienced professional experts in fields of social-ecological sustainability and agricultural landscapes in each region. Analyses including Latent Block Modelling were applied to interview results on types and extent of cross-landscape connectivity in both conventional and alternative agriculture.
RESULTS and CONCLUSIONS: The structured literature review identified the predominance of three types of broad-scale agricultural landscapes in Spain: intensive, "traditional" rural, and peri-urban/urban. Analysis of case-study results revealed variation of the extent and structure of connectivity among clusters of landscape interactions and social-ecological factors. Landscape-level connectivity created both negative agricultural impacts (e.g., extensive water transfers and nutrient pollution in conventional agriculture) and positive impacts (e.g., knowledge system and seed exchanges in alternative agriculture). Interactions of alternative agricultural systems in peri-urban/urban and "traditional" rural landscapes have benefitted from cross-landscape connectivity amid accelerated agricultural change.
SIGNIFICANCE: Research and policy on the landscape-level connectivity of agricultural systems are needed to strengthen sustainability-enhancing resilience of both conventional and alternative agriculture. This study's approach and results are a strategic complement to existing emphasis on within-landscape cycles of social-ecological factors in alternative agriculture. This study's insights are important in the transition phases of alternative agriculture and associated food systems amid changes due to agricultural intensification/disintensification and urbanization. Understanding selective cross-landscape connectivity is important for spatial approaches to strengthen the sustainability-enhancing resilience of agricultural systems.

1. Introduction

Intensification and urbanization pose accelerating global challenges in agriculture and food systems (Meyfroidt et al., 2018; Vanbergen et al., 2020). These challenges include global climate changes (Rosenzweig et al., 2020; Willett et al., 2019), threats to the biodiversity of agriculture and food systems (Zimmerer et al., 2019), and human dietary and nutrition transitions (Bach-Faig et al., 2011; Moragues-Faus, 2016). A high priority for research and policy is to understand the relations of agricultural systems to global-change dynamics of both agricultural intensification (Rockström et al., 2017; Scherer et al., 2018; Tittonell, 2020) and urbanization (Seto and Ramankutty, 2016; Zimmerer et al., 2021a, 2021b). This pair of predominant global-change processes powerfully influence the environmental and social parameters of agricultural systems and the prospects for sustainability and resilience.

Agricultural landscapes are a key spatial dimension of the potential for sustainability-enhancing resilience that refers to the "capacity….to continue in a qualitatively similar state controlled by a given set of processes [and] ability to provision desired outcomes" (with sustainability a principal desired outcome; Bennett et al., 2021: 5). Connectivity of agricultural landscapes often incurs negative spatial externalities (Blesh and Wolf, 2014). These environmental and socioeconomic damages reduce resilience. In other cases, the resilience of agricultural landscapes depends positively on the connectivity of social-ecological networks (Jennings et al., 2020; Lewis et al., 2008). These networks are comprised of environmental resources, resource-user populations, and governance (Partelow, 2018: 2). Social-ecological networks strengthening agricultural resilience includes corridor-type connectivity of resource movement and management, knowledge sharing, and cross-scale adaptive governance (Barnes et al., 2017; Beilin et al., 2013; Boudet et al., 2020; Bruce et al., 2021; Tittonell, 2020).

This study is focused on the social-ecological connectivity of agricultural landscapes that are impacted by intensification/disintensification trends and peri-urban/urban expansion. Intensification and disintensification are defined as agricultural production inputs and/or outputs per land area that are either increasing (intensification) or decreasing (disintensification) (Meyfroidt et al., 2018). Disintensification is characteristic of many "traditional" agricultural landscapes (Plieninger et al., 2018). This study's first goal is to identify and characterize broad-scale agricultural landscapes being influenced by current intensification/disintensification and peri-urban/urban expansion. The second goal is to assess the types and extent of social-ecological connectivity occurring between agricultural landscapes. The overarching purpose is to improve the understanding of social-ecological connectivity that influences the sustainability-enhancing resilience of agricultural landscapes amid accelerating changes.

Spain is representative of European and Mediterranean trends of agri-food changes fueled by combined intensification/disintensification and urbanization (Levers et al., 2018; Malek and Verburg, 2017; Soulard et al., 2018; Stellmes et al., 2013; Voltz et al., 2018). Both agricultural intensification and disintensification are expanding widely and have become globally common trends (Meyfroidt et al., 2018). Similarly, globally expanding urban and peri-urban areas and populations are estimated to grow by 25% or more by the end of the century (UN Habitat, 2020; Zimmerer et al., 2021a). Strengthening agricultural resilience amid these challenges requires developing alternative agriculture (Bennett et al., 2021), agroecological transitions (Tittonell, 2020), sustainable intensification (Rockström et al., 2017) and food systems (Willett et al., 2019).

This study first develops a conceptual approach to landscape-level agricultural systems and social-ecological connectivity influenced by combined intensification/ disintensification and urbanization (Conceptual Approach). Next, it utilizes a structured literature review to identify broad-scale agricultural landscapes in Spain and to guide case studies of social-ecological connectivity between landscapes (Methods). The analytical literature review identifies and validates three major types of agricultural landscapes that were then used to select case-study sites (Results, 4.1–4.2). Next, results of the case studies of social-ecological connectivity are analyzed (Results, 4.3–4.4). Discussion is focused on the roles of cross-landscape connectivity in agricultural systems. These insights focus on (1) structure of landscape connectivity amid major agricultural changes; (2) connectivity in conventional and alternative agriculture; and (3) connectivity of alternative agriculture between "traditional" rural and urban/peri-urban landscapes. Major findings and significance are distilled in the Conclusion.

2. Concepts: Agricultural landscape characteristics, connectivity, and resilience

This study treats agricultural landscapes as multi-functional spatial units centered on agricultural production systems and surrounding environments (Bennett et al., 2021; Fischer et al., 2006; García-Martín et al., 2016). Using this concept, landscape characteristics are linked to changes of: (1) intensification (Levers et al., 2018; Malek and Verburg, 2017; Stellmes et al., 2013; Plieninger et al., 2016; Vanbergen et al., 2020); (2) disintensification or stagnation of "traditional" agricultural landscapes including partial-to-full abandonment and extensification of low-intensity production (Jiménez Olivencia et al., 2015; Muñoz-Ulecia et al., 2021; Plieninger et al., 2018); and (3) expanding urbanization in food systems, markets, and expanding urban and peri-urban areas influencing agricultural production (Soulard et al., 2018; Voltz et al., 2018; Zimmerer et al., 2021a, 2021b).

Social-ecological characteristics of agricultural landscapes correspond to three principal, process-based domains: environmental resource use and production systems, agricultural producers and other actors (including knowledge systems of demographic groups), and agri-food governance including sociocultural and economic organization involving both markets and non-market activities (Partelow, 2018). Although the impacts of current agricultural intensification/disintensification and peri-urban/urban expansion are widely studied, research to-date has not characterized the social-ecological connectivity of changing landscapes and agricultural systems (Tello and González de Molina, 2017).

Connectivity of social-ecological elements of agricultural landscapes consists of cross-landscape movements that comprise a network structure (sense of Janssen et al., 2006). In agricultural landscapes, connectivity often creates negative environmental, economic, and social impacts such as damaging nutrient pollution and agrochemical contamination (Blesh and Wolf, 2014; Lewis et al., 2008), as well as harmful pest and disease movements (Margosian et al., 2009). Conversely, connectivity can confer benefits to sustainability-enhancing resilience through biotic movements such as corridors crossing agricultural landscapes (e.g., movements of crop pollinators, beneficial insects, and wild agrobiodiversity in hedgerow habitats; Boudet et al., 2020; Dindaroglu, 2021; Jennings et al., 2020; Sahraoui et al., 2021). Other beneficial cross-landscape networks are multi-farmer livestock movements (Nicholson et al., 2001), seed exchanges (Labeyrie et al., 2016), and information sharing (Nelson et al., 2014). Further examples are the spatial movements and patterns of conservation networks of key social actors across space and time (Guerrero et al., 2013). Kinship networks, such as clans that link connectivity-producing social networks to forest patches, also can support sustainability-enhancing resilience (Bodin and Tengö, 2012). In sum, social-ecological connectivity benefitting sustainability-enhancing resilience can arise from networks that are: (1) explicitly social-ecological (Bodin and Tengö, 2012; Felipe-Lucia et al., 2021; Janssen et al., 2006); (2) principally ecological (see above); and (3) primarily social network-based (Beilin et al., 2013; Bruce et al., 2021; Isaac, 2012; Labeyrie et al., 2016; Rockenbauch and Sakdapolrak, 2017).

This study's approach incorporates a triad of key insights to guide the social-ecological characterization of connectivity in agricultural landscapes. The first insight is to focus on the connectivity of agricultural processes per se (such as irrigation, soil nutrient, and seed flows as well as farm labor and agri-food governance; Bennett et al., 2021; Huttunen, 2019; Zimmerer, 2010). Second, this study utilizes the concept of broad-scale, coarse-grain agricultural landscapes. It complements distinct approaches that emphasize individual fine-grain landscapes (Mata Olmo and Sanz Herráiz, 2004; Zoido Naranjo and Jiménez Olivencia, 2015), remote-sensing characterization (Malek and Verburg, 2017; Stellmes et al., 2013), and gradient-style continua (Arnaiz-Schmitz et al., 2018; Shaw et al., 2020).

