Building capacities for the design of agroecological landscapes

Sandrine Petit, Audrey Alignier, Roland Allart, Stéphanie Aviron, Hugues Boussard, Pierre P. Franck, Caroline Gibert, Maxime Moncamp, Sylvie Ladet, A. Vialatte, et al.

Agriculture, Ecosystems and Environment 342 (2023) 108263

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Building capacities for the design of agroecological landscapes: The added-value of Landscape Monitoring Networks

Sandrine Petit[a,*], Audrey Alignier[b], Roland Allart[a], Stéphanie Aviron[b], Hugues Boussard[b], Pierre Franck[c], Caroline Gibert[d], Sylvie Ladet[e], Claire Lavigne[c], Lou Lecuyer[a], Maxime Moncamp[d], Lucile Muneret[a], Sylvain Poggi[f], Benoit Ricci[a], Adrien Rusch[g], Aude Vialatte[e], Juliette Young[a]

[a] Agroécologie, INRAE, Institut Agro, Univ. Bourgogne, Univ. Bourgogne Franche-Comté, F-21000 Dijon, France
[b] BAGAP, INRAE, Institut Agro-AgroCampus Ouest, ESA, F-35042 Rennes, France
[c] PSH, INRAE, F-84000 Avignon, France
[d] SOLAGRO, F-31000 Toulouse, France
[e] Dynafor, INRAE, Univ. Toulouse, F-31326 Castanet Tolosan, France
[f] IGEPP, INRAE, Institut Agro-AgroCampus Ouest, F-35042 Rennes, France
[g] SAVE, INRAE, ISVV, Univ. Bordeaux, Bordeaux Sciences Agro, F-33883 Villenave d'Ornon Cedex, France

A R T I C L E I N F O

Keywords:
Operational knowledge
Generic knowledge
Prediction
Pest control services
Collective action

A B S T R A C T

The evidence that most agricultural landscapes are failing to deliver on biodiversity conservation and ecosystem services provision suggests that future landscapes will need to be more explicitly designed. Although recent research has produced a number of ecological and social principles that should form the basis of agricultural landscape design process, implementation is still in its infancy. One difficulty is the context-dependency of ecological responses and the resulting limiting capacity to predict the benefits of landscape transformation for the targeted organisms or services. In addition, there is a poor understanding of the obstacles to and levers for the implementation of collective management at the landscape scale. In this paper, we argue that Landscape Monitoring Networks (LMN), i.e. long-term and standardized monitoring of ecological and managerial processes within a set of replicated regional landscapes, can contribute to tackling these issues. We first present the current challenges in designing agroecological landscapes before outlining the principles of LMN and how these research facilities could help deliver ecological and social understanding along a gradient from place-based to generic knowledge. We then discuss critical issues that need to be solved to ensure that LMN delivers relevant knowledge for landscape design. We illustrate this through the experience of an ongoing LMN that was created in France in 2014 to address biodiversity and pest control services in agricultural landscapes.

1. Introduction

There is a growing awareness, in both scientific and policy-making circles, that addressing current threats on biodiversity and ecosystem services (ES) requires a transformation in how we use and manage agricultural systems (Vanbergen et al., 2020). If the shift towards more ecologically-friendly in-field farming practices is well under-way (Pretty et al., 2018), promoting ecological processes also requires consideration of the landscape as a whole (Jeanneret et al., 2021). Landscape is defined here as the mosaic of crop and off-crop habitats resulting from the amount and spatial patterns of non-cultivated land (field boundaries, semi-natural habitats), the diversity of crop management at farm level and the fine interweaving of farm territories across the landscape. The evidence that most agricultural landscapes fail to deliver on biodiversity conservation and ES provision suggests that future landscapes will likely need to be explicitly designed.

Over recent decades, scientists have produced a number of generic ecological principles that could form the foundation for informed agricultural landscape design (Landis, 2017; Kleijn et al., 2019). Such a landscape redesign approach to promote biological control was previously attempted over 10 years ago (Steingröver et al., 2010). But scientific uncertainties have been a strong limitation of the exercise.

* Corresponding author.
E-mail address: sandrine.petit-michaut@inrae.fr (S. Petit).

https://doi.org/10.1016/j.agee.2022.108263
Received 12 June 2022; Received in revised form 11 October 2022; Accepted 3 November 2022
Available online 8 November 2022

Empirical evidence suggests inconsistencies in the responses of specific ES to in-field management and landscape properties, yielding a theory-to-practice gap to implement landscape transformation (Pelosi et al., 2010; Bretagnolle et al., 2019; Kleijn, 2019). The development of targeted (place-based) research is an alternative approach to foster landscape transformation, often considered as more effective for developing the specific knowledge that local stakeholders need to enact change (Geertsema et al., 2016). It may however be considered as lacking the degree of genericity required to contribute to advances in our general understanding of biodiversity and ecological processes in landscapes. The current need for a stronger orientation on implementation requires tackling this trade-off between generality and realism.

Combining basic and applied ecology with social science to support the implementation of landscape design has been identified as a way forward (Landis, 2017) and could help tackle this trade-off. For example, mixed approaches combining literature review and case studies can yield structured generic procedures matched with tailored, problem-specific results (Weltin, 2018). This mixed approach enables the development of links and comparisons between scientific and operational knowledge. In the same vein, bringing under a common conceptual and methodological framework several case studies could foster both theory and operationality. For example, Bretagnolle et al. (2019) proposed such a framework in their call for integrating over ten long-term socio-ecological research sites dealing with adaptive management. In this case, formalism was set as an objective, but the fact that the ten research sites targeted different types of ecosystem services limited the scope for linking operational (place-based) and generic knowledge. One option to overcome this limitation is the set-up of networks of monitoring sites, with a common focus on one type of ecosystem and the monitoring of the same ecological processes. Because there is no optimal scale for managing biodiversity and ecosystem services, each monitoring site should include multiple scales, from local (e.g. field scale) to landscape scales. Such landscape monitoring networks (Petit et al., 2021) may be restricted in the range of processes they address but could nonetheless deliver both generic and operational knowledge guiding the design of future landscapes.

In this paper, we explore the potential added-value of landscape monitoring networks (LMN) for the design of agroecological landscapes. We first present the current challenges in designing agroecological landscapes, the principles of LMN and how these research facilities could help deliver ecological and social understanding along a gradient from place-based to generic knowledge. We then discuss critical issues that need to be addressed to ensure that LMN delivers relevant knowledge in support of landscape design. We illustrate this process using the experience of a LMN set up in France in 2014 focusing on biodiversity and pest control services in agricultural landscapes.

3. Current challenges for designing agroecological landscapes

There is a consensus that the intensification of agriculture has led to a significant decline in biodiversity and ES in recent decades (Rusch et al., 2016; Dainese et al., 2019). In most landscapes, managing pest damage to crops remains a major challenge (Savary et al., 2019) with a continued heavy reliance of agriculture on pesticides despite the detrimental effects to human health and the environment (Geiger et al., 2010; Sánchez-Bayo and Wyckhuys, 2019). Reducing pesticide use in agricultural landscapes would benefit consumers, society as a whole and farmers, provided economically viable alternatives are available. One alternative is the enhancement of natural pest control (defined here as the regulating action of natural enemies that are naturally occurring in cropped fields on herbivore pests and weeds through predation or parasitism) as it reduces the reliance on pesticides but also potentially leads to increased biodiversity and crop yields (Gagic et al., 2017; Dainese et al., 2019; Duflot et al., 2022). Increasing natural pest control requires the consideration of multiple spatial scales, from local (e.g. in-field agroecological practices) to landscape (semi-natural habitats, spatio-temporal organization of the agricultural land mosaics). There is thus a strong rationale for the enhancement of natural pest control as a shared goal in a landscape design process. In light of the potential benefits of natural pest control services, studies aiming at identifying their local and landscape drivers have increased over the last decade and have yielded significant advances in our understanding of how to enhance these services. Nevertheless, there are still limitations in our understanding of the underlying processes and in our capacity to predict the pest control benefits of landscape transformation.

