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Governance of Ecosystem Services in Agroecology: When Coordination is Needed but Difficult to Achieve

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Abstract: Transitioning towards agroecology involves the integration of biodiversity based ecosystem services into farming systems: for example, relying on biological pest control rather than pesticides. One promising approach for pest control relies on the conservation of semi-natural habitats at the landscape scale to encourage natural enemies of insect pests. However, this approach may require coordination between farmers to manage the interdependencies between the providers and beneficiaries of this ecosystem service. The main objective of this study was to identify hindrances to landscape-scale coordination strategies to control pests. To this end, we used a theoretical framework specifically designed to explore social interdependencies linked to ecosystem services. We applied this framework to a participatory research case study on pest control in apple orchards in southwest France to identify and describe key obstacles. We found four main impediments: (1) The perception of most stakeholders that the landscape does not deliver significant pest control services, (2) the challenge of coping with agroecological uncertainties, (3) an integrated vertical supply chain focused on pesticide use, (4) the existence of independent, non-collective alternatives. We discuss the potential of overcoming these obstacles or turning them into opportunities that promote a transition to agroecology and the integration of ecosystem services in farms and their supply chains.

Keywords: biological pest control; landscape management; semi-natural habitats; social interdependencies

1. Introduction

The integration of biodiversity-related ecosystem services into farming systems is central to the transition towards more agroecological ways of farming [1,2]. For example, soil fertility can be enhanced by biological processes rather than by the use of chemical fertilizers, while local biodiversity can be used to regulate pathogens, pests, weeds, etc. [3]. The potential contribution of agroecology to achieving worldwide sustainable development goals has been stressed by international organizations including the United Nations [4]. One promising example is biological pest control, an ancient agroecological approach that consists of making use of certain organisms to control others. However, transitioning towards more agroecological ways of farming is challenging, as many farmers still favor an approach based on ecosystem simplification (e.g., monoculture) and intensive use of inputs, despite negative consequences for a wide range of ecosystem services [1]. For instance, it is increasingly acknowledged that the use of pesticides and the simplification of farming systems lead to lower levels of biological pest control [5,6]. While pesticide use could be reduced or replaced by increased biological pest control [7], its substitution on the ground can confront a variety of behavioral, institutional and technical barriers.

In this study, we focused on one specific agroecological approach to biological pest control, which relies on the positive effect of certain landscape compositions on the regulation of insect pests by their natural enemies [8]. In this context, 'natural enemies' are any species that prey on or parasitize a pest. Landscape ecology studies have shown that agricultural landscapes with a high proportion of semi-natural habitats (SNH), such as woods, hedgerows or meadows, are favorable to biological pest control by natural enemies [9,10]. These habitats often lower pest pressure by providing shelter, food and egg-laying sites to natural enemies. For example, landscapes with abundant field margins and perennial crops have been correlated with lower aphid establishment [11] and higher yields in spring barley in Sweden [12].

Some authors have suggested that farmers and other landholders could engineer landscapes in order to create a high proportion of favorable habitats for natural enemies, an approach that would require collaboration between stakeholders [8]. The key role of landscape structure and the proportion of non-crop habitats to enhance biological control in agroecosystems was first stressed by the seminal study of reference [13]. Potential benefits for farmers could include reduced pesticide use, decreased pest damage to crops, or increased sales through the promotion of their agroecological practices to consumers. Some modeled simulations have shown that managing the proportion of SNH at the landscape scale could be beneficial to farmers [14,15]. To encourage this, some public policies in Europe offer to subsidize farmers to help them develop SNH [16,17]. Furthermore, a recent French government report on transitioning from intensive pesticide use towards more agroecology practices showed policymakers' willingness to provide support for a landscape approach to pest control [18]. Nevertheless, the positive relationship between landscape composition and pest control often remains site specific, making general recommendations for landscape management difficult [19]. Operationalizing the potential of biological pest control and making it mainstream is still at the research stage for landscape ecologists [20,21]. While enhanced biological pest regulation through landscapes rich in SNH appears to be a promising agroecological innovation that is supported by scientific findings and public policymakers, very few real cases of coordination with this aim have been documented [22]. This study seeks to understand why such a gap exists, by identifying the current obstacles to landscape-scale coordination strategies for pest control.