Third, this study's focus on the resilience of agricultural landscapes uses the quoted definition above to identify potentially supportive social-ecological capacities of networked functions (Bennett et al., 2021). These include: (1) social-ecological connectivity such as seed networks that strengthen the structural complexity of agricultural landscapes; (2) heterogeneity and gradients in agricultural landscapes such as sustainability managed crop fertilization and nutrient management; (3) corridors of connecting habitats such as pollinator corridors; (4) diversity and complementarity within and between crop and livestock systems such as agrobiodiversity; and (5) resource management capable of spatial complexity for "pattern-oriented management strategies" (Fischer et al., 2006: 81). These social-ecological connectivity functions support landscape spatial capacities associated with sustainability-enhancing resilience. By contrast, the absence, reduction, and low levels of such processes tend to reinforce and extend spatial and social-ecological uniformity, thus reducing resilience.

Finally, the goal of strengthening local flows of nutrients, water, energy, and other inputs in alternative agricultural systems differ from the frequently damaging connectivities of intensive, industrial agriculture. The cross-landscape connectivities of intensive industrial farming often represent harmful externalities as described above. Certain other forms of landscape connectivity can contribute to sustainability-enhancing resilience of alternative agriculture (Hedberg, 2020; Lewis et al., 2008; Sundkvist et al., 2005). This is important due to interest in cross-scale adaptive capacity to support sustainability-enhancing resilience through alternative agriculture, agroecological, and local-food initiatives (Jennings et al., 2020; Kremen and Merenlender, 2018).

This study examines the connectivity of both conventional and alternative agriculture in Spain. Conventional agriculture in Spain ranges from industrial, corporate systems to smallholder family farms. Examples of alternative agriculture are organic, certificated geographic production, "ecological agriculture", and local-food initiatives that are important in Spain and elsewhere in Europe (Bowen and Mutersbaugh, 2014). Both alternative and conventional agriculture are influenced by global processes of intensification/disintensification and urbanization (Wezel et al., 2018). Research also has demonstrated common intermediate forms between conventional and alternative agriculture (Carolan, 2018; Marsden and Sonnino, 2012; Shellabarger et al., 2019). Inter-related dynamics and continuaa of conventional and alternative agriculture suggest the need for new research that considers both of these broad categories of farming systems.

3. Research methods and materials

This study utilized a mixed-method, two-phase approach to research (Lacoste et al., 2017). It combined a structured literature review to identify broad-scale types of agricultural landscapes followed by case studies of social-ecological connectivity. "Characterizing systems" and then "identifying relationships" based on multi-criteria assessment is a common design in broad-scale agricultural research (Lacoste et al., 2017).

The structured literature review designated 12 widely used indicators of intensification/disintensification and urbanization in broad-scale agricultural landscapes (Table 1). Each indicator was designed for

Table 1
Indicators, Descriptions, and Range of Agricultural Intensification (rows 1–6) and Urbanization (rows 7–12) Used in the Structured Literature Review.

Indicator and Description	Explanation of Range of Estimates (1–5)	References
1. Frequency and Magnitude of High-Intensity Agriculture	1 = uncommon; 2 = occurs regularly but low frequency; 3 = common or moderate occurrence; 4 = highly common; 5 = continuous high-intensity agriculture	Arnaiz-Schmitz et al., 2018; Hammond et al., 2021; Levers et al., 2018; Malek and Verburg, 2017; Meyfroidt et al., 2018; Stellmes et al., 2013
2. Mechanization Level (farm machinery)	1 = low, mainly animal power and hand tools; 2 = mixed non-mechanized and small-scale mechanization; 3 = moderate level of mechanization; 4 = highly mechanization; 5 = highly mechanized with digital systems	Arnaiz-Schmitz et al., 2018; Hammond et al., 2021; Levers et al., 2018; Malek and Verburg, 2017; Meyfroidt et al., 2018; Stellmes et al., 2013
3. Purchased Seed and Breeding Inputs	1 = entirely seed-saving and exchange; 2 = mainly seed-saving and exchange with some purchased inputs; 3 = most inputs purchased; 4 = entirely purchased inputs; 5 = entirely purchased inputs through seed and livestock dealers	Hammond et al., 2021; Lázaro et al., 2013; Levers et al., 2018; Malek and Verburg, 2017; Meyfroidt et al., 2018; Stellmes et al., 2013
4. Water Resource Management	1 = irrigation absent uncommon; 2 = irrigation restricted, only local; 3 = irrigation moderately common; 4 = irrigation highly common; 5 = irrigation approaches universal or nearly, use digital technologies	Arnaiz-Schmitz et al., 2018; Hammond et al., 2021; Levers et al., 2018; Malek and Verburg, 2017; Meyfroidt et al., 2018; Stellmes et al., 2013
5. Labor Intensity of Agriculture	1 = low level or extensive production; 2 = combined extensive and moderate-intensity; 3 = predominantly or entirely moderate intensity; 4 = predominantly high-intensity; 5 = entirely high intensity	Arnaiz-Schmitz et al., 2018; Hammond et al., 2021; Levers et al., 2018; Malek and Verburg, 2017; Meyfroidt et al., 2018; Stellmes et al., 2013
6. Land Value	1 = low; 2 = low-medium; 3 = medium; 4 = medium-high; 5 = high	Arnaiz-Schmitz et al., 2018; Hammond et al., 2021; Levers et al., 2018; Malek and Verburg, 2017; Meyfroidt et al., 2018; Stellmes et al., 2013
7. Distance to Major Urban Area (estimated distance to urban core)	1 > 160 km; 2 > 80 km; 3 > 40 km; 4 > 20 km; 5 < 20 km (Distance to Intermediate Urban Areas of 250,000–500,000 persons: 1 > 80 km; 2 > 40 km; 3 > 20 km; 4 > 10 km; 5 < 10 km of urban area)	Gonçalves et al., 2017; Pérez-Campaña et al., 2011; Shaw et al., 2020; Soulard et al., 2018; Yacamán Ochoa et al., 2019
8. Economic Linkages to Urban/Peri-Urban	1 = low level of linkages; 2 = low-moderate linkages; 3 = intermediate linkages; 4 = moderate-high linkages; 5 = highly linked to urban and peri-urban	Gonçalves et al., 2017; Pérez-Campaña et al., 2011; Shaw et al., 2020; Soulard et al., 2018; Yacamán et al. 2019; Wiskerke, 2015
9. Transportation Linkages to Urban Area	1 = low density of transportation network and ties to urban and peri-urban; 2 = low-moderate linkages; 3 = intermediate linkages; 4 = moderate-high linkages; 5 = highly linked to peri-urban and urban	Gonçalves et al., 2017; Pérez-Campaña et al., 2011;Shaw et al., 2020; Soulard et al., 2018; Yacamán Ochoa et al., 2019; Wiskerke, 2015
10. Socio-Cultural Influence	1 = lowest level of urban socio-cultural influence; strongest rural identity; 2 = low-moderate urban socio-cultural influence; 3 = intermediate urban socio-cultural influence; 4 = moderate-high urban socio-cultural influence; 5 = high level of urban socio-cultural influence	Gonçalves et al., 2017; Pérez-Campaña et al., 2011; Shaw et al., 2020; Soulard et al., 2018; Yacamán Ochoa et al., 2019; Wiskerke, 2015
11. Governance and Administrative Processes	1 = low presence of urban-source governance and administration; highest level of rural-centered governance and administration; 2 = low-moderate; 3 = intermediate; 4 = moderate-high; 5 = high level of the presence of processes tied to urban-based governance and administration	Gonçalves et al., 2017; Pérez-Campaña et al., 2011; Shaw et al., 2020; Soulard et al., 2018; Yacamán Ochoa et al., 2019; Wiskerke, 2015
12. Demographic and Infrastructure Density	1 = low demographic and infrastructure density; 2 = low-moderate density; 3 = intermediate density; 4 = moderate-high density; 5 = high density	Gonçalves et al., 2017; Pérez-Campaña et al., 2011; Shaw et al., 2020; Soulard et al., 2018; Yacamán Ochoa et al., 2019; Wiskerke, 2015

scoring on a 1.0–5.0 scale. Threshold values were identified where possible to guide scoring values.[2] Indicators were chosen to create composite indices as the mean values of the intensification/ dis-intensification indicators (rows 1–6; Agricultural Intensification, AGINT Index) and urbanization (rows 7–12, Urbanization Influence, URBIN Index). Significance to each index was used to justify the aggregation of indicators in a composite (Gómez-Limón and Sanchez-Fernandez, 2010).

Table 1 approximately here (currently placed at end of this file).

This study applied the scoring design described above to a sample of publications that were compiled using relevant search terms in Google Scholar ("agriculture intensification urbanization sustainability Spain landscape") and explicit criteria for inclusion/exclusion that included the publication period of 2005–2018 (Table A1.1). Once the sample was assembled and scored (see Results), we applied independent statistical means and K Means Cluster Analysis to categorize publications. The optimal number of clusters of publications was determined by statistical significance and correspondence to levels of agricultural intensity and peri-urban/urban linkages. Verification was then applied using independent sources of information on landscape categorization in Spain. It examined spatial co-occurrence based on field-based categorization (Mata Olmo and Sanz Herráiz, 2004) and remote-sensing classification (Malek and Verburg, 2017). Validation rates were estimated using both these sources. Characterization thus used multiple data-based methods to categorize and verify broad-scale types of agricultural landscapes.