The local management and landscape-scale factors that can enhance natural pest control have been extensively studied over a wide range of agroecosystems and across most continents. Available syntheses (e.g. Chaplin-Kramer et al., 2011; Batáry et al., 2011; Rusch et al., 2016; Karp et al., 2018) tend to confirm the generic expectation that extensive agricultural systems situated in complex landscapes harbor higher levels of functional biodiversity and natural pest control services than intensive systems located in simplified landscapes without compromising crop yield. These studies also reveal a great variability in the response of natural pest control and a context-dependency of results which questions their operational value. There could be multiple causes of this inconsistency such as the ecological complexity of tri-trophic interactions (Ratsimba et al., 2022), history of disturbances (Le Provost et al., 2020) and extinction debts (Kuussaari et al., 2009). Methodological issues may also explain this variability. For example, several authors consider that the variability in responses results in part from a poor account of the diversity of farming management (Veres et al., 2013; Karp et al., 2018). Besides, owing to the large sampling effort required in landscape studies, patterns observed are usually a snapshot, one year in one crop type, and this restricted spatio-temporal scope limits our capacity to understand processes underlying the provision of pest control services. For example, little knowledge is available regarding the pest control benefits of farming management across the crop rotation (Kleijn et al., 2019; Bohan et al., 2021), the temporal stability of pest control services within and between years and the role of abiotic variables (e.g. climatic conditions) in the dynamics of organisms delivering pest control services. Finally, syntheses derived from existing studies face the challenge of dealing with variables very often measured with different protocols, with variable sampling efforts and along landscape gradients that are not always comparable.

The existing variability in pest control response to management means that producing reliable predictions of natural pest control remains challenging (Alexandridis et al., 2021). There is a lack of general models of consistent links between specific management/landscape factors and enhanced pest control and at the same time, the transferability of relevant ecological models outside the specific cases for which they were developed is largely unknown and remains to be explored (Lautenbach et al., 2019). On one hand, these knowledge gaps and uncertainties are key factors likely to hamper the implementation of landscape transformation by farmers (Kleijn et al., 2019; Salliou et al., 2019a). On the other hand, farmers may decide not to follow scientific evidence because they are unsure about the relevance of generic recommendations from scientific studies for their specific farms and conditions. In addition, while enhancing pest control services at the landscape scale requires coordinated decisions (Landis, 2017) to boost natural pest control, farmers currently appear more likely to act individually than to engage into collective action (Vialatte et al., 2021). Further research is required to increase our understanding of barriers, levers and opportunities for collective action aiming at designing agroecological landscapes.

4. The principles of Landscape Monitoring Networks

LMNs are a long-term and standardized monitoring of ecological and managerial processes within a set of regional landscapes. LMNs share many principles with the well-established Long Term Ecological

Research networks (LTER) established in America and in Europe that aim at identifying drivers of ecosystem change across environmental gradients (Müller et al., 2010). LMNs also have some specificities, and notably the focus on the landscape dimension of agricultural systems where managerial and ecological processes are monitored in a network of replicated landscapes over time. The selection of the replicate landscapes that form a LMN determines the range of pedoclimatic and socio-economic contexts under study.

LMNs have four main principles, each with specific added-values for advancing both generic and operational knowledge (Table 1). The long-term dimension (1) offers opportunities to address the temporal dimension of ecological processes per se and their response to landscape transformation but also to other factors, e.g. the impact of yearly climatic conditions on processes. Within each replicate landscape, the long-term dimension is an asset to ensure sustained engagement with local stakeholders, with opportunities to assess current trends and possible futures for managerial and ecological processes (4). Multiple regional landscapes (2) ensure data collection over a large number of sample sites and over a wide range of situations, thus increasing the robustness and genericity of findings. It also provides the capacity to conduct comparative studies which can be relevant to stakeholders in specific regional landscapes. Standardized protocols for collecting a detailed account of ecological and managerial processes (3) authorize transversal analyses and at the same time offer the scope to deliver specific guidelines to land managers. These principles were used as a basis to set-up a French LMN on biodiversity and pest control services, as described in Box 1.

Table 1
The four characteristics of landscape monitoring networks and their potential added-values for generic and operational knowledge.

LMN Characteristics	Added value for Generic knowledge	Added value for Operational knowledge
1-Long-term	• Dynamics of biodiversity • Ecological responses to transformation: resilience, time lags • Dynamics of management factors over multiple years • Account of interannual variations in local climatic variables	• Record of local ecological/management transformations • Impact of annual local climatic conditions • Engagement with stakeholders
2-Multiple regional landscapes	• Large sampling size • Wide range of management options • Wide range of pedoclimatic and socio-economic context • Increased genericity and robustness • Scope for comparative studies	Impact of specific management not yet present locally but likely to emerge.
3-Detailed & standardized account of ecological processes, management and landscape	• Scope to detect generic signals • Making sense of the context-dependency • Scope for comparative studies • Development of generic indicators	• Detection of thresholds • Specific guidelines to managers
4-Engagement with local stakeholders	Detect generic expectations, attitudes and behaviours regarding transformations	• Realistic scenarii for transformation • Identify successful transformation • Initiate transformation • Open innovation and crossed knowledge, direct connection between research and farmers

5. Landscape monitoring networks for designing agroecological landscapes

The design of agroecological landscapes can be defined as the process of intentionally planning and shaping the landscapes where farming occurs towards a defined goal or outcome (Haan et al., 2021) - in our case the enhancement of natural pest control. It cannot be considered as a top-down process but rather, it results from a collaborative process between scientists, practitioners and stakeholders. As such, it can be seen as a link between science and landscape change, i.e. it allows science to affect landscape change (Nassauer and Opdam, 2008). It involves understanding the diverse needs of stakeholders and integrating them with scientific knowledge about how landscape function can be modified to increase desired services (Barrett, 1992). Although there are few examples of implementation of landscape design for promoting natural pest control available to date (but see Steingröver et al., 2010), some general guiding principles have been proposed by Haan et al. (2021) that encompass the ecological and social dimensions of landscape design. The ecological principles refer to the knowledge of factors underlying the delivery of natural pest control service, e.g. identification of the key management and landscape factors enhancing pest control. Here, LMNs can be a powerful research facility as they are tailored to identify the drivers of long-term spatio-temporal variations in ecological processes, but also to understand the ecological responses to landscape transformations. The social principles refer to the necessity to quantify and take on board in the design process the stakeholders need and want for the landscape. It may involve an assessment of the current situation, as well as the exploration of alternative futures meeting stakeholders' expectations. The long-term engagement with stakeholders within a LMN provides a suitable context to conduct such collaborative explorations.