From a social perspective (the main point of view of this study), a landscape-based agroecological approach to pest control is associated with specific challenges associated with (i) the collective action required and (ii) the difficulty of excluding beneficiaries due to the public nature of this ecosystem service [23]. In such situations, there is no clear distinction between service providers and beneficiaries, since the farmers who pool their land (increasing the proportion of SNH) may take both roles, creating a high degree of interdependency between agents [24]. However, farmers who decide not to participate can also benefit from the service. This situation is similar to the classic conceptualization of public goods games, in which players make individual choices to invest or not to invest in a public good, but the benefits derived from it are equally shared between all players, independently of their contribution [25]. A biodiverse landscape with a high composition of SNH can be considered a public good, delivering biological pest control to all farmers in the area of impact, independently of their shares in the common pool of SNH.

Challenges concerning the provision of public goods usually arise because concerted action between many parties is needed, and free riders may benefit without contributing [26]. The possibility of free riding can discourage potential contributors to the provision of the collective good [26]. Such a situation is typical of 'the tragedy of ecosystem services' [27], in which potential beneficiaries are dependent on the decisions of other agents in order to benefit from an ecosystem service. In this specific case, potential beneficiaries of biological pest control are dependent on the overall proportion of SNH in the landscape, which depends on the individual decisions of potential providers in order to create a critical mass of the desired habitats [2,28,29] (see Figure 1).

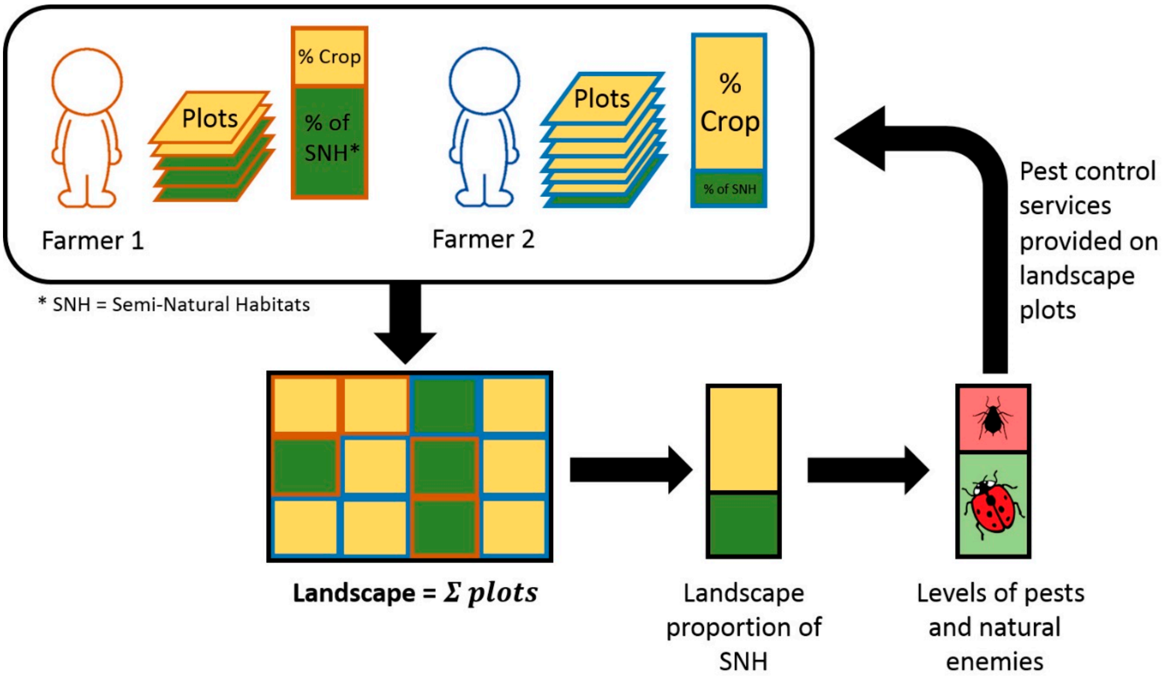

Figure 1. Landscape-based provision of biological pest control from the composition of Semi-Natural Habitats (SNH).