Methods to estimate social-ecological connectivity began with the

[2] Threshold values were identified in regard to extremely common High-Intensity Agricultural Systems (Indicator 1, 4≥ 2000 m2 /km2); moderate levels of farm machinery (Indicator 2, 4 = 5.0 or more tractors or similar elements of medium- and large-scale farm equipment/ km2); water resource management (Indicator 4, 3≥ 20% agricultural land under irrigation); land value (Indicator 6, 4 = majority of land in highest two quintiles; distance to urban area (indicator 7); road density linked to adjoining urban area > 500 m/ square km (indicator 9); and population density > 1100 persons/square km (indicator 12).

selection of regions well suited to containing agricultural landscape types that could serve as case studies. Regional sites were considered in central and southeastern Spain to complement existing concentration of landscape-level research on agricultural systems in Barcelona, Murcia, and Sevilla.[3] Following the results on regional-site selection (see Results 4.2), expert interviews were used to investigate the connectivity of social-ecological factors among the case-study agricultural landscape types. Expert interviews used a structured design that drew on widespread use of this technique in ecosystem and landscape research (Holland et al., 2017; Jacobs et al., 2015).

Expert interviewees represented four groups of stakeholder professions: planners and managers in government institutions and NGOs (12 interviews), scientists and academics (6 interviews), farmers and farmer-organization representatives (6 interviews), and agricultural sustainability and food movement leaders, practitioners, and activists (6 interviews). Design of the interview sample to represent these four groups of stakeholder professions reflects awareness that the social-ecological connectivity of agricultural landscapes needs to be understood through the combination of planning and management (Jennings et al., 2020), scientific and academic insights (Bennett et al., 2021), processes of "worked landscapes" (Kremen and Merenlender, 2018), and social goals and aspirations (Darnhofer, 2021). Larger size of the first group of stakeholder interviewees (planners and managers) reflected its prominence in landscape-level initiatives and policy on agricultural systems in Spain.

Interviewees with stakeholder experts were carefully chosen to provide active, professional expertise in social-ecological facets of agricultural landscapes that included sustainability (Table A2.1). Each stakeholder expert possessed extensive training and professional experience with at least 10 years of employment in one of the study regions (Table A2.1). Expert interviewees were all knowledgeable about the in-practice conditions and interaction contexts of agricultural landscapes, as well as about both conventional and alternative agriculture. The principal domains of social-ecological connectivity (environmental resources, resource users, and governance) are recognized as important to each profession contained in the interview sample.

The interviewees were recruited as a snowball sample through professional networks in each study region. The utilization of multiple professional networks and the upper limit of two interviews per network minimized possible sampling bias. A total of 30 interviews ($n = 15$ interviewees/region) were conducted by the lead author and co-authors in May–July 2017 and 2018 and then analyzed in May–July 2019. In sum, the capacity of interviewees to estimate accurately the types and extents of the flows of environmental resources, resource users, and governance was ensured by the above-specified criteria: (1) representative types of professional expertise in social-ecological functions and interaction contexts of agricultural landscapes; (2) extensive experience including practical in-the-field knowledge of multiple types and interaction contexts of agricultural landscapes; and (3) combined professional training and experience focused on the social-ecological conditions and interaction contexts of agricultural landscapes.

Interview notes were taken, and transcriptions of recordings analyzed in the RQDA qualitative data analysis package (Huang, 2016). Coding focused on interviewees' responses to semi-structured questions (Table A3.1) asking them to describe social-ecological "flows" of resources, resource users, and governance that occur between the broad-scale agricultural landscapes identified in their region (Results in 4.2). Occurrences of connectivity were counted only if the interview included a corresponding example. Treating these occurrences as count data is common in qualitative research (Campbell et al., 2013; Miles et al., 2014) and was consistent with interview design.

This count data characterized the extent of social-ecological connectivity (rather than magnitude). The real-world relevance of count data was ensured through the requirement of an example in each counted occurrence. Mean values of counted occurrences were estimated. Each counted description of cross-landscape connectivity included information on landscape and agriculture types, direction of flow, and social-ecological factors. Results in this study on cross-landscape connectivity refer to statistically significant differences (chi-square, $p < .05$) of count-based occurrences unless noted.

Latent Block Modelling (LBM) was used for the purpose of examining the structure of connectivity involving bipartite agricultural landscape interactions (between landscape pairs) combined with social-ecological factors (domains of environmental resources, resource users, and governance). LBM principles assume a mixture distribution on both the rows and columns (Keribin et al., 2015), which enables simultaneous clustering based on the incidence matrix. LBM methods are well suited because they can be applied to clustering of landscape-pair interactions (rows) and social-ecological factors (columns). LBM reveals connectivity-based clusters of landscape pairs and social-ecological factors. The numbers of LBM-derived clusters or "blocks" were determined by the maximum value of the Integrated Conditional Likelihood function. LBM was programmed using version 4.2.1 of R and version 1.1.5 of the blockmodels package (Leger et al., 2021; R Core Team, 2022). These clusters provide insights into the structure of connectivity (on related analysis of interaction and network structures related to agricultural resilience and resources see Blazquez-Soriano and Ramos-Sandoval, 2022; Thomas et al., 2015).

4. Results

4.1. Identification of agricultural landscapes

Table 2
Estimates of Agricultural Intensification (1–6, left column) and Urbanization (7–12, left column) Applied to Reviewed Publication Corresponding to Three Broad-Scale Agricultural Landscapes (Urban/Peri-Urban, Intensive, "Traditional" Rural).

Indicator	peri-urban/ urban	intensive	traditional rural
1. Frequency of High-Intensity Agriculture	4.3	3.8	1.9
2. Mechanization Level (farm machinery)	3.6	4.3	1.7
3. Purchased Seed and Breeding Inputs	3.4	4.3	1.7
4. Level of Water Management	3.1	4.4	1.8
5. Labor Intensity	3.8	4.4	1.4
6. Land Value	3.9	3.9	2.1
7. Distance to Major Urban Area	5.0	2.7	2.2
8. Economic Linkages to Urban	4.5	2.5	2.1
9. Transportation Linkages to Urban Area	4.5	3.1	2.1
10. Socio-Cultural Influence of Urban	4.2	2.5	2.2
11. Governance and Administrative Linkages to Urban Areas	4.4	2.5	2.3
12. Demographic and Infrastructure Density	4.1	3.1	1.9
Agricultural Intensification Index (Indicators 1–6)	3.7	4.2	1.8
Urbanization Influence Index (Indicators 7–12)	4.4	2.7	2.1

Search results identified a sample of 39 publications containing landscape-specific descriptions suitable for scoring (Table A1.2). This sample yielded a total of 44 descriptions due to five publications with descriptions of more than one type of agricultural landscape. Independent statistical means (Table 2, Table A1.3). K Means Cluster Analysis (Fig. 1) identified three well-defined clusters corresponding to the following descriptors of agricultural landscapes: (1) intensive; (2)

[3] This evaluation of the geographic concentration of existing studies was based on the structured literature review (Table A1.2) and additional sources.

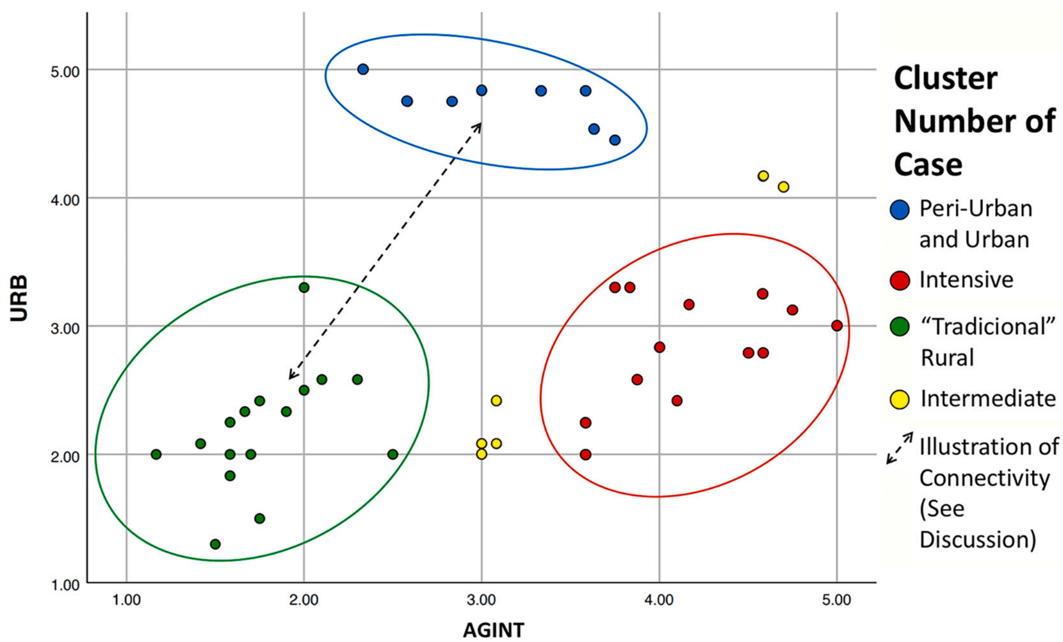

Fig. 1. Results of K Means Cluster Analysis of Published Descriptions of Agricultural Landscapes ($n = 44$) in Spain (publications in each cluster in bottom row of Table 2).