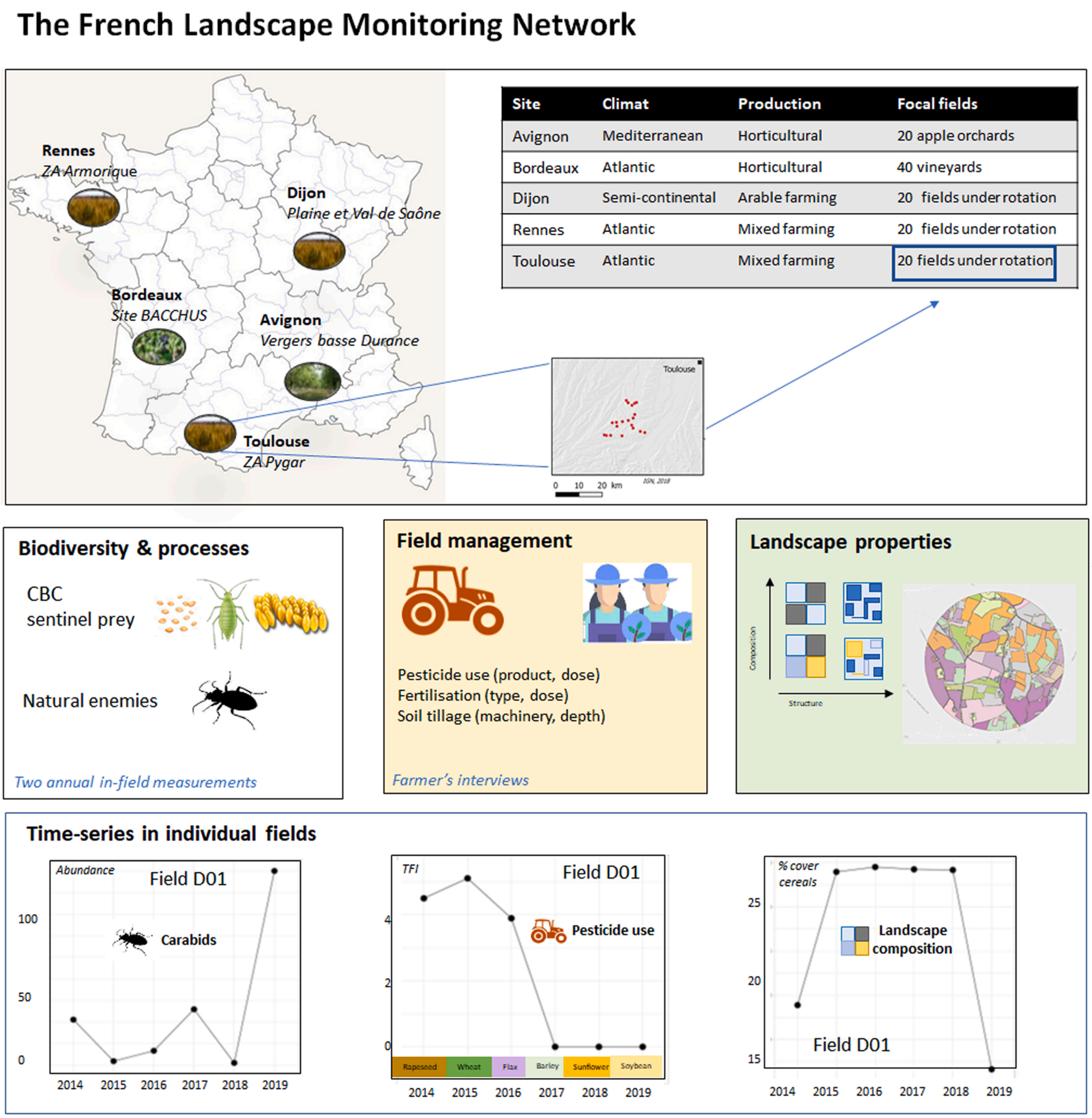
In its simplest representation, a landscape design process in a single monitoring landscape site can be considered as an iterative process between 'monitoring and understanding', 'engaging with stakeholders' and 'predicting and designing' (Fig. 1). Here, we posit that building the design process on a LMN, i.e. a network of replicate landscape sites, can offer added-value and deliver transversality, i.e. the capacity to move along a gradient between place-based knowledge and generic, formalized knowledge, provided that three conditions are met (Fig. 1). A first condition to ensure transversality is the development of unified and generic frameworks, notably to ensure a smooth translation of detailed fine-scale data into generic and meaningful indicators with limited degradation of information. The second condition for LMNs to provide added-value to landscape design is to engage with stakeholders not only regarding individual needs and wants for the landscape but also on their willingness to act collectively to promote pest control services. Here, the mobilization of standardized methods in LMNs can help identify local specificities but also generic trends across the replicate landscapes. A third critical issue is the difficulty in producing general reliable predictions of natural pest control, especially as such predictions are a central element in the landscape design process. Here, building on the multiple landscapes studied in the LMN, we present the analytical framework used to model pest control services in these landscapes and explore the issue of transversality and transferability of models predicting natural pest control in response to local and landscape-scale factors.

6. Developing unified and generic frameworks

As stated above, the main limitations in global or large-scale datasets on natural pest control services is the large variability in the way response and explanatory variables are measured. Studies about natural pest control services in agricultural landscapes include measures of top-down control by natural enemies, e.g., using exclusion experiment or sentinel prey, pest prevalence or abundance or pest damage (Karp et al., 2018). These variables are very often measured with different protocols,

Box 1
The French LMN on biodiversity and pest control services.

The French LMN on pest control services was set up in 2014 in five regional landscapes, and monitors 120 fields annually, 60 fields in annual rotational systems and 60 fields of perennial crops. The target fields were selected in each regional landscape according to the landscape characteristics of their surrounding (compositional and configurational heterogeneity in 1 km^2). *Biodiversity and Pest control service*. Standardized protocols were developed to sample natural enemies (carabid beetles) and natural pest control (sentinel prey, aphids and weed seeds exposed on the ground and aphids and Ephestia eggs in the vegetation - see Ricci et al., 2019) *Field management*. One specificity in the French LMN is the choice of a detailed recording of technical routes implemented by farmers, rather than a simple record of the farming system in place (e.g. organic vs. conventional farming) which is often used in landscape-scale studies. This choice results from the fact that many farmers envisage changes as a redesign of their system, which by essence will mobilize modifications of a whole set of practices in combinations and over a pluriannual time scale. In each regional landscape, annual interviews are conducted using a standardized questionnaire on the technical route. The data is recorded in a single information system, AgroSyst which ensures a standardized estimation of indicators derived from the questionnaire, for example calculation of Treatment Frequency Index for pesticide use. *Landscape properties*. Land use in the 1km2 surrounding the focal field is recorded in the field annually using a standardized thematic classification. Additionally, an automatic procedure for mapping landscapes was developed in order to increase the spatial extent of landscape description around each field (Allart et al., 2021).



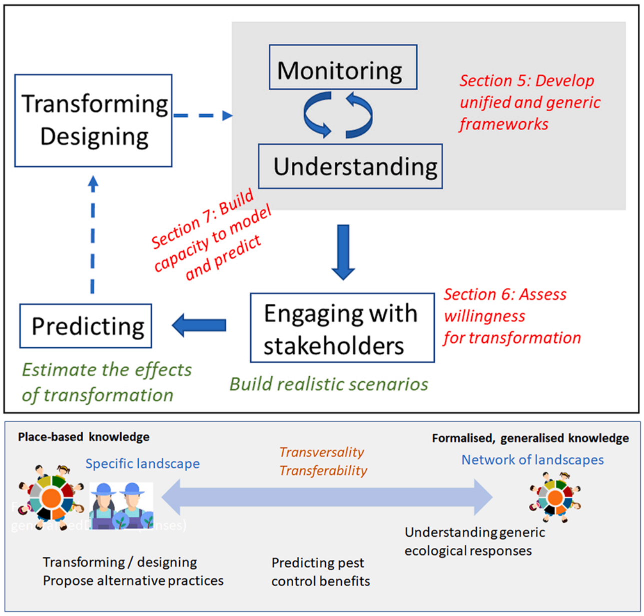


Fig. 1. Landscape Monitoring Networks and the process of designing agricultural landscapes: Framework and associated challenges.

with variable sampling efforts and along landscape gradients that are not always comparable. If databases are large enough, it is of course always possible to include protocol types or the range of variation in landscape gradients as explanatory variables in statistical models to investigate if and how such variability affects the response variables. In the same vein, using meta-analytical approaches at the global scale allow potential comparisons of data collected using different protocols or in different contexts. However, this lack of homogenization in data collection very often limits our understanding of processes or can only be solved by degrading primary data (e.g., use an over simplistic landscape gradient to merge datasets as opposed to a large diversity of landscape gradients tailored to specific context) to use as much data as possible. In addition, empirical studies often lack a precise and shared description of habitats in the landscape and use different experimental designs (e.g., focal habitat sampling along landscape gradients, multiple habitats sampling, regular grid) or explore different spatial or temporal extents (Petit et al., 2020) making it difficult to compare results across studies and contexts. LMN approaches solve most of these issues, as they implement standardized experimental designs, standardized protocols and data collection. In the French LMN on pest services, data collection of predation of sentinel preys is fully standardized and can be used directly. Similarly, landscape metrics are directly comparable across the 5 regional landscapes. The most challenging is probably to deal with the huge variety of cropping systems that are implemented by farmers across the LMN. The detailed account of farming operations is necessary to fulfill the dual objective of (i) deepening our understanding of ecological responses to farming management and (ii) providing information that can guide farmers in adjusting their management. It also yields a wealth of information and variables that require interpretation before they can be used to explain variations in pest control and useful for farmers willing to adjust their cropping systems. This issue has been central in the French LMN on pest services and two complementary approaches have been developed that mobilize the data collected between 2014 and 2018 in 57 fields across the three regional landscapes dominated by annual cropping systems.

A first approach consisted in classifying the 57 fields according to the farming operations conducted over the 2014–2018 period, regardless of the regional landscape context they sit in and of the production system (i.e. conventional vs. organic farming). The classification was based on the type of crop grown in the crop sequence (winter vs spring crop), the presence/absence of intercrop, pesticide use intensity (herbicides, pesticides, fungicides, seed treatment), the number of plowing and soil interventions for mechanical weeding, and the nature (organic/mineral) and quantity of fertilization (N amount/ha/yr). Multiple Factor Analysis (MFA) and hierarchical cluster analysis on the first axes of the MFA enabled the identification of five clusters of fields, i.e. fields with common management variables. This analysis highlighted three main points. First, the French LMN covers a high diversity of cropping systems (Table 2). Second, although two clusters were landscape-specific and related to specific types of agricultural production (cash crop or mixed crop-livestock production), the three other clusters combined fields from the three regional landscapes which suggests that the classification is relevant for cross-landscape analyses. Finally, a significant number of conventionally farmed fields (6 fields) were merged with organically farmed fields (all organic fields from the three regional landscapes being in the same cluster), which suggests that some conventional cropping systems are close to organic ones.

