Co-innovating in agroecology: integrating stakeholders' perceptions of using natural enemies and landscape complexity for biological control into the research and innovation process

KeyWords : Landscape, Biological pest control, Uncertainty, Collective action, Action-research

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Abstract : Scientific findings in landscape ecology suggest that a patchy landscape including hedgerows, meadows and woods favours insect pest biological control by conservation of habitats for natural enemies. Some scientists foresee the possibility for farmers to act together in order to generate such conditions in their landscape. For such grass-root collective action to be possible, local stakeholders must first perceive landscape elements and/or natural enemies as resources; and the same stakeholders must be willing to co-operate through a collective management approach. Our objective was to investigate stakeholders' perceptions of landscape elements and natural enemies in relation to the potential for innovation in the form of coordinated management of the landscape. To do this, we used a participatory research approach in an area specialized in fruit tree production in south-west France, known for its high pest pressure and use of insecticides in orchards, and consequently high risk associated with any alternative approach in this domain. We conducted thirty comprehensive interviews with stakeholders about their pest control strategy to explore their perceptions of landscape elements and natural enemies in particular. The results indicated that natural predators were regularly perceived as resources. Stakeholders mostly perceived them as public goods requiring public institution interventions for their conservation, acclimation and management. Some interviewees perceived natural enemies as private goods where they can be captured and released onto specific crops, as is the case in greenhouses and with new technology such as anti-insect nets surrounding orchards; a practice on the rise in the region. By contrast, landscape elements were not perceived as resources in biological pest control. Our analysis of stakeholder perception indicates that a public or private approach to natural enemy action are favored in natural predator management. Finally, most farmers did not relate landscape to any biological control benefit and were therefore not motivated to act in this regard. Consequently, our co-innovation process with stakeholders will be oriented towards questioning the knowledge gap between scientists and local stakeholders regarding the effect of landscape on natural predators and biological control.

1. Introduction

It is well established that farming practices are one of the major phenomenon contributing to biodiversity loss worldwide (McLaughlin & Mineau 1995). In particular, the use of chemicals as biocides has been under scrutiny for their impact on biodiversity as well as on human health. In 2009, the European commission established a directive aiming at achieving "a sustainable use of pesticides" in order to reduce their negative impacts. Each member state was invited to introduce its "National Action Plan" by 2014 in the spirit of "promoting the use of integrated pest management and of alternative approaches or techniques such as non-chemical alternatives to pesticides". In France, the national plan was named "Ecophyto" and aimed at 50% pesticide use reduction by 2018.

In this context, there is a growing interest for research in agroecology and biodiversity-based agriculture that favours and makes use of biodiversity (Duru *et al.*, 2015). Findings in landscape ecology demonstrate in particular that complex landscapes can enhance biological control on farms through their positive impact on the abundance and/or diversity of insect pests' natural enemies (Bianchi *et al*. 2006, Rusch *et al*., 2010, Chaplin-Kramer, 2011). Natural enemies include all types of predators and parasites, which reduce insect pest populations through their life cycle. Complex landscape is understood as an agricultural patchy landscape with a high proportion of semi-natural and wooded habitats.