"traditional" rural; and (3) peri-urban/urban (Table 2).[4] Significant statistical differences occurred along both the AGINT and URBIN axes (Table A1.4; F = 75.290, $p < .001$ and F = 91.143, p < .001, respectively). Comparisons to independent information sources produced internal validation estimates of 97.8% and 73.3% (columns 5–9; Table A1.3).[5]

Table 2 approximately here (currently placed at end of this file).

The intensive agricultural landscape was defined by 13 published descriptions exceeding the AGINT threshold of 3.5 with several near-maximum values (red cluster, Fig. 1; Table 2; Table A1.3). Predominant agricultural systems were high-intensity crop and livestock production operations with specialized industrial mechanization, agribusiness-integrated supply and marketing chains for national and international markets, and, in some cases, elevated seasonal labor demands (vegetables and intensified grape and olive production) (Table 3, 2nd column). Large- and medium-scale ownership, including both individual and corporate, were characteristic. High levels of yield and technology, including advanced irrigation, distinguished intensive agricultural systems in this type of agricultural landscapes.[6]

Results characterized the traditional rural agricultural landscape (17 publications in green cluster of Fig. 1; Table 2; Table A1.3) as utilizing less-intensive production.

(AGINT <2.5). Predominant agricultural systems in this landscape combined cereal, legume, and vegetable and fruit crops with considerable livestock and tree production (Table 3, 3rd column). In addition, this agriculture was associated with land-system transitions incorporating agroforestry and agropastoral systems. Several publications in this cluster described alternative agricultural systems.

Table 3 approximately here (currently placed at end of this file).

Peri-urban/urban agricultural systems were represented by eight publications (blue cluster in Fig. 1; bottom row in Table 2, and Table A1.3). Their AGINT values ranged from 2.4 to 3.8, with lower values reflecting agricultural systems in disintensification transitions involving the local decline of farming. Higher AGINT values reflected local predominance of medium-size agricultural systems with moderate production and farm-labor intensity that included examples of peri-urban and urban agriculture as well as agrarian parks in Barcelona and Murcia (Table 3). All peri-urban/urban agricultural systems showed high Urbanization Influence values (URBIN >4.0, Table 1) through multiple indicators (Table 3, 4th column).

In sum, this study categorized 86% of published descriptions as either intensive, traditional rural, or peri-urban/urban agricultural landscapes (Fig. 1; Table 3). Six descriptions, or 14%, were intermediate in cluster-analysis results (yellow in Fig. 1). These included four intermediate descriptions with AGINT values near 3.0 indicating blended characteristics of traditional rural and intensive agricultural landscapes. Intermediate status also included two descriptions with characteristics combining intensive with peri-urban/ urban (URB > 4.0). Descriptions of each landscape type contained examples of both conventional and alternative agricultural systems.

4.2. Case-study landscapes and agricultural systems

Case-study landscapes of intensive, traditional rural, and peri-urban/urban landscapes were selected in the Madrid and Granada regions. This selection utilized the criteria defined in the previous section to select each landscape type in these regions (Table A2.2). Cartographic information (Fig. 2), visual documentation (Fig. 3), and 20-plus field visits by the authors (2017–19) verified that the case-study landscapes were representative of the broad-scale agricultural landscapes and systems identified above.

Specific agricultural systems of the case studies exemplified the characteristics of landscape types identified in the structured literature review (Section 4.1; Fig. 3). In intensive agricultural landscapes, the predominant systems were technologically intensive grape and olive production systems (*producción tecnificada*) in Castilla-La Mancha

[4] Initial quotation marks denoting "traditional" rural landscape were used to reflect the historical and ongoing prevalence of dynamic changes (rather than static customs) (Antrop and Van Eetvelde, 2017; Denevan, 2001; Doolittle, 2000; Renes, 2015). Subsequent usage of "traditional" does not utilize quotation marks.

[5] Methodological limitations of this technique include the unstated degrees of uncertainty in landscape identifications in the Mediterranean (Malek and Verburg, 2017).

[6] Specific examples of these agricultural systems are given below in Section 4.1.

Table 3
Characteristics of Predominant Production Systems in the Broad-Scale Agricultural Landscapes of Spain Identified in this Study.

	Intensive	Traditional rural	Peri-urban/urban
Production and Land Use	High-level specialization; Packaged fresh vegetables and fruit for national and export markets; livestock confined feeding operations; technified olive and grape	Range-based livestock (e.g., hog-acorn and cattle *dehesas*), tree crops (olives) and vineyards; cereals (wheat, barley) and pulses (beans, favas, garbanzos, lupines)	Fresh vegetable and fruits; cash crops (e.g., asparagus, maize; historically, tobacco, sugar beet); Transition to urban built environment
Value Chains	Supermarket retail; Vertical integration of processing. Sub-groups adopting certified organic.	Multi-scale; includes products with Protected Designation of Origin (PDO, see Table 3)	Agribusiness chains; Direct marketing (*canales cortos*); PDO (see Table 3)
Resource Inputs and Management	Intensive agrochemical inputs; sub-groups utilizing Integrated Pest Management (IPM)/ bioeconomy	Extensive resource management, includes diverse agrosilvopastoral and agroforestry systems	Moderately intensive manage-ment, includes conventional and alternative management
Irrigation	Varied, includes capital-intensive irrigation and water management (e.g., extensive drip irrigation; hydroponics)	Primarily rainfed, with range of irrigation, modern and traditional (e.g., walled-field *ruedos*)	Various irrigation technologies, including longtime and extensive canal systems near cities
Characteristic socio-economic processes	Labor- and capital intensive, including high level of dependence on immigrant labor; significant producer associations and cooperatives	High level of pluri-activity (livelihood diversification); moderate hired farmworkers; producer associations	Integrated with urban; pluri-livelihood diversification, land market competition, resident, immigrant farm labor
Technology	High level of mechanization	Low-intermediate mechanization	Varied mechanization
Alternative food system processes	Includes organic (as high as 10%) though minor overall (characterized as "weak ecological modernization")	Includes EU-supported integrated farming, organic farming, and protective territories (Table 3)	Distinct ecological production and social organization (direct urban consumer participation)
Corresponding publications[a]	1, 7, 10, 11, 12, 13, 17, 21, 22, 26, 29, 37, 40 (intermediate: 9, 15, 16, 25)	3, 4, 5, 6, 8, 14, 18, 20, 23, 27, 28, 36, 38, 39, 41, 42, 44	2, 19, 24, 30, 33, 34, 35, 43 (intermediate: 31, 32)

[a] Aznar-Sánchez et al., 2011 [1]; Bacon et al., 2012 [2]; Bernués et al., 2016 [3]; Campón-Cerro et al., 2014 [4]; Coq-Huelva et al., 2014 [5]; Correal et al., 2009 [6]; Egea et al., 2018 [7]; Escribano et al. 2016 [8]; Farah and Gómez-Ramos, 2014 [9]; Galán et al., 2016 [10]; Galdeano-Gómez et al., 2013 [11]; Galdeano-Gómez et al., 2016 [12]; García-Arias et al., 2015-case 1 [13]; García-Arias et al., 2015-case 2 [14]; García-Llorente et al. 2016 [15]; Gómez-Limón and Sanchez-Fernandez, 2010-case 1 [16]; Gómez-Limón and Sanchez-Fernandez, 2010-case 2 [17]; Guzmán et al., 2013 [18]; Guzmán Casado and González de Molina 2009 [19]; Hinojosa-Rodriguez et al., 2014 [20]; Irabien and Darton, 2016 [21]; Juntti and Downward, 2017 [22]; Lázaro et al., 2013 [23]; Martínez-Fernández et al., 2013 [24]; Moragues-Faus and Sonnino 2012 [25]; Padró et al., 2017-case 1 [26]; Padró et al., 2017-case 2 [27]; Palomo-Campesino et al., 2018 [28]; Pardo et al., 2017 [29]; Pedreño et al., 2015 [31]; Pedreño et al., 2014 [32]; Pili et al., 2017 [33]; Pinna, 2016 [34]; Pinna, 2017 [35]; Riesgo and Gallego-Ayala 2015-case 1 [36]; Riesgo and Gallego-Ayala 2015-case 2 [37]; Rigueiro-Rodríguez et al., 2009 [38]; Rodriguez-Cohard and Parras, 2011-case 1 [39]; Rodriguez-Cohard and Parras, 2011-case 2 [40]; Schaller et al., 2018 [41]; Swagemakers et al., 2011 [42]; Villace et al., 2014 [43]; Villanueva et al., 2015 [44]

(greater Madrid region) and high-intensity vegetable production (tomatoes, green peppers, cucumbers, squash) in the "greenhouse zone" (*zona de invernaderos*) of Las Dalias-Almería (greater Granada) (Fig. 2, Fig. 3a, d). Ownership and organization encompassed large corporate and medium-scale family-based enterprises. These agricultural systems were seasonally labor intensive and highly integrated in national and international markets (e.g., Castilla-La Mancha produces more than one half the wine grapes of Spain and most Las Dalias-Almería vegetable production is exported).