A second approach was developed to characterize the cropping systems in terms of their suitability for ground-dwelling arthropods contributing to pest control, e.g. ground carabid beetles or ground-dwelling spiders. Here, the challenge was to develop a framework enabling a common and generic representation of the diversity of cropping systems encountered within the LMN. For example, 32 different crops have been grown on the 57 fields over the 5 year-period. Another requirement was to develop a 'functional' framework, i.e. a representation of cropping systems that was ecologically relevant for natural enemies. The farming operations conducted in the 57 cropping systems were thus converted into two ecological gradients, a resource gradient and a disturbance gradient. The resource gradient was based on (i) daily crop height estimated via crop growth models with the underlying assumption that the higher crop height, the better for natural enemy prey availability and (ii) fertilizer inputs, with the underlying assumption that organic fertilization increases prey availability whereas mineral fertilization reduces it. The disturbance gradient was based on

Table 2
Typology of cropping systems in the French LMN into five clusters. Number of fields in each replicate landscape and average of different agronomic variables over the period 2014–2018.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
# fields in the Dijon site	3	0	2	7	8
# fields in the Rennes site	5	8	2	3	0
# fields in the Toulouse site	10	0	6	1	0
Mean occurrence of intercrops	0.07 ± 0.25	0.4 ± 0.49	0.04 ± 0.20	0.05 ± 0.23	0.30 ± 0.46
Mean # years under winter crops	0.47 ± 0.50	0.58 ± 0.50	0.69 ± 0.46	0.75 ± 0.44	0.80 ± 0.40
Mean # years under spring crops	0.20 ± 0.40	0.43 ± 0.50	0.22 ± 0.42	0.25 ± 0.44	0.20 ± 0.40
Mean # years under grassland	0.34 ± 0.48	0.03 ± 0.16	0.04 ± 0.20	0.04 ± 0.19	0
Mean total TFI	0.61 ± 1.52	3.82 ± 1.38	4.05 ± 2.20	4.44 ± 2.01	5.79 ± 2.45
Mean amount of organic N (kg/ha)	18.52 ± 43.1	98.95 ± 104.4	22.61 ± 112.9	50.29 ± 100.7	0.25 ± 1.6
Mean amount of mineral N (kg/ha)	23.81 ± 44.8	3431.5 ± 21,207.6	123.62 ± 77.4	128.69 ± 75.4	138.90 ± 79.3
Mean # soil tillage operations	2.73 ± 2.61	1.38 ± 0.86	1.92 ± 1.34	3.16 ± 2.02	0.85 ± 1.70

(iii) soil and tillage operations cultivation, with the assumption that the more in-depth and animated agricultural equipment, the more disturbing for natural enemies and on (iv) pesticide use intensity with the assumption that high values of the Treatment Frequency Index would be detrimental for natural enemies. Each of the 57 fields were thus characterized each year by four variables (Fig. 2). The ecological relevance of these four generic descriptors was then confronted to annual carabid data collected in the 57 fields, alongside other potential explanatory variables, namely the LMN site, weather conditions and landscape composition (Muneret et al., 2022). Our models explained 30% of the variations in the abundance of carabids, of which 36% were explained by the four descriptors of ecological gradients, mostly crop height and chemical disturbance (Fig. 3a). Similarly, we explained 30% of the variations in carabid species richness, of which 44% was explained by ecological gradients, with a marked role of crop height (Fig. 3b). Furthermore, this functional approach is complementary to the typology method to classify cropping systems because hypotheses associated with ecological gradients implicitly induce the ecological mechanisms linking technical routes to biodiversity and the provision of services. Moreover, it allows measuring the relative effect of each gradient on biodiversity and services while the typology describes "agricultural systems". As shown above, many of them are only implemented within some regions. However, the two approaches provide consistent results in terms of cropping systems description (Fig. 2) because ecological gradients are well discriminated by clusters from typology.

7. Engaging with stakeholders to assess the potential and willingness for landscape transformation

One key aspect in the design of agroecological landscapes is the scope for collective action, i.e. an "action taken by a group [.] in pursuit of members' perceived shared interests" (Scott and Marshall, 2009). It is often argued that uncoordinated decisions may not yield the benefits expected at the landscape scale (Landis, 2017) and that agroecological transition requires landscape level innovations and coordination mechanisms among farmers (Duru et al., 2015). Specifically, as pest control services imply multiple ecological processes that occur at field and landscape scales and are impacted by management practices at these scales (Ricci et al., 2019; Muneret et al., 2019), farmers are interdependent for the provision of these ecosystem services in their fields. However, while farmers consider natural enemies as public good resources (in the sense described by Ostrom, 1990), they are more likely to embrace field or farm management approaches -e.g. implantation of linear semi-natural habitats around some of their fields- than collective management practices -e.g. establish a connected network of linear semi-natural habitats on a small territory – (Salliou and Barnaud, 2017; Salliou et al., 2019a). Coordination at the landscape scale has little chance of spontaneously emerging from unregulated interactions between individual farmers (Costello et al., 2017; Cieslik et al., 2021). Collective management requires polycentric governance mechanisms (Biggs et al., 2012; Ostrom, 2010). These mechanisms can be favoured by increasing public information on individual choices to coordinate actions in order to limit strategic interactions such as free-riding i.e., strategically letting the other farmers enhance pest control in the landscape (Singerman and Useche, 2019; Lence and Singerman, 2022). Increasing farmer's awareness of their interdependencies is also another factor for the implementation of such polycentric governance mechanisms (Barnaud et al., 2018). Characterizing the local obstacles, levers and opportunities for collective action is a prerequisite to deal with specific local agroecological issues.

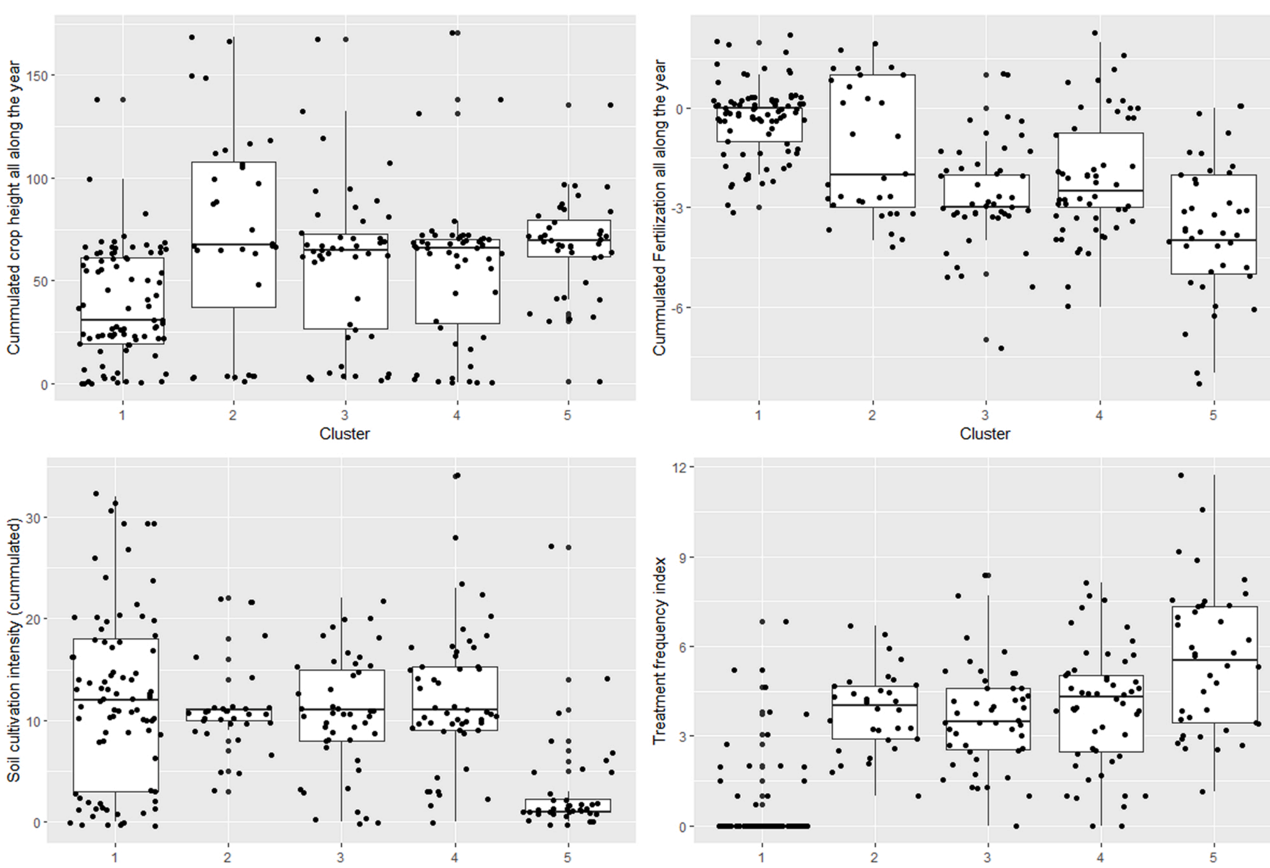


Fig. 2. Distribution values of the four ecological indicators across the five agronomic clusters in the annual cropping systems of the French LMN. Each point represents a field a given year (57 fields for 5 years).