Coordination is defined as the management of dependencies between agents [30]. Dependencies occur when an agent's benefits are conditioned by something or someone not entirely under his or her control. One of the main roles of institutions—markets, the state, the community or a combination of these—is to enable the coordination needed to solve problems arising from a situation of dependency [31,32]. Coordination between agents can be complex due to the heterogeneity of both providers and beneficiaries. Different stakeholders tend to have diverse objectives and may frame social and ecological interdependencies differently [24].

These theoretical insights on coordination can be useful to elucidate the challenges of landscape-scale strategies for pest control, especially the problems associated with collective management [33] and the willingness of farmers to cooperate [34]. These challenges may explain why very few real cases of a coordination aiming at increasing SNH for biological pest control have been documented [22], despite encouraging scientific findings and the support of public policymakers. To explore why such a gap exists, we used a conceptual framework designed to characterize social interdependencies underlying ecosystem services in agrarian socio-ecological systems [24]. By analyzing key interdependencies in a specific case study in southwest France, we identified four main hindrances to the emergence of a coordinated response for ecosystem service provision: (1) the common perception that the landscape delivers low pest control services, resulting in low interdependency between stakeholders, (2) high scientific uncertainty about the agroecological processes at play, (3) the presence of an integrated supply chain that locks farmers into pesticide use, and (4) the existence of alternative individual options to collective agroecological solutions. Based on these findings, we discuss the potential of overcoming obstacles to deploying agroecological solutions for pest control.

2. Materials and Methods

2.1. Case Study

Our case study is located in southwest France, in Tarn-et-Garonne, an agricultural region specializing in apple production. The Aveyron and Tarn rivers form a landscape of alluvial terraces with fertile soil and access to water for irrigation. The location is highly favorable for growing fruit trees. Most apple producers in the area use intensive chemical treatments to control a wide variety of pests. For example, national statistics from 2012 indicate that apple farmers in this region apply on average over 11 insecticide treatments each year. The intensity of chemical treatment is linked to the commercial necessity for farmers to harvest fruit without any aesthetic defects in order to obtain the best prices.

In the 1980–90s, public authorities began to promote integrated pest management practices. A first success in the use of natural enemies to regulate pests was achieved against the European red mite (*Panonychus ulmi*) on apple trees. The integration of *Aphelinus mali*, which parasitizes woolly aphids (*Eriosoma lanigerum*), and the introduction of *Neodryinus typhlocibae* against *Metcalfa pruinosa* invasive pests are some notable later successes [35]. While further advances in integrated pest management have been achieved, pesticide use remains by far the main pest control option in the area, which reflects the general situation in France. In fact, pesticide use has increased in recent years [36]. Exclusion nets, which limit pest access by enclosing orchards or trees, have been a non-chemical technology on the rise in the area. The efficacy of this method lies in its capacity to create a physical boundary to pests. In our study area, nets are implemented to prevent the incidence of the codling moth (*Cydia pomonella*) [37], a major pest in apple orchards, but they can be applied to diverse types of pests and crops [38].

2.2. Framework of Analysis: Characterizing Interdependencies to Identify Obstacles for Coordination

We adopted a conceptual framework that uses the lens of ecosystem services to characterize social interdependencies between people and highlight potential or existing cooperation between them [24]. This framework proposes to start identifying the key ecosystem services at stake – in our case, in concerted landscape management for biological pest control. Next, the beneficiaries and providers of the ecosystem services, as well as the intermediaries that indirectly influence decision-making, are identified. Finally, the social interdependencies between these stakeholders are identified and analyzed by exploring (i) the cognitive framing of interdependencies, (ii) institutions, (iii) levels of organization, and (iv) power relations. This study focuses on the first two dimensions. When identifying the cognitive framing of interdependencies, i.e., the stakeholders' representations of these interdependencies, we aimed to assess in particular the degree to which stakeholders perceive themselves as interdependent with other stakeholders. This is indeed critical in terms of motivation for collective action if people do not feel mutually interdependent, i.e., if they do not feel that they need one another to solve a problem or improve their situation, they are unlikely to invest time and energy in collective action [24,39]. The second task aimed at finding out whether the institutional context favored landscape-scale collaboration between farmers for biological pest control.