Predominant agricultural systems in the traditional rural landscape were the extensive production of rainfed crops, including tree crops (olives, walnut, figs) as well as cereal and legume crops (wheat, barley, fava bean, common bean) and livestock-raising (Fig. 3b, e). These agricultural systems were mixed with small and moderate-size areas of low-technology irrigation, principally for vegetable production. Livestock (cattle, pigs, sheep, goats) are extensively produced in rangelands and pasture areas that are important in the predominant agricultural systems of this landscape. These agricultural systems are primarily smallholder-based, with a minor admixture of corporate ownership. Specific examples described here pertained to both the Guadarrama area of greater Madrid and the Alpujarra area of greater Granada (Fig. 2). Production is predominantly for regional and national markets though some export is also integrated.

Peri-urban/urban agricultural systems varied between community agriculture (e.g., the Parque Agraria Fuenlabrada) and nationally and internationally integrated, high-value commercial production that also included short food-chain marketing (*canales cortos*). (Fig. 3c, f). These case-study landscapes were tightly integrated to Madrid and Granada, respectively (Fig. 2). Crops encompassed diverse vegetable production (e.g., export-oriented asparagus production in Granada and a locally unique lettuce variety in the Parque Fuenlabrada) as well as fodder (maize and alfalfa) for dairy operations and export. Irrigation was common in peri-urban agriculture. Mixed ownership of these agricultural systems ranged from family-owned to corporate enterprises. Technology and mechanization levels varied widely.

4.3. Estimated connectivity among case-study agricultural landscapes

Estimated connectivity among landscape pairs was first visualized by linking the mean counted inputs to corresponding landscape sources (Fig. 4) and by diagramming the extent of outputs among the twelve cross-landscape pairs (Fig. 5, left side) matched to type of social-ecological factor (Fig. 5, right side). Results of Latent Block.

Modelling (LBM) revealed two clusters (blocks) of the cross-landscape pairs and four clusters (blocks) of the social-ecological factors (Fig. 6). The final LBM result in Fig. 6 is derived from the detailed LBM cell-level heatmap displayed in Fig. A4.1. To evaluate connectivity results, the findings of these techniques are reported first for the landscape level and then for conventional and alternative agriculture.

Cross-landscape inputs to intensive agriculture comprised 41.3% of the total in-flow connectivity among landscape pairs. These input flows to intensive agriculture (categories 5, 6, 11, and 12, left side, Fig. 5) encompassed 15 of 16 types of specific social-ecological factors (Table 4; right side, Fig. 5). Water resources and water-governance influences were the largest inputs (Fig. 5; see also Table 4). Inputs to intensive agriculture showed LBM clusters for the flows from the peri-urban/urban landscapes (upper block, Fig. 6) and from the traditional rural landscapes (lower block, Fig. 6). Similarly, the inputs directed from intensive agriculture to the peri-urban/urban landscapes clustered in the lower rows and block of the LBM (Fig. 6) whereas flows to intensive

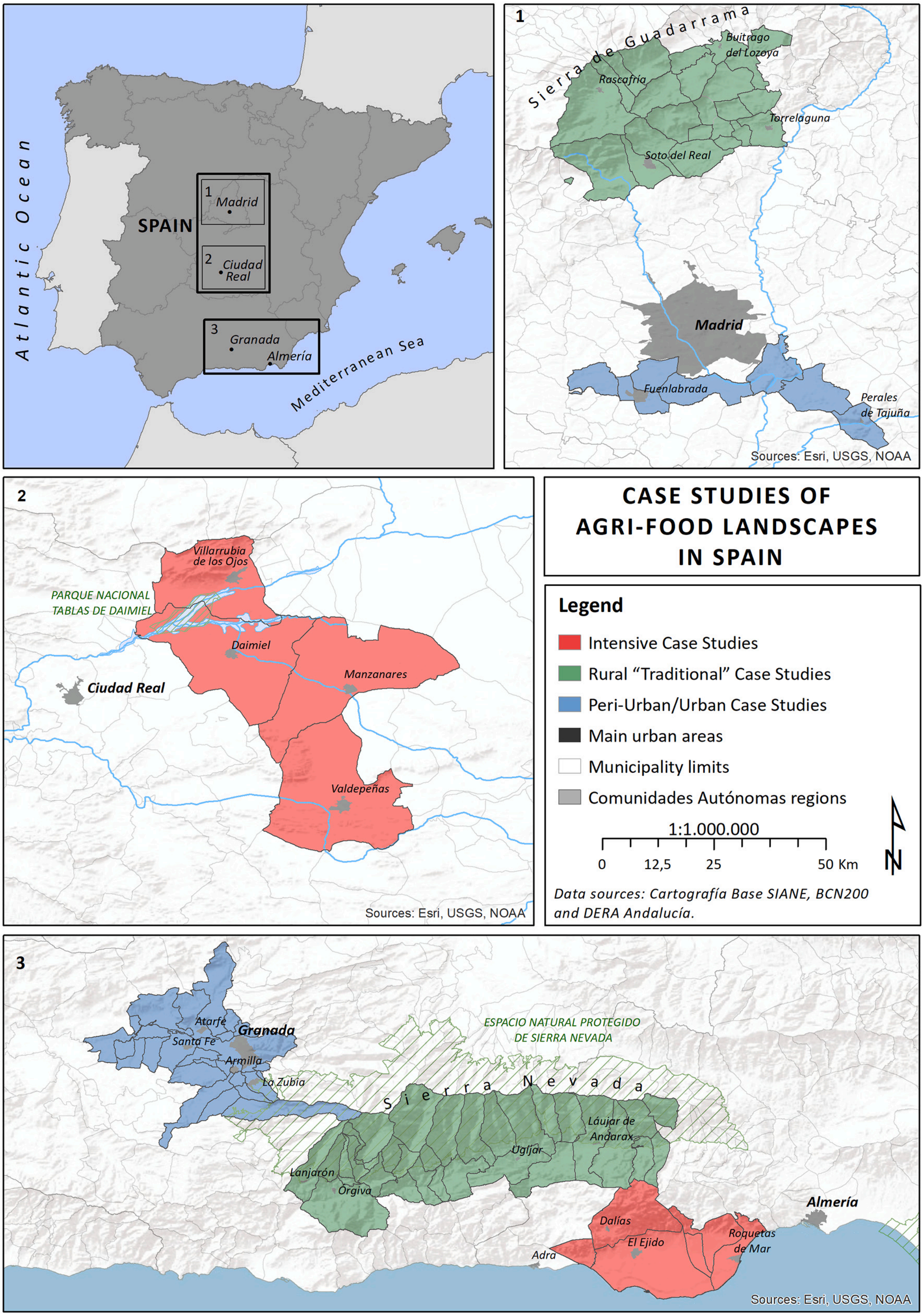

Fig. 2. Map of Case-Study Landscapes in Central and Southeastern Spain.

agriculture directed to the traditional rural landscapes clustered in the upper block (Fig. 6). This variation in the LBM clusters reflected contrasting patterns of cross-landscape connectivity associated with the input versus output factors of intensive agriculture.

Table 4 approximately here (currently placed at end of this file).

The traditional rural landscapes showed connectivity comprised of predominant outward-directed flows (green line of Fig. 4; green-shaded flows of Fig. 5). Estimated output flows from these landscapes accounted for 41.0% of the total outward-directed flows that were recorded (Fig. 5). LBM showed that the flows from traditional rural landscapes to

Fig. 3. Illustrations of the three broad-scale types of agricultural landscapes selected as case studies in the Greater Madrid Region (GMR) and Greater Granada Region (GGR) (clockwise from upper left): (a) intensive vineyard in global wine value chain (GMR) (b) traditional rural in S. de Guadarrama (GMR) (c) peri-urban/urban, Agrarian Park of Fuenlabrada (GMR) (d) intensive, agro-export vegetable production in greenhouse in Almeria (GGR) (e) traditional rural, crop cultivation in the Alpujarra (GGR), and (f) peri-urban/urban, asparagus in the Vega of Granada (GGR). These landscape types correspond to intensive (a, d), traditional rural (b, e), and peri-urban/urban (c, f).

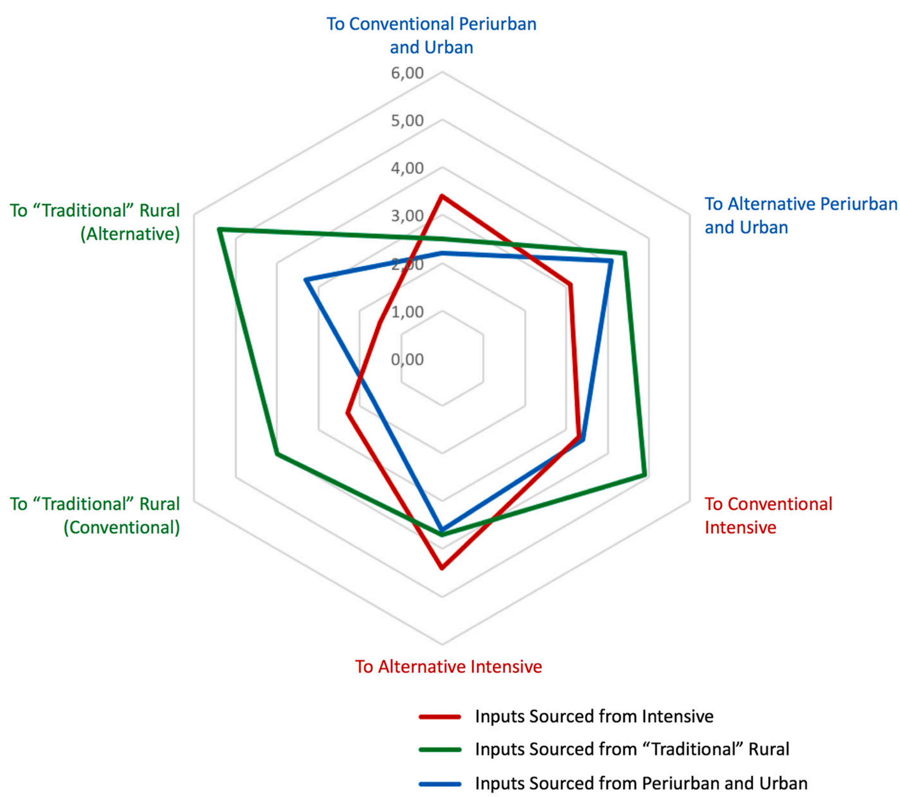

Fig. 4. Mean Numbers of Count Estimates of the Cross-Landscape Flows in Case Studies (Expert Interview Results).