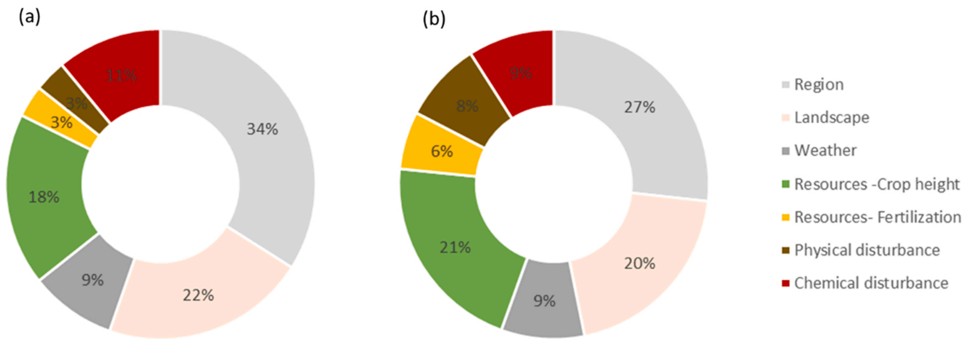


Fig. 3. Share by environmental factor to explained variations in (a) carabid abundance and (b) carabid species richness. Based on the analysis of the annual cropping systems of the French LMN (57 fields for 5 years).

In the French LMN, we aimed to engage with farmers through workshops in each regional landscape in 2020, with the main objective to co-design for each regional landscape a scenario of transformation, i.e. changes in practices and landscape promoting natural pest control that would be acceptable and realistic to the local farmers. Due to the COVID restrictions, only one workshop could be carried out. During the course of the workshop, a specific session was dedicated to the exploration of the awareness of interdependencies between farmers regarding natural pest control and their perspectives regarding collective action (and potential gaps in the current system for promoting collective action). The workshop design was then used as a template to design an online questionnaire, in order to replicate the process while adhering to the COVID restrictions in place.

A total of 55 respondents (between 9 and 13 farmers per regional landscape) were asked to react to a series of statements (Fig. 4); they included farmers most advanced in the transformation of their farm (i.e. not necessarily representative of the farmers in each regional landscape but informative in terms of what can be achieved in each regional context). The analysis first revealed that despite the regional differences in terms of agricultural production (horticultural, arable, mixed farming) and socio-economic contexts, the response to statements did not differ among the five regional landscapes. Overall, respondents agreed that semi-natural habitats and crop diversity were beneficial to stakeholders, and that it was advantageous for farmers to act collectively in terms of implementing practices at the landscape scale (Fig. 4). The majority of farmers agreed or strongly agreed that the implementation of practices at the landscape scale was possible while continuing to work the plots individually, and that this decision could be taken by the farmers themselves. Other factors, such as the Common Agricultural Policy, were not considered to be an obstacle to such management. However, if collective management was perceived by interviewees as possible, it was not perceived as being easy, with 19 interviewees disagreeing with the statement "It is easy for me to act collectively in the implementation of new practices". There was also less agreement on whether collective management could reduce costs at the farm level: On the latter question, 14 of the 55 farmers interviewed neither agreed nor disagreed, and 7 farmers disagreed (Fig. 4). In terms of subjective norms, respondents identified a variety of actors that had the most influence on their decision to work collectively, with the vast majority citing neighbors (Fig. 4). Other influential actors were consumers, cooperatives, chambers of agriculture. With regard to the links between these influential people and collective management, most respondents stressed that these groups were in favor of collective management and that it was important to follow their expectations (Fig. 4). Based on the above

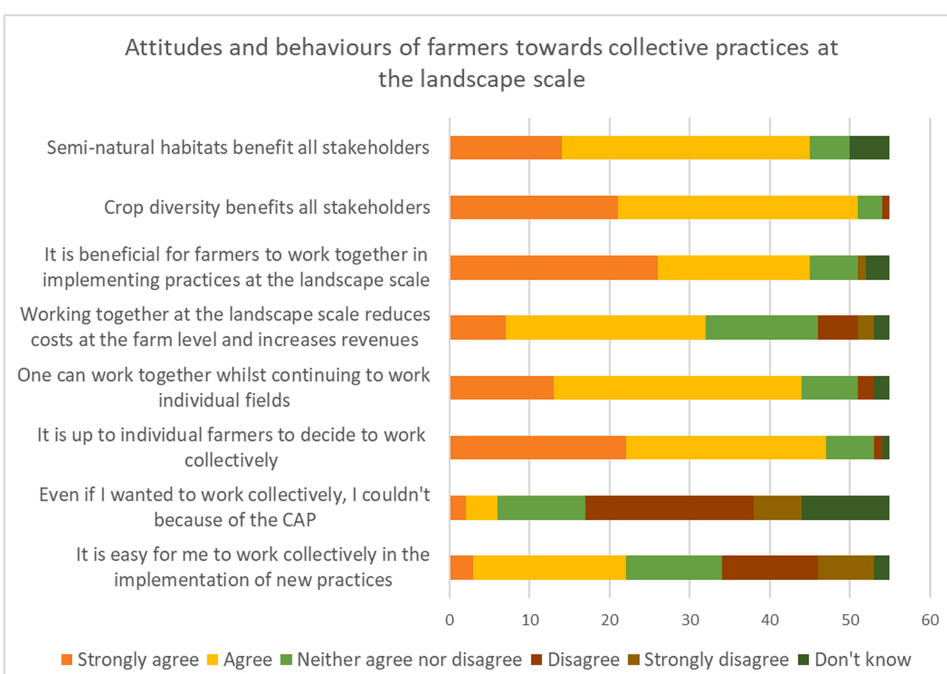


Fig. 4. Attitudes and behaviors of farmers towards collective practices at the landscape scale across the five replicate landscapes of the French LMN (55 respondents).

preliminary results, it appears crucial to further explore the reasons why farmers do not agree with the statement "It is easy for me to act collectively in implementing new practices". The LMN approach also offers the opportunity to determine how behaviors, attitudes and norms around collective management will change over time.

8. Building capacity to deliver predictions of natural pest control

Making sense of the large variability very often observed in the effect of on-field and off-field management options on the natural pest control services strongly limits our ability to extrapolate to other contexts (Karp et al., 2018; Petit et al., 2020). Mainstreaming natural pest control services in agricultural landscapes would clearly benefit from: (i) a unified framework to understand how several environmental variables (e.g., farming practices, land use, climate) jointly affect the flow of natural pest control services in multiple production contexts, and (ii) reliable predictive tools validated in a large variety of contexts.

LMN provides large and robust datasets with fine temporal and spatial resolution, with multiple observations taken along environmental gradients or in contrasted production contexts with sufficient repetitions over time and space. As such, LMN can directly support explanatory and predictive statistical models. Such models can directly feed the development of more mechanistic models, thereby contributing to bridge the gap between the generality of theoretical mechanistic models and the realism of statistical models investigating the effects of environmental variables in a given context (Alexandridis et al., 2021). We propose here a framework, i.e. the overall workflow used to analyze data generated in LMN and to build capacity to deliver predictions of natural pest control in agricultural landscapes. The framework includes three steps: (i) fitting models, (ii) validating models and (iii) using models in *in silico* experiments (Fig. 5).