2.3. Data Collection: A Participatory Modelling Process

We applied this conceptual framework to analyze data collected during a participatory modelling process conducted from 2014 to 2017, which aimed at exploring the potential of a landscape-based biological pest control approach with key local stakeholders. Previous publications presented some of the methods that were developed and the results obtained from this participatory process [35,40,41]. For the current study, we adopted a broader stance to draw lessons from the whole process. We used the framework presented above [24] to revisit the collected data in order to identify the current hindrances to innovative approaches using landscape composition for biological pest control. The methodological steps implemented for data collection were as follows:

(i) *Context analysis*: We conducted 30 semi-structured individual interviews with stakeholders (farmers, technical advisors, public institutions, landowners) in order to identify key stakeholders, including beneficiaries and providers of pest control ecosystem services.

(ii) *Framing key issues with stakeholders*: We carried out individual interviews with public institutions overseeing agriculture in order to identify the highest stakes concerning pest control and which pest control issues were the most salient for local stakeholders.

(iii) *Eliciting stakeholders' representations of the socio-ecological systems*: We conducted 20 individual interviews with farmers, technicians and landowners in the study site to formalize their mental model about pest control. These mental models show key socio-ecological interactions from each stakeholder's subjective perspective (details are presented in reference [35]). From these interactions, the interdependencies were identified and characterized.

(iv) *Collective workshops integrating different types of knowledge and exploring scenarios using simulation tools*: We organized collective workshops that included scientific, technical and experiential knowledge. Integrating a diversity of knowledge has been emphasized as a key feature in exploring agroecological innovations [24]. With local stakeholders, we co-constructed models to simulate different facets of the socio-ecological system regarding biological pest control in the area. In particular, a Bayesian network model was co-constructed to integrate the different types of knowledge. Simulations were conducted with the stakeholders to explore the potential of landscape-based biological pest control [40], as well as alternative pest control strategies. More details about the Bayesian network model and results of each scenario are presented in references [40,41].

3. Results

Figure 2 summarizes the main components of the socio-ecological system using our conceptual framework [24]. It represents the key social interdependencies at stake in the potential use of SNH in landscapes for biological pest control, and the key stakeholders' cognitive framing of these interdependencies.

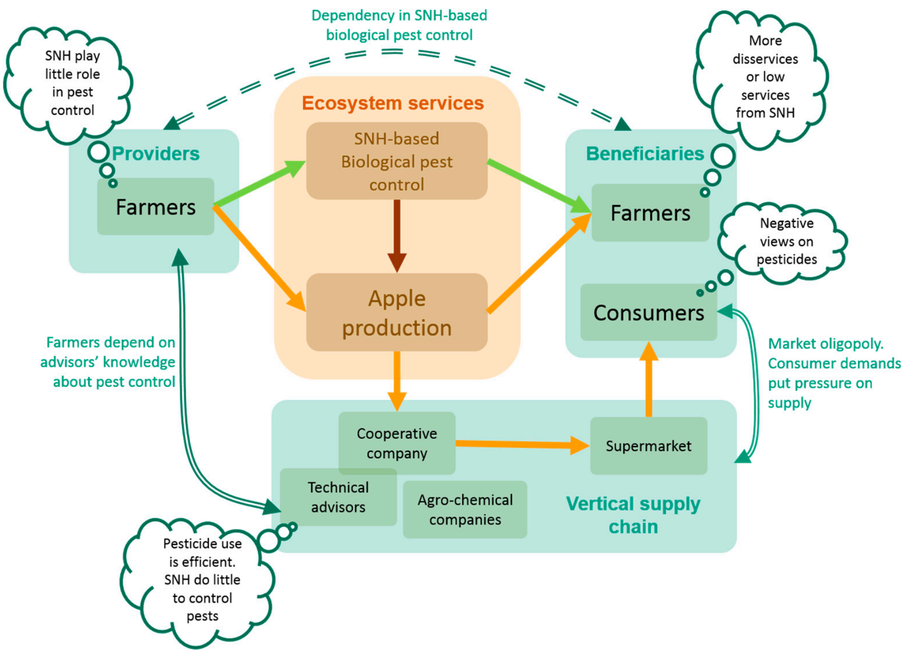

Figure 2. Representation of main social interdependencies (double-lined arrows) and ecosystem flows (green and orange arrows) from providers to beneficiaries. Bubbles represent the dominant perspectives of key stakeholders on pest control (SNH: semi-natural habitats).

Based on an analysis of these social interdependencies, we identified four main hindrances to the use of SNH in landscape composition to promote biological pest control.