both peri-urban/urban and intensive-agriculture areas were clustered in the upper block (Fig. 6). In addition to water resources (Factor 14 in Fig. 6), these out-flows encompassed a range of agricultural inputs (Factors 1–10). The LBM showed that the flows toward traditional rural landscapes are clustered in the lower block (Fig. 6). The inputs to traditional rural landscapes were exemplified by the comparatively high

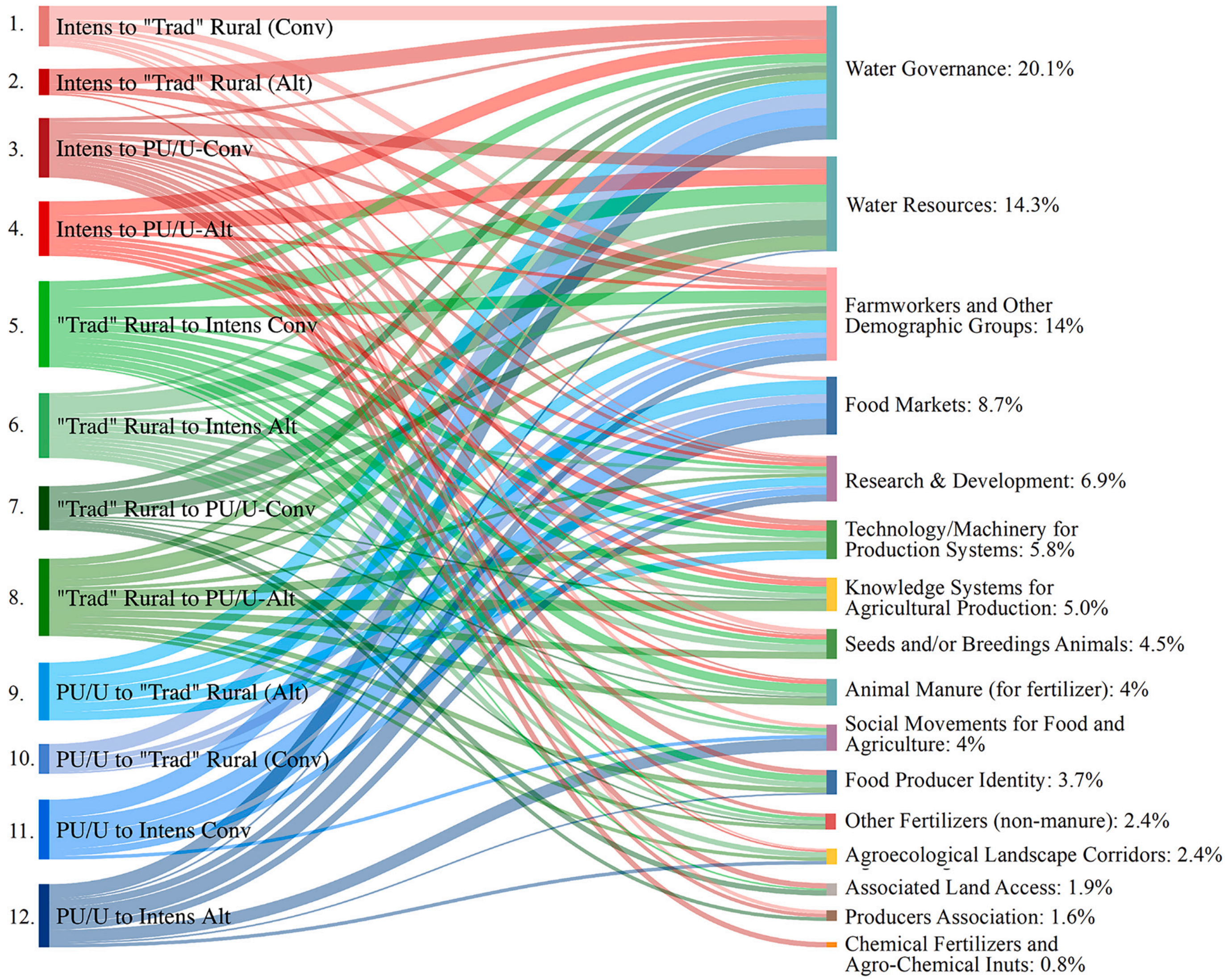

Fig. 5. Sankey Diagram of Types and Extents of Connectivity for Bipartite Cross-Landscape Categories (Left) and Specific Social-Ecological Factors (Right) ("Conv" and "Alt" indicate conventional and alternative agriculture).

levels of the influence of such external influences as markets and research-and-development (Factors 11–12 in Fig. 6).

Cross-landscape inputs to peri-urban/urban agriculture comprised 35.4% of the total in-flow connectivity among landscape pairs (Fig. 5). These inputs consisted of flows from both intensive and traditional rural agricultural landscapes. The substantial extent of these inputs was shown also by peak value of the orange line at the "conventional peri-urban" axis of Fig. 4. LBM results demonstrated the characteristically larger levels and extent of production inputs to peri-urban/urban agriculture (lower-left block, Factors 1–10 in Fig. 6). Cross-landscape water inputs were also characteristically high (Factor 13, Fig. 6). By contrast, the outward-directed flows from peri-urban/urban areas were characterized by larger influences of agriculture-related markets and governance emanating from the peri-urban/urban areas (Factors 11–13, 15–16; Fig. 6). Finally, extensive bi-directional interactions characterized the connectivity of peri-urban/urban agriculture to both traditional rural landscapes and intensive agriculture (Figs. 4 and 5). These flows accounted for 31.5% and 35.7%, respectively, of total cross-landscape connectivity.

4.4. Estimated connectivity of conventional and alternative agricultural systems

Conventional and alternative agriculture exhibited similar extents of cross-landscape connectivity in the mean-value estimates (Fig. 4) and in landscape-level totals (Fig. 5). Interview-based, summed estimates of this connectivity involving conventional agriculture yielded the total count of 196 input-output examples. This total was statistically insignificant in comparison to the sum of 183 input-output examples for alternative agriculture. Certain connectivity was similar in conventional and alternative agriculture. For example, both required substantial cross-landscape flows of water resources and water governance (Fig. 5).

Analysis using Latent Block Modelling showed the general structural similarity of cross-landscape flows involving conventional and alternative agriculture belonging to each of the cross-landscape pairs (Fig. 6). LBM results showed that conventional and alternative agriculture of each cross-landscape pair were adjacent in clustered organization of the rows in each block. This grouping of rows was statistically consistent since all the LBM scenarios resulted in the same adjacency of conventional and agriculture belonging to each cross-landscape pair.

The specific social-ecological factors contained in cross-landscape flows differed between conventional and alternative agriculture. Diverse types of labor, local agro-technical knowledge, nutrient flows,

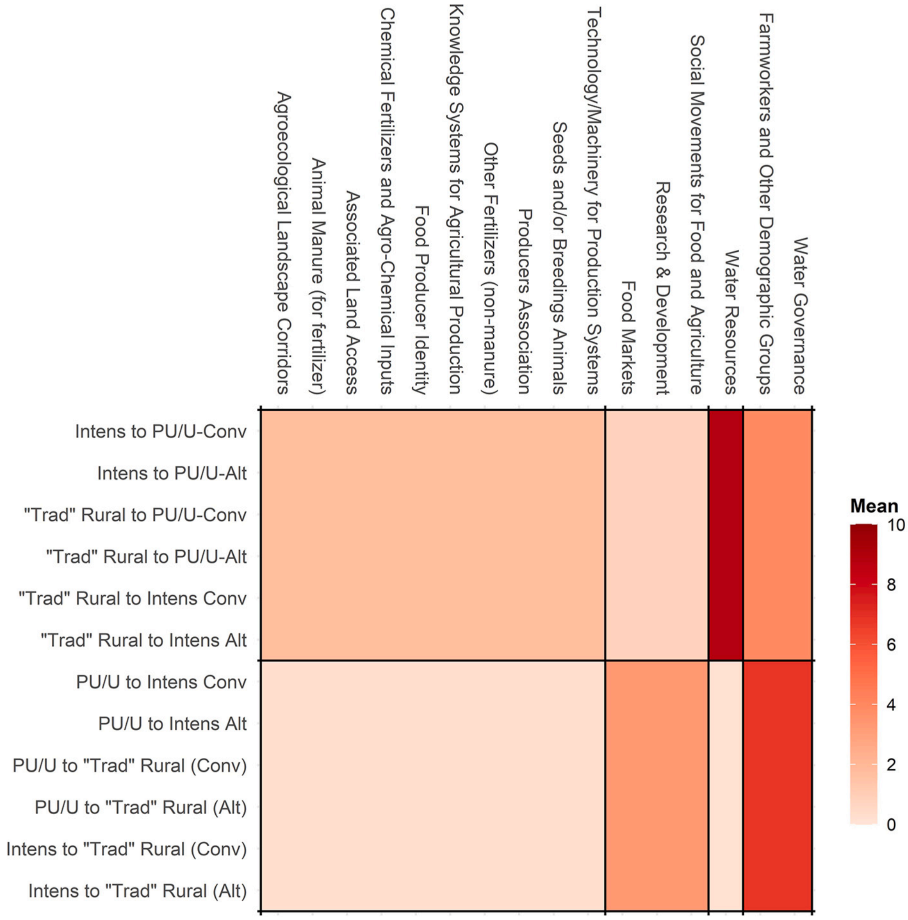

Fig. 6. Results of Latent Block Modelling. Shading shows two clusters of bipartite landscape interactions (upper and lower blocks) and four clusters of social-ecological factors (Factors 1–10, Factors 11–13, Factor 14, and Factors 15–16).