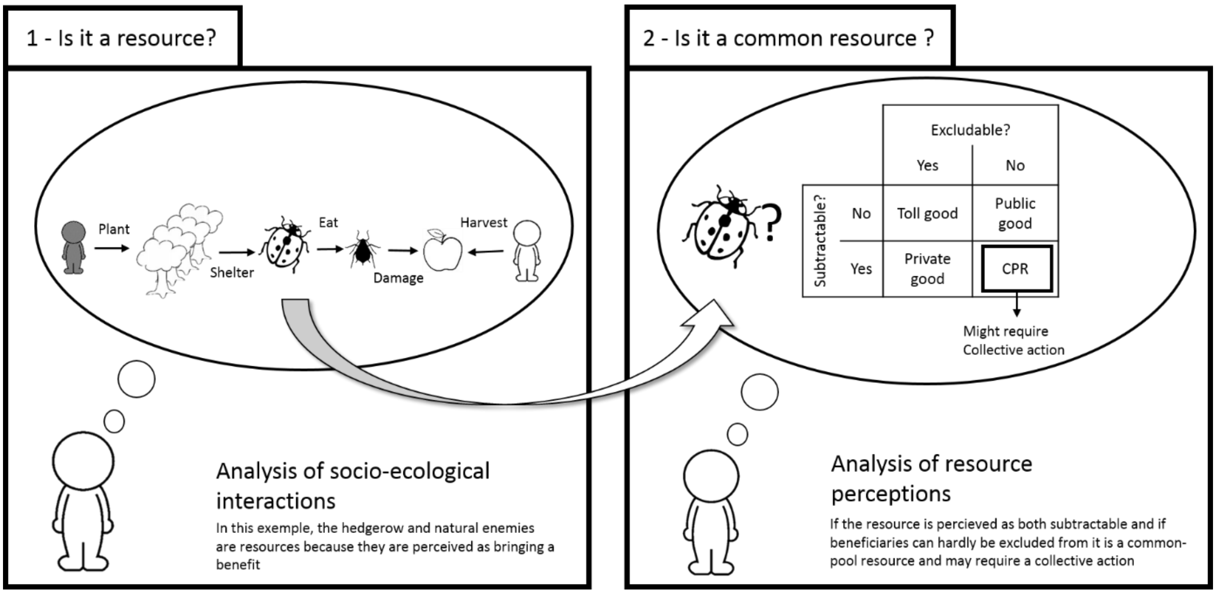
While such findings open up new possibilities of pest control practices at the landscape level (Cong *et al*., 2014), little is known about the concrete feasibility of such practices (Tscharntke *et al*., 2005, Schellhorn *et al*., 2015). Stallman (2011) suggested that, among different kinds of ecosystem services, biological pest control was potentially highly suitable for collective landscape management. It is also our point of view that because agricultural landscapes are produced collectively by many individuals, a biological control strategy using complex landscape regulation properties might require co-ordinated action among these individuals. However, as Cong and his colleagues state "scant attention has been paid to the question of whether it is in the interest of farmers to manage habitats at the landscape scale for generating ecosystem services". Our research aims to fill this gap and reach a better understanding of stakeholders' views on managing habitats for pest control; in particular to see whether or not collective action could be an option for pest regulation at the landscape scale.

We explored collective action as defined by Ostrom (1990), namely the possibility of collective self-organization in managing complex socio-ecological systems (SES - Ostrom, 2009) as an alternative to top-down natural resource management (Holling & Meffe, 1996). However, in Ostrom's work, the "resource" (water, forest, fisheries) tends to be obvious to users because SES were studied where such elements were well established and key to users' survival (Ostrom, 1990). In our case, elements such as "insect natural enemies" or "landscape" are only potential resources. As we have seen in the landscape ecology literature they can potentially bring a benefit, but it is not known whether or not users perceive them as resources. In the field of agro-ecological design innovation, resources and users are indeed often not pre-defined (Berthet, 2013). The specificity of our work is to add a constructivist approach to resource qualification prior to the Ostrom framework on collective action. Constructivism considers that it is the interaction of individuals with their environment that creates meaning. In this regard we used the definition of a resource given by Raffestin and Bresso (1979). For these authors, a resource is an element of an individual's environment in which they have invested time and energy in prospect of a benefit. In our research it means that a natural enemy or landscape as a resource does not exist *per se* unless an individual interacts with these elements. This approach is notably different from a naturalistic view on resources, which describes resources as objective elements independent of an individual's interaction with them (Kebir, 2006; Labatut, 2009). This constructive approach, where resources are the result of individual interactions within a socio-ecological system, is an original addition to SES frameworks (Binder *et al*., 2013).

Ostrom's framework distinguishes different types of resources according to their subtractability and their excludability: a subtractable resource means that if someone uses this resource, there will be less for someone else, and an excludable resource means that someone can easily keep someone else from using it. She studied collective action in the specific case of common pool resources (CPR), which are subtractable and non-excludable resources, such as irrigation water or fisheries. Her work stresses that different types of resources imply different kinds of management strategies and that the collective action she studied was specific to CPR situations. It was therefore important for us to analyze what type of resource local stakeholders perceived "insect natural enemies" and "landscape" to be within Ostrom's resources framework, and consequently what management strategies might be relevant.