The first obstacle is the current state of many stakeholders' mental representations regarding the effect of this agroecological innovation on biological pest control. We analyzed 24 mental models held by conventional as well as organic farmers. In these models, SNH are perceived as virtually unconnected with any biological pest control process in their farms [35]. In fact, some perceive that certain pests are stimulated by SNH. This shows that many farmers are aware that SNH have an influence on insects, but they mostly associate their impact with pest enhancement. The perception of local farmers that SNH favor the incidence of pests rather than natural enemies may explain the generally negative opinion about the pest control potential of this agroecological practice. Our simulations show that different types of stakeholders currently share the view that including SNH in landscape composition does not translate into significant ecosystem services for them [40,41]. Thus, the current cognitive representations indicate a very low level of perceived interdependency between potential providers and beneficiaries.

A second major hindrance involves uncertainties about the agroecological processes at play. In individual interviews, two technical advisors mentioned that previous scientific experiments (conducted in the 1990s) on the effects of SNH on biological pest control produced unconvincing results. These past experiments looked at the effect of SNH at the plot scale rather than at the landscape scale. Our participatory modeling process revealed that the ecologists taking part attributed a stronger effect of SNH on pest control than local stakeholders did [41]. While some academic studies have shown a positive correlation between SNH composition and control of pests by natural enemies [9,10], a recent review questions the consistency of this positive correlation [42]. In short, the capacity of a high proportion of SNH in a landscape to enhance pest control remains difficult to assess [43,44]. Indeed, landscape ecologists have recently put forward five hypotheses on why it can fail [21]. This shows the high degree of epistemic uncertainty regarding the underlying agroecological processes that may allow SNH to deliver ecosystem services. Farmers in the studied area have developed optimized cultivation systems regarding pest control and have a low tolerance for such a high level of uncertainty. This prevents farmers from investing in landscape engineering.

The third major hindrance we identified has to do with the vertical and concentrated structure of the supply chain. In our study area, the apple supply chain is highly integrated. Few farmers are independent, i.e., have their own distribution system. Most sell their harvest to one multinational company that in turn supplies a handful of supermarkets. Technical advice on pest control is mainly provided by technicians from this company, the local government agricultural agency or the local experimentation center (which tests and adapts new practices for farmers in the area). The interests of these institutions are closely intertwined, and technicians pool their information about pest control to provide consistent advice to local orchard farmers. This collective approach is a clear indicator of a highly integrated supply chain. In our interviews, many farmers indicated their high degree of dependency on technical advice for pest control strategy (Figure 2).

Such an integrated supply chain offers little room for agroecological innovations. While consumers exert some pressure for change, driven by general negative representations of pesticide use (in particular the perceived potential health consequences of chemical residues), they also depend on supply chains that promote pesticide-based pest control strategies. There is a rising demand for organic fruits, resulting in a shift in production systems towards more ecological ways of farming, though this is occurring at a slow pace. Some farmers supplying the multinational company have converted a portion of their farm to utilize organic standards of production. Nevertheless, these changes remain limited. First, they primarily involve substituting inputs (i.e., from chemical to natural pesticides) with little concern about redesigning the system. Second, because most of these farmers have more land under conventional production and consider organic fruit simply as an economic opportunity, they show little genuine interest in more agroecological farming methods.

We noted that the less integrated a farmer was in the mainstream supply chain, the more he or she seemed interested in exploring agroecological innovations. Less integrated farmers were also more willing to participate in our research by attending collective workshops, and were more accepting of being interviewed and co-designing models. They included individuals that had links to government agencies and public pesticide reduction policies (Ecophyto plan, see reference [18]), had adopted agroecological and/or organic practices, or were conventional farmers with an independent distribution network (not the dominant multinational company). The latter were particularly interested in finding out about innovations that could give them a competitive advantage. This observation seems to suggest that a highly integrated supply chain can co-exist with diverse agents interested in exploring agroecological innovations. Further participatory research could prioritize these types of agents.

The final main obstacle we identified concerns the existence of private alternatives to collective agroecological solutions. We found that individual solutions are preferred by farmers, as well as technicians, compared to collective agroecological options that require landscape-scale action. In the context of pest control, the use of pesticides is by far preferred to biological alternatives, as confirmed by the collected mental models of farmers and technicians. As a consequence, many farmers criticize public policies that regulate the use of pesticides or take them off the market. From their perspective, this removes efficient solutions from their portfolio of pest control options. This issue can cause tension between farmers and representatives of government agencies controlling pesticide use.