crop seeds, and breeding animals characterized the cross-landscape connectivity of alternative agriculture. The heterogeneity of resource management resulting from this social-ecological connectivity increased the spatial complexity of agricultural systems. For example, cross-landscape inputs for alternative agriculture included sources of diverse social-ecological inputs (such as agrobiodiverse crop types and varieties) and knowledge exchanges with expert farmers to develop site-specific production approaches. Additional cross-landscape movements in alternative agriculture included livestock-manuring. This movement enhanced heterogeneity by diversifying the soil-resource and nutrient management of agricultural systems.

The examples of cross-landscape connectivity in alternative agriculture described in the preceding paragraph characterized the outward-directed movements from traditional rural landscapes to peri-urban/urban agriculture (category 8 in Fig. 5). Related connectivity included the influence of peri-urban/urban product markets and demographic movements of ex-urban migrants who were new, first-generation farmers or back-to-landers (locally *neo-rurales* or "neoagrarians") moving to traditional rural landscapes (category 9 in Fig. 5). Overall, substantial connectivity between alternative agriculture in traditional rural and peri-urban landscapes is noteworthy since it often occurred across non-contiguous locations at distances of 50–150 kms (Fig. 2) and involved landscape types differing significantly in environmental, economic, and social characteristics.

The greatest extent of within-landscape flows was found in the alternative production of traditional rural landscapes (Fig. 4). Examples included consumption of local production and within-landscape cycles of seed and livestock, including distinctive local varieties and breeds. Internal flows provided water since this agricultural landscape is also a common water source. Within-landscape flows in alternative production included local food chains, referred to as "short channel" (*canales cortos*), that supplied local food and contributed resilience to the agri-food system (see Alternative Peri-Urban/Urban axis of the blue line in Fig. 4). Still, the overall extent of within-landscape flows was lower in peri-urban/urban agriculture due to limited spatial extent and lesser levels of agricultural populations and infrastructure.

5. Discussion

5.1. Connectivity of major types of agricultural landscapes

Accelerating changes of agricultural systems require new understandings of landscape-level, spatial connectivity and other network structures that influence sustainability and resilience. Our study was focused on the connectivity of agricultural production per se, thus extending beyond research to-date on the connectivity of patches, corridors, and social networks related to uncultivated environments that are mostly wild habitats (Jennings et al., 2020). By analyzing the connectivity attributes (type, direction, extent) of agricultural landscapes as networked structures, this study highlights the spatial interactions of agricultural spatial units. It adds a connectivity emphasis to state-of-the-art characterizations of agricultural-landscape and land-system types as individual units (Levers et al., 2018; Malek and Verburg, 2017; Stellmes et al., 2013; Voltz et al., 2018).

Results of the first part of this study showed three broad-scale types of agricultural landscapes in Spain (intensive, traditional rural, peri-

Table 4
Types, Examples, General Categories, and Counted Estimates of Social-Ecological Factors Identified in Interviews as Examples of Cross-Landscape Connectivity.

Social-ecological factor identified in interview	Example(s)	General social-ecological category (RS, UK, GM—see below)	Total counted cross-landscape flows
Water Resources	Irrigation from surface and groundwater	Resources and Resource-Production Systems (RS)	54
Water Governance Including Coordination and Conflicts	Irrigation apportioning, coordination, and conflicts	Governance and Markets (GM)	76
Technology/ Machinery for Crop and Livestock Production Systems	Tractors and other equipment for production	Resources and Resource-Production Systems (RS)	22
Practical Knowledge Systems for Crop and Livestock Production	Farm-level knowledge, mostly shared informally	Resource Users and Knowledge Systems (UK)	19
Research & Development	Agricultural knowledge, mostly shared formally	Resource Users and Knowledge Systems (UK)	26
Farmworkers and Other Demographic Groups	Spanish and immigrant farmworkers, back-to-landers	Resource Users and Knowledge Systems (UK)	53
Producers Association	Agricultural cooperatives and other organizations	Governance and Markets (GM)	6
Land Access	Access to land and resources (e.g., pasture)	Governance and Markets (GM)	7
Food Producer Identity	Farming-related cultural identity	Resource Users and Knowledge Systems (UK)	14
Chemical Fertilizers and Other Agro-Chemicals	Purchased nutrient inputs	Resources and Resource-Production Systems (RS)	3
Other Fertilizers (non-manure)	Mineral fertilizer inputs for soil management	Resources and Resource-Production Systems (RS)	9
Animal Manure (for fertilizer)	Animal manure inputs for soil management	Resources and Resource-Production Systems (RS)	15
Seeds and/or Breeding Animals	Purchases, exchange, and self-sourcing	Resources and Resource-Production Systems (RS)	17
Food Markets	Food buyers and consumers	Governance and Markets (GM)	33
Social Movements for Food and Agriculture	Farmer movement organizations (e.g., seed groups)	Governance and Markets (GM)	15
Agroecological Landscape Corridors	Pollinator corridors, hedgerows	Governance and Markets (GM)	9

urban/urban). Findings of the second part showed expanding intensive agriculture accounted for the highest level of cross-landscape connectivity. Many transfers of intensive agriculture reduced capacities for resilience and sustainability through resource deterioration, over-use, and spatial uniformity that undermine social-ecological integrity and complexity (Rosenzweig et al., 2020). Selective but important counter-examples included the cross-landscape inputs to expanding organic agriculture in this study's intensive agricultural landscapes (Fig. 3a, d). The cross-landscape capacity utilized by intensive producers to adopt alternative techniques offers a significant, additional spatial dimension to support the transitions needed for resilient, sustainable agricultural intensification (Tittonell, 2020).

Connectivity of traditional-rural agricultural landscapes, which comprised 41.0% of estimated outward-directed flows, reflected spatial integration through resource, labor, and governance systems that included market linkages. This study's results expand insight into inter-landscape water transfers and governance that increasingly threaten the resilience of traditional-rural agricultural systems (Sanchis-Ibor et al., 2019). In contrast to these negative impacts, the study's traditional-rural landscapes (Fig. 3b, c) were supported through several other types of cross-landscape connectivity. This landscape connectivity-based support provides a new view of the multi-scale dynamics of traditional-rural agricultural landscapes as key resilience capacities contributing to their viability as important agri-food systems (García-Martín et al., 2016, 2022; Gomez et al., 2016; Plieninger et al., 2018).

Finally, this study's analysis of the spatially differentiated connectivity of peri-urban/urban agriculture in relation to traditional-rural versus intensive farming is an important advance. This spatial analysis builds on generalized assessments of urban-rural connectivity as a focus for current research to foster sustainability-enhancing resilience in agriculture (Boudet et al., 2020). Differentiated connectivity was characteristic of this study's examples of peri-urban/urban agriculture in both peri-urban Madrid and peri-urban Granada. Overall, the cross-landscape connectivity of peri-urban/urban agriculture demonstrated in this study contributes original insight to current research in this domain (Soulard et al., 2018; Zimmerer et al., 2021b).

5.2. Connectivity in conventional and alternative agriculture

This study's results demonstrate that overall extents of cross-landscape connectivity were similar among alternative agriculture and conventional agriculture. In the case of conventional agriculture, this connectivity is widely associated with resource overuse and degradation such as nutrient pollution that is transferred across landscapes. In the case of alternative agriculture, this study revealed how cross-landscape connectivity offers new insight for research and policy on multi-scale interactions needed to strengthen these agricultural systems (Sundkvist et al., 2005; Sundstrom et al., 2022). Advancing multi-scale research and policy is a strategic complement to the predominant focus on local, closed-loop agroecological cycles (Bruce et al., 2021; Hedberg, 2020; Wezel et al., 2018). This study reveals how the functions of cross-landscape connectivity for alternative agriculture showed important "positive spillovers," which are often overlooked (Lewis et al., 2008) and can be non-proximate in current farming systems (Sundstrom et al., 2022).

This study illustrates how selective extra-landscape connectivity can play a key role in supporting agroecological transitions to build sustainability-enhancing resilience (Tittonell, 2020). Specific social-ecological factors involved in selective cross-landscape connectivity included alternative production knowledge systems, the role of skilled farm labor (including immigrant farmworkers), and nutrient management as well as seed and breeding-animal networks supporting the biodiversity of plants, animals, and agroecosystems. This study's treatment of connectivity among several factors across multiple agricultural landscapes provides a concrete example of called-for research on multiple networks and networked structures (Bodin and Tengö, 2012).