Comprehensive explanations of model fitting or variable selection as well as a comparison of the relative merits or limits of the different types of statistical models are readily available in the literature and are beyond the scope of this paper (Dormann et al., 2007, Burnham and Anderson, 2002; Grueber et al., 2011 for detailed review on those topics). In the French LMN, we explored two, non-exclusive, statistical approaches (Fig. 4). A first exploratory approach consisted in investigating the relationships between a vast set of explanatory variables and the resulting level of natural pest control without strong a priori hypotheses about their relative importance, using machine learning algorithms such as random forests (Breiman, 2001). Such exploratory tools assess the relative importance and ranking of explanatory variables with regard to their impacts on the level of pest control. Furthermore, the flexibility of such models generally entails good regression performance provided that data are representative of the contexts for which natural pest control services are investigated. The vast array of situations present in LMN generated data is thus highly suited to this type of modeling approach. A second approach consisted in developing hypotheses-based models, i.e. testing much more specific hypotheses regarding the impact of environmental variables on pest control services based on parameter

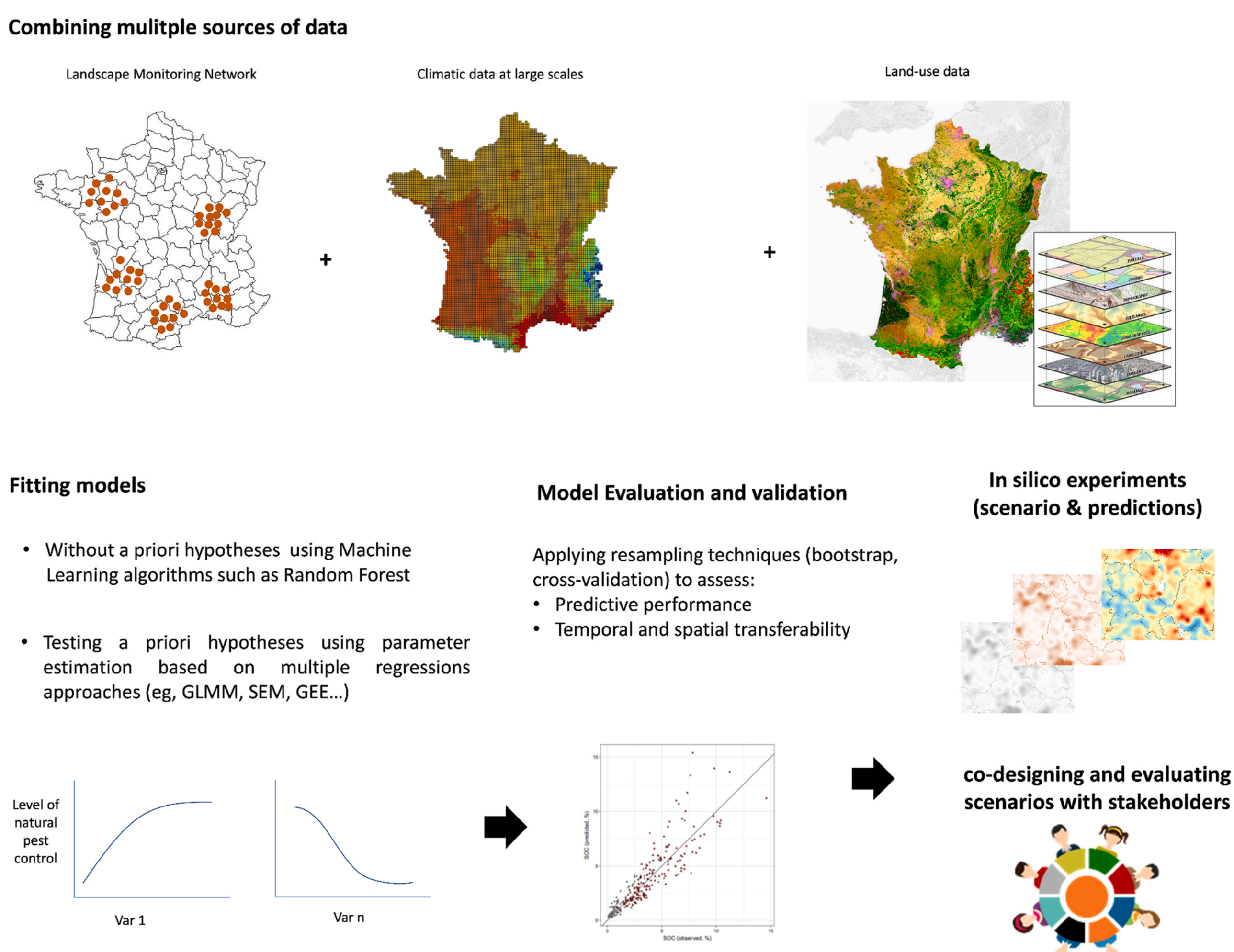


Fig. 5. illustration of the overall workflow used to analyze data generated in the French LMN to build capacity to deliver predictions on pest control services in agricultural landscapes.

inference. Once models have been fitted and basic assumptions of models have been checked, parameter estimation of well-fitted models can be used to assess the validity of the specified biological hypotheses. This approach refers to Generalized Linear (Mixed) Models, Structural Equation Modeling, Generalized Estimating Equations, or Bayesian models that offer multiple options to deal for instance with the nature of the response variables, the error distributions, the spatial or temporal autocorrelation, or the hierarchical nature of the design. Such models require parsimony to avoid multicollinearity issues and are thus well-suited to analyze data derived from experimental designs controlling confounding factors. Although not fully experimental, the design of LMN is suited to this type of approach and hypotheses-based models have been successfully applied across the French LMN (Ricci et al., 2019). However, the focus on specific hypotheses and the requirement for parsimony tend to favor their development on a specific regional landscape rather than over the whole landscape network given that the number of important explanatory variables increases with the number of regional contexts explored. Overall, these two statistical approaches feed each other and make it possible to fit statistical models about pest control services with reasonably good explanatory powers.

Model evaluation and validation is a major step to ensure the reliability and generalization capacity of the models. Goodness-of-fit is usually used to assess the model performance, however, this is not enough to guarantee that the model performs well in situations that do not appear in the data set. For this purpose, resampling techniques such as bootstrap or cross-validation are relevant and make it possible to assess the robustness of predictions based on the fitted models using a variety of metrics assessing predictive performance (e.g. root mean square error of prediction). Remarkably, in the context of LMN, the provision of data over multiple years and replicate landscapes enables to perform stratified cross-validation procedures where only a subset of data is used to develop the model and the remaining data is used to validate the model. Such cross-validation procedures can be mobilized to evaluate model transferability in space (i.e. between LMN sites) and time (i.e. between years on the same LMN site).

Finally, in our framework, once models are fitted and considered reliable, they are used in *in silico* experiments to explore how different scenarios affect pest control services. This exploration provides a basis for discussing collective action at the landscape scale among stakeholders with the goal of designing agroecological landscapes (Poggi et al., 2018). Comparing the outcomes of contrasted landscape-change scenarios is a valuable approach to perform this exploration while accounting for a realistic representation of landscape constraints (e.g. dependency between field size and hedgerow network density and agronomical constraints (e.g. crop allocation at the farm level, Martel et al., 2019). Such modeling tools are very useful with stakeholders to highlight the potential effects of changes in practices and the interdependencies of farmers with respect to biological control. They can help collective action in a given context while producing generic knowledge about lock-ins and leverage points to improve collective actions. However, for a transdisciplinary approach, such tools must be transparent about uncertainties, such as those governing the links between landscape structure, agricultural practices and biological control (Steingröver et al., 2010; Salliou et al., 2019b). It is important to recognize that actors who engage in agroecological practices are subject to risks of failure to achieve expected gains. Raising awareness among actors of the uncertainties, expected gains and losses associated with changes in agricultural practices is a key dimension of transdisciplinary research (Coolsaet, 2015).