There are a number of reasons why pesticide use remains the preferred option of farmers, including acquired knowledge of use, local availability, investment in spraying equipment and the low price of chemical products. However, new challenges are facing farmers, as European policies are seeking to regulate or ban pesticides, pests are becoming resistant to some pesticides and there are growing health and environmental concerns related to their use. This context may encourage farmers to increasingly explore alternative options such as biological pest control. However, exclusion nets are a recent and popular technological development that allow farmers to enclose patches of orchards to avoid the arrival of undesirable pests using a physical rather than a chemical barrier. This practice, implemented individually by farmers, is in a way the opposite of a landscape approach, since the farmer seeks to isolate his or her farm from the effects of the surrounding landscape; indeed, while the nets prevent pests, they also prevent natural enemies from accessing the orchard. Although this technique is more costly than pesticides, it will likely gain popularity as pesticides are phased out by regulations.

4. Discussion

What are the opportunities to overcome these four main obstacles to a coordinated approach to landscape-scale agroecological innovations? First, our most striking finding is the perceived low importance of the landscape as an ecosystem service provider regarding pest control by most participants in our research. This cognitive obstacle seems consistent with recent ecological studies that describe the difficulty of convincing farmers of the link between landscape composition and enhanced ecosystem services [21,44], and more broadly with the general challenge of operationalizing biodiversity in agriculture [43,45]. From an action-research perspective, this suggests that farmers and technicians need more robust evidence to encourage them to start exploring landscape-based solutions to pest control. The question of effectiveness is particularly important for apple farmers in the study area, as they are highly integrated in global markets and receive no subsidies for meeting conservation objectives. In other contexts, farmers may favor different value systems and give more priority to biodiversity or agroecological production systems in their practices [46]. But when farmers perceive low or no benefits from a potential innovation based on interdependencies, it is not surprising that they show little interest in exploring the collective action necessary to achieve it. Ostrom [47] has also stressed 'the importance of the resource' as a key factor in the likelihood that interdependent stakeholders will organize collectively to manage the resource.

Given the perception that the landscape has low importance for pest control, 'bundling' this ecosystem service with several other collective agroecological benefits may enhance interest in landscape management [48]. Furthermore, it might increase interdependencies between providers and beneficiaries. For example, our Bayesian network model indicates that stakeholders consider that pest control, pollination and water availability have interdependent relationships [41]. A way forward might be to search for agroecological solutions that group these three ecosystem services. Multifunctional landscape management is already showing promising results [49], although key challenges remain [50]. One of these is that bundling ecosystem services can increase complexity since more socio-ecological interactions are potentially at stake. In general, the governance of ecosystem services involves high costs between involved parties [51]. Moreover, bundling ecosystem services may raise the probability of trade-offs between them, requiring additional organizational costs to understand, monitor and integrate these trade-offs into day-to-day agricultural practices.

Second, in systems with vertical integrated supply chains, such as in our case study, there are strong social interdependencies between farmers, distributors (e.g., cooperatives or supermarkets) and consumers. In this context, the dependency on pesticides [52] is just one element of a highly integrated system that also involves information and commercialization dependencies. Transitioning to an agroecological system in such a context would likely require a more radical redesign, not only at the level of farms [7], but rethinking the whole institutionalized system at a higher level (e.g., markets and organizations) [53]. This could potentially mean redesigning the entire supply chain from farmer to consumer. Alternatives include box schemes and coop supermarkets, which often promote agroecological methods of production. These may offer some opportunities for rethinking supply chains [54], although they currently remain marginal. In these alternative supply chains, consumers may cover some of the additional costs resulting from their small scale and higher ecological uncertainty (e.g., consumers in box schemes often pay in advance for whatever the harvest produces).