This study's results on cross-landscape connectivity in alternative agriculture yield insight for new spatial approaches designed to recognize the roles of scale and networks in alternative agricultural systems (FAO, 2020; Huttunen, 2019; Moragues-Faus et al., 2020; Vonthron et al., 2020; Zimmerer et al., 2021b). These approaches seek to identify and support territory-level assessments of agri-food systems and such territorial units as the city region. Spatial initiatives require understanding the social-ecological connectivity of alternative agriculture in and among territorial units. Results of this study show that agri-food territorial designs, including the spatial designs of sustainable intensification, can benefit from the importance of identifying and promoting sustainability-enhancing resilience functions that draw on cross-landscape connectivity.

5.3. Connectivity of alternative agriculture between traditional rural and peri-urban/urban landscapes

Social-ecological connectivity between traditional rural and urban/peri-urban agricultural landscapes revealed significant inter-landscape movements, such as large water transfers and unequal governance, that are deleterious. At the same time, this connectivity type also incorporated specific movements between alternative agriculture in the traditional rural and urban/peri-urban agricultural landscapes that offer benefits to sustainability-enhancing resilience. Examples in this study included agro-technical know-how and farm skills in addition to specific resources such as seed, livestock, and manure to peri-urban/urban agriculture and the roles of markets and new farmers and farm movements to the traditional rural landscape. These factors are recognized to contribute to social-ecological functions and spatial-landscape capacities that strengthen sustainability-enhancing resilience.

This study's analysis showing the substantial connectivity of traditional rural and peri-urban/urban agriculture adds to a pair of state-of-the-art arenas of new research. First, in the case of alternative agriculture, our results indicated that this cross-landscape connectivity reflected important networks that enhance agricultural resilience. Cross-scale capacity broadens the spatial role of social networks as potentially underpinning agricultural resilience, which to-date has been viewed mostly viewed within single landscapes (such as remote-rural agriculture; Bruce et al., 2021).

Second, the cross-landscape interactions of traditional rural and peri-urban/urban agriculture included networked connections among "actors with different attributes [that contribute] an essential form of diversity" (Barnes et al., 2017: 7). Examples in this study were the agricultural interactions of diverse farmer groups whose cross-landscape movements contributed to the exchange of agricultural knowledge in working landscapes (Kremen and Merenlender, 2018; Sundstrom et al., 2022). These included the back-to-landers (*neorurales*, or neoagrarians), the traditional rural farmers who have become sources of professional advice and inputs to new agri-food actors, and the immigrant farmworkers that often reside in peri-urban/urban spaces while they work seasonally in the other landscapes (Zimmerer et al., 2020). These examples of traditional-rural connectivity with peri-urban/urban agriculture can aid the co-learning of diverse sociocultural groups that is emerging as a crucial focus to enhance farming-system resilience (Darnhofer, 2021).

Finally, this study's results on the sustainability-enhancing resilience of traditional rural and urban/peri-urban agricultural connectivity underscore the influential roles of non- and extra-landscape factors. Identifying networked influences and institutions that extend beyond landscape spaces is important to the multi-scale analysis of agriculture (Boudet et al., 2020; Friis et al., 2016). In this study, agriculture-and-food social networks that promote the sustainability-enhancing resilience of peri-urban landscapes (e.g., the *Salvamos la Vega* movement and others in Spain; Yacamán Ochoa et al., 2019) rely extensively on non-landscape connectivity. Other extra-landscape social drivers that impact agricultural landscapes are national and European Union programs (e.g., Protected Denominations of Origin, PDO, Table 5). At the same time, the challenges of policy initiatives intended to support traditional rural agriculture (García-Martín et al., 2016, 2022)

Table 5
Examples of External, Non-Local Policies and Programs Related to Major Agricultural Landscapes in Spain (examples assembled based on Coq-Huelva et al., 2014; Egea et al., 2018; Escribano, 2016; García-Martin et al. 2016; García-Arias et al., 2015; Guedes and Silva 2014; Hinojosa-Rodriguez et al., 2014; Yacamán and Mata Olmo 2014; as well as experience of the team of authors).

	Examples of European Union Policies and Programs	Examples of Policies and Programs of National and Regional Governments	Examples of Market Dynamics and Direct Global Policy Impacts
Peri-Urban and Urban	1) Dictamen del Comité Económico y Social Europeo (CESE) sobre "Agricultura periurbana" (NAT/204-CESE 1209/2004) and successor legislation 2) Organic farming (EU Reg 2092/1991 and later amendments) 3) CAP PDO and PGI (e.g., asparagus in peri-urban Granada) (includes national and regional govt. counterpart legislation) 4) Note peri-urban is not typically deemed CAP Zone 1 and receives lower benefits	1) Agro-export policies (see Intensive) 2) Plan for the Development of Agrarian Employment (PER, Plan de Fomento de Empleo Agrario, 1986-) 3) National government statutes for agrarian cooperatives and irrigator associations 4) Regional Research and Development institutions (e.g., IMIDRA-Madrid; IFAPA-Granada) 5) National Periurban agriculture map and inventory	1) Uruguay Round, General Agreement on Trade and Tariffs (GATT) 2) Peri-urban land and wáter markets 3) Labor markets and employment in off- and non-farm activity; diversified livelihoods of households (*pluri-actividad)* 4) Partial utilization of contracted farmworkers including migrant labor 5) Non-profit organizations (NGOs)
Inten-sive	1) EU Common Market Organization of Fruit and Vegetables, including food quality, health, and safety standards 2) EU-facilitated Quality Control such as certificates of value-chain transparency 3) CAP PDO and PGI apply (e.g., tomatoes from intensive production (includes national and regional government counterpart legislation)	1) Agroexport subsidies through national programs such as ICEX 2) Major government-supported irrigation works, and land and wáter legislation 3) Research & Development institutions (e.g., IFAPA-Mojonera) 4) Public-private consortia guided government agencies, universities, and businesses and cooperatives supporting technological institutes	1) Uruguay Round of the General Agreement on Trade and Tariffs (GATT) 2) Major product, labor, and investment markets 3) Conventional and organic third-party certifiers (Ecofruit: ISO 2200) 4) Agri-food trade unions (e.g, General Union of Workers; CCOO, and others
"Tradi-tional" Rural	1) New Common Agricultural Policy/CAP (2014–20, builds on major initiatives and reforms. Includes direct production payments and environmental sustainability incentives; Qualify as Zone 1 in CAP and receive higher benefits 2) Rural development support through a series of programs that include Desarrollo Local Leader (2014–2020) 4) Protected Designation of Origin/PDO and Protected Geographical Indicators/PGI through Regulation 1151/2012 of the EU	1) National Sustainable Rural Development Acts 2) Regional Development Plans 3) Statutes for agrarian cooperatives, irrigator associations, and community-based resource management (e.g., *dehesas*) 4) Research and Development institutions 5) Pensions support agricultural activity 6) Certification of agricultural products from protected areas 7) National PDO and PGI legislation (e.g., PDO Regulation 510/2006; PGI (Regulation 510/2006); Regulation 479/2008 of wine market	1) Labor markets and employment in non-farm activity leading to diversified livelihoods (*pluri-actividad)* 2) Niche markets including specialty and organic products (e.g., "Snowflake" variety of local potato, *Copo de Nieve*, from the Sierra Nevada in Granada 3) Tourism and health markets, including agri-tourism and direct-marketing of food products and experience to tourists (e.g., pick-your-own-berries) 4) Non-profit organizations (NGOs)

demonstrate the need for networked landscape approaches that can build on selective peri-urban/urban connectivity as shown in this study.

Table 5 approximately here (currently placed at end of this file).

6. Conclusion

Structured literature review of publications identified the predominance of three major types of broad-scale agricultural landscapes in Spain: intensive, traditional rural, and peri-urban/urban. Case studies of landscapes in the Madrid and Granada regions revealed extensive cross-landscape connectivity of social-ecological factors. Intensive agricultural systems were dependent on the largest extent of cross-landscape inputs whereas traditional rural landscapes are characterized by outward-directed flows. Although much connectivity of conventional agricultural landscapes is environmentally and socially damaging, alternative agriculture also relies on selective, cross-landscape interactions that contribute to viability. The connectivity of alternative agriculture in the traditional rural and peri-urban/urban landscapes incorporates nutrient and seed flows as well as important market influences, farm labor, and knowledge systems supporting co-learning. These selective social-ecological factors networked across landscapes are key elements that can strengthen sustainability-enhancing resilience.

The substantial extent of cross-landscape spatial connectivity involving social-ecological factors is important to alternative agriculture amid accelerated agricultural intensification/disintensification and urbanization changes. Analysis of existing cross-landscape connectivity is needed for the current and future transitional phases of agricultural sustainability. The perspective of cross-landscape connectivity is a complement to the continued goal of developing the local, within-landscape processes of alternative agriculture. Methods and concepts for the analysis of cross-landscape connectivity offer research, policy, management, and spatial-design tools to support sustainability-enhancing agricultural resilience amid accelerating changes.

Declaration of Competing Interest

The authors declare no conflict of interest.

Data availability

Approximaely one half of th data is sharable and contained in the Supplement; the other approximately one half of the data is confidential

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Appendix A. Supplementary data

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