8. Conclusion

To meet the challenges of sustainability, future agriculture landscapes will likely need to be explicitly designed. We illustrated here that landscape monitoring network approaches can help building capacities for designing agroecological landscapes, by providing a continuum of ecological and social knowledge ranging from place-based specific findings to more formalized and generic responses. The example of the existing French LMN on natural pest control services is one of many implementations of long-term socio-ecological approaches that can foster the development of agroecology. Methodological advances that are emerging may well shape the future of such research facilities and modify their potential contribution to the design of agricultural landscapes. In the near future, it is likely that the amount of data that can be collected will increase, both in quantity and quality, with increased scope for predicting ecological processes across landscapes. For example, recent advances in remote sensing methods are proving highly valuable to characterize landscape heterogeneity of agricultural landscapes at fine spatial scale (Soti et al., 2018) and to capture how this heterogeneity varies within and between years (Mercier et al., 2019). The widespread use of passive sensors could facilitate a joined-up approach to agricultural landscapes because they could both combine biomonitoring across different agricultural habitats and provide metrics that could be linked to the activities of individual farmers (Reboud et al., 2021). These ‘Big data’ hold the promise of being highly fitted to the discovery of patterns in data that allow a reasonable prediction of ecological processes in agricultural landscapes. In addition, if one considers the design process as a link between science and landscape change, some lessons can be drawn from our analysis that can feed back into the research developed within landscape networks. LMNs are not specifically designed to enact landscape transformation, however, such research facilities could be mobilized to tackle social issues in landscape transformation. Overcoming internal differences amongst farmers could be an important step to clarify local perspectives and knowledge and strengthen local actors’ capacity to engage towards long-term solutions enhancing biodiversity and ecosystem services (Skrimizea et al., 2020). This could be achieved through initiatives that bring land managers together to work more cohesively together in their locality One example are the development of farmer’s clusters in the UK, which are landscape-scale, farmer-led projects or groups that aim to deliver greater benefits for soil, water and wildlife at a landscape scale (https://www.farmerclusters.com/). Partnerships, which are strong, pluralistic forms of governance could also be developed within LMNs. They could integrate, for example, initiatives between farmers, consumers and agri-businesses that would promote best practices in agricultural landscapes but also higher standards of living and rural developments for farmers, building awareness and trust and reducing the negative perception consumers can have of farmers (Lécuyer et al., 2021).

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The corresponding author is associate editor for AGEE; she is also one of the guest editor of the VSI 'Biodiverse Landscapes' to which the present ms is being submitted.

Data Availability

Data will be made available on request.

Acknowledgements

Research reported in this publication was conducted under the PREPARE project, supported by the French Office for Biodiversity (OFB) as part of the call Ecophyto on “Territorial levers to reduce the use and risks linked to phytopharmaceutical products” launched by the French Ministries in charge of Ecology, Agriculture, Health and Research. We also acknowledge long-term financial support from INRAE.

References

Alexandridis, N., Marion, G., Chaplin-Kramer, R., Dainese, M., Ekroos, J., Grab, H., Jonsson, M., Karp, D.S., Meyer, C., O'Rourke, M.E., Pontarp, M., Poveda, K., Seppelt, R., Smith, H.G., Martin, E.A., Clough, Y., 2021. Models of natural pest control: towards predictions across agricultural landscapes. Biol. Cont. 163, 104761.

Allart, R., Ricci, B., Poggi, S., 2021. R package alm: automated landscape mapping. Porta Data INRAE V2. https://doi.org/10.15454/AKQW7Y.

Barnaud, C., Corbera, E., Muradian, R., Salliou, N., Sirami, C., Vialatte, A., Choisis, J.-P., Dendoncker, N., Mathevet, R., Moreau, C., Reyes-García, V., Boada, M., Deconchat, M., Cibien, C., Garnier, S., Maneja, R., Antona, M., 2018. Ecosystem services, social interdependencies, and collective action: a conceptual framework. Ecol. Soc. 23 (1), 15.

Batáry, P., Báldi, A., Kleijn, D., Tscharntke, T., 2011. Landscape-moderated biodiversity effects of agri-environmental management: a meta-analysis. Proc. R. Soc. B 278, 1894–1902.

Biggs et al. Toward principles for enhancing the resilience of ecosystem services A. Gadgil D.M. LivermanAnnu. Rev. Environ. Resour. 37 2012 421 Biggs, R., et al., 2012. Toward principles for enhancing the resilience of ecosystem services. In: Gadgil, A., Liverman, D.M. (Eds.), Annual Review of Environment and Resources 37, 421.

Bohan, D.A., Schmucki, R., Abay, A.T., Termansen, M., Bane, M., Charalabidis, A., Cong, R.G., Derocles, S.A.P., Dorner, Z., Forster, Therond, O., Young, J., Zalai, M., Pocock, M.J.O., 2021. Designing farmer-acceptable rotations that assure ecosystem service provision in the face of climate change. Adv. Ecol. Res. vol 65, 169–244.

Breiman, L., 2001. Random forests. Mach. Learn. 45, 5–32. https://doi.org/10.1023/A:1010933404324.

Bretagnolle, V., Benoit, M., Bonnefond, M., Breton, V., Church, J.M., Spiegelberger, T., Fritz, H., 2019. Action-orientated research and framework: insights from the French long-term social-ecological research network. Ecol. Soc. 24 (3), 10.

Burnham, K.P., Anderson, D.R., 2002. A practical information-theoretic approach. Model Sel. Multimodel Inference 2, 70–71.

Chaplin-Kramer, R., O'Rourke, M.E., Blitzer, E.J., Kremen, C., 2011. A meta-analysis of crop pest and natural enemy response to landscape complexity. Ecol. Lett. 14, 922–932.

Cieslik, K., Cecchi, F., Damtew, E.A., Tafesse, S., Struik, P.C., Lemaga, B., Leeuwis, C., 2021. The role of ICT in collective management of public bads: The case of potato late blight in Ethiopia. World Dev. 140, 105366.

Coolsaet, B., 2015. Transformative participation in agrobiodiversity governance: making the case for an environmental justice approach. J. Agric. Environ. Ethics 28 (6), 1089–1104.

Costello, C., Quérou, N., Tomini, A., 2017. Private eradication of mobile public bads. Eur. Econ. Rev. 94, 23–44.

Dainese, M., Martin, E.A., Aizen, M.A., Steffan-Dewenter, I., 2019. A global synthesis reveals biodiversity-mediated benefits for crop production. Sci. Adv. 5 eaax0121.

Dormann, F., McPherson, C.M., Araújo, J.B., Bivand, M., Bolliger R, J., Wilson, R., 2007. Methods to account for spatial autocorrelation in the analysis of species distributional data: a review. Ecography 30, 609–628.

Duflot, R., San-Cristobal, M., Andrieu, É., Choisis, J.P., Esquerré, D., Ladet, S., Vialatte, A., 2022. Farming intensity indirectly reduces crop yield through negative effects on agrobiodiversity and key ecological functions. Agric. Ecosyst. Environ. 326, 107810.

Duru, M., Therond, O., Fares, M., 2015. Designing agroecological transitions; a review. Agron. Sustain. Dev. 35, 1237–1257.

Gagic, V., Kleijn, D., Báldi, A., van der Putten, W.H., van Gils, S., Bommarco, R., 2017. Combined effects of agrochemicals and ecosystem services on crop yield across Europe. Ecol. Lett. 20, 1427–1436.

Geertsema, W., Rossing, W.A., Landis, D.A., Bianchi, F.J., van Rijn, P.C., Schaminée, J.H., Tscharntke, T., van der Werf, W., 2016. Actionable knowledge for ecological intensification of agriculture. Front. Ecol. Environ. 14, 209–216.

Geiger, F., Bengtsson, J., Berendse, F., Weisser, W.W., Emmerson, M., Morales, M.B., A, Hänke, S., Fischer, C., Goedhart, P.W., Inchausti, P., 2010. Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. Basic Appl. Ecol. 11, 97–105. https://doi.org/10.1016/j.baae.2009.12.001.

Grueber, C.E., Nakagawa, S., Laws, R.J., Jamieson, I.G., 2011. Multimodel inference in ecology and evolution: challenges and solutions. J. Evolut. Biol. 24, 699–711.

Haan, N.L., Iuliano, B.G., Gratton, C., Landis, D.A., 2021. Designing agricultural landscapes for arthropod-based ecosystem services in North America. Adv. Ecol. Res. 64, 191–250.

Jeanneret, Ph, Aviron, S., Alignier, A., Lavigne, C., Helfenstein, J., Herzog, F., Kay, S., Petit, S., 2021. Agroecology Landscapes. Land. Ecol. 36, 2235–2257.

Karp, D.S., Chaplin-Kramer, R., Meehan, T., Xiao, H., Yasuda, M., Yoshioka, A., Zou, Y., 2018. Crop pests and predators exhibit inconsistent responses to surrounding landscape composition. Proc. Natl. Acad. Sci. USA 115, e7863–e7870.