Theories of change usually refer to two main types of change: incremental and radical [55]. In France, incremental change is already occurring through the slow but steady rise in organic certification among conventional farmers faced with demand from consumers. However, in the last decade, while organic production has risen, so has the overall use of pesticides. Radical change usually requires a significant crisis to occur, such as a paradigm shift in science or technology [56] or a socio-ecological collapse, which may open new possibilities for reorganizing the system [57]. Using a panarchy framework [57], vertical supply chains are systems with high connectedness between parties and could be considered in a 'K' phase, in which the probability of collapse is low, but adaptation capacity in case of significant shock is limited. An analogy here is that mainstream agents in vertical supply chains hold a similar dominant and stable position to high trees in the canopy, while alternative innovations are promising seedlings struggling at the ground level for nutrients and light. If conventional supply chains suffer a crisis, it is possible that alternatives could spread and conquer more market space, thus favoring more agroecological ways of farming. In this regard, consumer preferences could play an important role in shaping public policy to challenge established supply chains. In particular, rising concerns about the health and environmental impacts of chemical pesticides are pushing French policymakers to impose bans. For example, a recent major debate about the herbicide glyphosate highlighted the health concerns of the majority of the general public and led to the planned phasing out of the molecule despite unconvincing scientific evidence of its health impact on consumers [58]. It is possible that the public desire for health security could be taken further in the future through a generalized ban on pesticides. In this case, conventional farmers and supply chains may have to reorganize in radical ways and redesign production systems to integrate ecological processes. In practice, this reorganization could happen quite rapidly, as many farmers are ready to employ more environmental practices when these are aligned with clearly expressed societal needs [59]. Other scientific findings have also shown a high willingness of farmers to get involved in collective pest management [34]. This suggests that if key obstacles are removed, collective landscape management for biological pest control could spread quickly.

Finally, our findings show that the role of science is particularly significant in relation to the predictability of agroecosystem dynamics (or epistemic uncertainty [60]). Ostrom [47] identified that low predictability of natural resource dynamics is related to lower probability of coordination between stakeholders. The traditional role of science is to reduce uncertainty, but this objective seems particularly challenging when attempting to unravel the complexity of socio-ecological interactions [61,62]. For example, our study found that many participants were unconvinced about the causality between higher SNH in landscapes and biological pest control. This could be explained by the fact that the concerned ecological processes are highly variable. Inconsistent ecological processes [42] can make experiential learning difficult for farmers and technicians. Schultz and Wieland [63] make the case that agroecological phenomena in general are fundamentally uncertain due to their complexity and non-linearity. Indeed, natural ecosystems are more complex than simplified systems such as conventional agriculture, which has been designed to ensure predictable outcomes [64]. As a consequence, agroecology may require farmers to accept uncertainties rather than trying to reduce them. On the other hand, such uncertainties may not be inherent in agroecology, but the consequence of a lack of scientific knowledge due to poor investment in research about this approach over the years compared to other types of agricultural innovations [65]. It is also possible that the inherent variability of ecological processes and the difficulty of predicting their behavior make agroecology less desirable to fund. In France, some policymakers have indicated their willingness to support landscape-based solutions for pest control, but on the condition that scientists are able to prove sufficiently clear-cut cause—effect behaviors [18]. In a sense, there is a causality dilemma, since funding agroecology research is needed in order to prove to policymakers that agroecological innovations are worthwhile to fund. In this regard, a real case of landscape engineering with the aim of increasing SNH that was initiated 10 years ago [22] should be investigated in an impact assessment, as this could help respond to outstanding questions. In terms of developing agroecological innovations in any given context, participatory research is often promoted as an effective approach [2,55], especially when it explicitly takes into account uncertainties [66] as well as diverse sources of knowledge.

5. Conclusions

This study analyzed social interdependencies to characterize the main challenges faced by a potential agroecological innovation that would rely on coordination between farmers. As many ecosystem services are similar to public goods, they may require some form of coordination to manage the dependencies between the providers and beneficiaries of these services. Concerning the specific case of biological pest control provided by SNH in the composition of a landscape, we identified four main hindrances in implementing this approach: (1) the mental representation that a landscape rich in SNH does not deliver significant pest control, (2) the challenge of coping with agroecological uncertainty, (3) a highly integrated vertical supply chain based on pesticide use, and (4) the existence of independent, non-collective alternatives. In line with other studies, the obstacles we identified suggest that a radical redesign, in particular regarding supply chain organization, is required for a more agroecological approach to farming to flourish. The conditions for such a radical redesign range from the collapse of traditional supply chains to the implementation of public policy, for example, pesticide bans.

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