Kleijn, D., Bommarco, R., Fijen, T.P.M., Garibaldi, L.A., Potts, S.G., van der Putten, W.H., 2019. Ecological intensification: bridging the gap between science and practice. Trends Ecol. Evol. 34, 154–166.

Kuussaari, M.R., Bommarco, R.K., Heikkinen, A., Helm, J., Krauss, R., Lindborg, E., Öckinger, M., Pärtel, J., Pino, F., Rodà, C., Stefanescu, T., Teder, M., Zobel, I., Steffan-Dewenter, 2009. Extinction debt: a challenge for biodiversity conservation. Trends Ecol. Evol. 24, 564–571.

Landis, D.A., 2017. Designing agricultural landscapes for biodiversity-based ecosystem services. Basic Appl. Ecol. 18, 1–12.

Lautenbach, S., Mupepele, A.C., Dormann, C.F., et al., 2019. Blind spots in ecosystem services research and challenges for implementation. Reg. Environ. Change 19, 2151–2172.

Le Provost, G.L., Badenhausser, I., Bagousse-Pinguet, Y.L., Clough, Y., Henckel, L., Violle, C., Bretagnolle, V., et al., 2020. Land-use history impacts functional diversity across multiple trophic groups. PNAS 117, 1573–1579.

Lécuyer, L., Alard, D., Calla, S., Coolsaet, B., Young, J.C., 2021. Conflicts between agriculture and biodiversity conservation in Europe: Looking to the future by learning from the past. Adv. Ecol. Res. 65, 3–56.

Lence, Sergio H., Singerman, Ariel, 2022. When does voluntary coordination work? Evidence from area-wide pest management. Am. J. Agric. Econ. 1–22.

Martel, G., Aviron, S., Joannon, A., Lalechère, E., Roche, B., Boussard, H., 2019. Impact of farming systems on agricultural landscapes and biodiversity: from plot to farm and landscape scales. Eur. J. Agron. 107, 53–62.

Mercier, A., Betbeder, J., Rumiano, F., Baudry, J., Gond, V., Blanc, L., et al., 2019. Evaluation of sentinel-1 and 2 time series for land cover classification of forest-agriculture mosaics in temperate and tropical landscapes. Remote Sens. 11, 979.

Müller, F., Baessler, C., Schubert, H., Klotz, S., 2010. Long-Term Ecological Research between Theory and Application. Springer, Dordrecht. https://doi.org/10.1007/978-90-481-8782-9.

Muneret, L., Auriol, A., Thiéry, D., Rusch, A., 2019. Organic farming at local and landscape scales fosters biological pest control in vineyards. Ecol. Appl. 29, e01818.

Muneret, L., Ricci, B., Vialatte, A., Aviron, S., Ducourtieux, C., Biju-Duval, L., Petit, S., 2022. **Carabid beetles have hump-shaped responses to disturbance and resource gradients within agricultural landscapes**. J. Appl. Ecol. In press.

Nassauer, J.I., Opdam, P.F.M., 2008. Design in science: extending the landscape ecology paradigm. Land Use Plan. 23, 633–644.

Ostrom, E., 1990. Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press, Cambridge.

Ostrom, E., 2010. Beyond markets and states: polycentric governance of complex economic systems. Am. Econ. Rev. 100 (3), 641–672.

Pelosi, C., Goulard, M., Balent, G., 2010. The spatial scale mismatch between ecological processes and agricultural management: do difficulties come from underlying theoretical frameworks? Agric. Ecosyst. Environ. 139, 455–462.

Petit, S., Muneret, L., Carbonne, B., Hannachi, M., Ricci, B., Rusch, A., Lavigne, C., 2020. Landscape-scale expansion of agroecology to enhance natural pest control: a systematic review. Adv. Ecol. Res. 63, 1–48.

Petit, S., Deytieux, V., Cordeau, S., 2021. Landscape-scale approaches for enhancing biological pest control in agricultural systems. Environ. Monit. Assess. 193.

Poggi, S., Papaïx, J., Lavigne, C., Angevin, F., Le Ber, F., Parisey, N., Ricci, B., Vinatier, F., Wohlfahrt, J., 2018. Issues and challenges in landscape models for agriculture: from the representation of agroecosystems to the design of management strategies. Land. Ecol. 8, 1679–1690.

Pretty, J., Benton, T.G., Bharucha, Z.P., Smith, P., Thorne, P., Wratten, S., 2018. Global assessment of agricultural system redesign for sustainable intensification. Nat. Sustain. 1, 441–446.

Ratsimba, N., Therond, O., Parry, H., Monteil, C., Vialatte, A., 2022. Inconsistent responses of conservation biocontrol to landscape structure: new insights from a network-based review. Ecol. Appl. 32 (2), e02456.

Reboud, X., Poggi, S., Bohan, D.A., 2021. Effective biodiversity monitoring could be facilitated by networks of simple sensors and a shift to incentivising results. Adv. Ecol. Res. 65, 339–365.

Ricci, B., Lavigne, C., Alignier, A., Thomas, C., Vialatte, A., Petit, S., 2019. Local pesticide use intensity conditions landscape effects on biological pest control. Proc. R. Soc. B 286, 20182898.

Rusch, A., Chaplin-Kramer, R., Gardiner, M., Winqvist, C., Woltz, M., Bommarco, R., 2016. Agricultural landscape simplification reduces natural pest control: a quantitative synthesis. Agric. Ecosyst. Environ. 221, 198–204.

Salliou, N., Barnaud, C., 2017. Landscape and biodiversity as new resources for agroecology? Insights from farmers' perspectives. Ecol. Soc. 22 (2).

Salliou, N., Muradian, R., Barnaud, C., 2019a. Governance of ecosystem services in agroecology: when coordination is needed but difficult to achieve. Sustainability 11, 1158.

Salliou, N., Vialatte, A., Monteil, C., Barnaud, C., 2019b. First use of participatory Bayesian modeling to study habitat management at multiple scales for biological pest control. Agron. Sustain. Dev. 39.

Sánchez-Bayo, F., Wyckhuys, K.A.G., 2019. Worldwide decline of the entomofauna: a review of its drivers. Biol. Conserv. 232, 8–27.

Savary, S., Willocquet, L., Pethybridge, S.J., Esker, P., McRoberts, N., Nelson, A., 2019. The global burden of pathogens and pests on major food crops. Nat. Ecol. Evol. 3, 430–439.

Scott, J., Marshall, G., 2009. A Dictionary of Sociology. Oxford University Press.

Singerman, A., Useche, P., 2019. The role of strategic uncertainty in area-wide pest management decisions of Florida citrus growers. Am. J. Agric. Econ. 101, 991–1011.

Skrimizea, E., Lecuyer, L., Bunnefeld, N., Butler, J.R.A., Young, J.C., 2020. Sustainable agriculture: recognizing the potential of conflict as a positive driver for transformative change. Adv. Ecol. Res. 63, 255–311.

Soti, V., Lelong, C., Goebel, F.R., Brévault, T., 2018. Designing a field sampling plan for landscape-pest ecological studies using VHR optical imagery. Int. J. Appl. Earth Obs. Geoinf. 72, 26–33.

Steingröver, E.G., Geertsema, W., van Wingerden, W.K., 2010. Designing agricultural landscapes for natural pest control: a transdisciplinary approach in the Hoeksche Waard (The Netherlands). Land. Ecol. 25, 825–838.

Vanbergen, A.J., Aizen, M.A., Cordeau, S., Garibaldi, L.A., Young, J.C., 2020. Transformation of agricultural landscapes in the anthropocene: nature's contributions to people, agriculture and food security. Adv. Ecol. Res. 63, 193–253.

Veres, A., Petit, S., Conord, C., Lavigne, C., 2013. Does landscape composition affect pest abundance and their control by natural enemies? A review. Agric. Ecosyst. Environ. 166, 110–117.

Vialatte, A., Tibi, A., Alignier, A., Angeon, V., Martinet, V., 2021. Promoting crop pest control by plant diversification in agricultural landscapes: A conceptual framework for analysing feedback loops between agro-ecological and socio-economic effects. Adv. Ecol. Res. 65, 133–165.

Weltin, M., Zasada, I., Piorr, A., Debolini, M., Geniaux, G., Moreno Perez, O., Scherer, L., Tudela Marco, L., Schulp, C.J.E., 2018. Conceptualising fields of action for sustainable intensification – A systematic literature review and application to regional case studies. Agric. Ecosyst. Environ. 257, 68–80.