In summary, the objective of this study was to investigate local stakeholder's perspectives in terms of the potential for innovative collective action in integrated pest management (IPM) at the landscape scale. To do this, we explored how local stakeholders related to and perceived their environment within the context of their current pest management strategy in order to see whether or not they perceived “insect natural enemies” and “landscape” as resources for pest management, and what were the characteristics of these resources (subtractability and excludability) (see Figure 1).

Figure 1 : Our two step theoretical approach to explore the social construction of a resource.



2. Method: comprehensive interviews and mental models

The research was carried out in south-west France in an area close to the Aveyron River that is dominated by orchards (mainly apples) and cereal production. This area, chosen in partnership with local agricultural public institutions, was particularly interesting for our investigation because fruit tree production is a capital intensive crop with a high level of pesticide use. As pest damage can have dramatic economic impacts, many producers tend to rely on chemical spraying to secure their investment.

We conducted thirty individual interviews mainly with farmers, but also with local landowners and agricultural technicians. Individuals interviewed covered the diversity of systems of production in the area. Each interview followed the comprehensive interview approach (Kaufmann, 2011), a semi-directive form of interview recognized for its capacity to let interviewees express their personal views as well as acknowledging the inter-subjectivity between the interviewer and the interviewee. Each individual interview included three steps: the interviewee was first asked a general description of his actual and past activities, second a description of his view and practices regarding pest management, and third about his perception of landscape elements and natural enemies in his pest management strategy - in case it was not spontaneously mentioned during the interview. To help the discussion, a google map of the farm was provided to discuss the influence of the local environment on farm and pest management. Each interview was recorded and the speech was translated into a conceptual model of their mental model of pest management using the Cmap program (Novak & Canas 2006). This model allows all socio-ecological interactions mentioned by the interviewee about their personal view on pest management to be represented in a single graph. When the interviewee mentioned a relationship between elements involving a benefit we indicated this element as a resource (for example, in the phrases “use of a pesticide against a pest” and “planting fruit trees”, the elements “pesticide” and “fruit trees” were considered as resources for this interviewee. The graphic formalism used the ARDI (Actors, Resources, Dynamics & Interactions) methodology to represent socio-ecological interactions (Etienne *et al.*, 2011). These graphs allowed us to evaluate the importance of landscape and insect natural enemies in their description of pest management, both quantitatively (how many times they were mentioned) and qualitatively (how did they mention it?), ultimately allowing us to determine whether the elements were perceived as resources and common pool resources.

3. Results

Results are presented in two steps: (1) we explore cases when natural enemies were perceived as resources and detail the six situations identified, (2) we introduce our findings regarding landscape perception.

3.1 Natural enemies as resources

Two thirds of interviewees mentioned insect natural enemies in their pest management. Thus, a majority of interviewed farmers perceived natural enemies as a resource and integrated them into their pest management mental model as a regulating benefit. The natural enemies and effects mentioned are summarised in Table 1. In the following section we detail the different perception of natural enemies as resources and also qualify the type of good they represent according to their excludability and subtractability expressed by interviewees. An overview of this resource perception qualification is summarised in Table 2.

Table 1 : Synthesis of natural enemies mentioned as resources involved in pest control during individual interviews

Natural Enemy mentionned	Pest controlled	Effect on pest	Instances in interviews	Socio-ecological interactions involved
Aphelinus Mali	Eriosoma lanigerum (Wolly aphid)	Parasiting	10	Chemical application (Emamectine) may kill second generation A. mali..Chemical product (Vamidothion) against woolly aphid (Killval) has been banned.
Ladybug (Coccinelidae)	Aphids	Predating	10	Anti-insects nets may interfere, Harmonia axydris releases compete with endemic coccinelidae
Phytoseids mites	Red acaris	Predating	8	Chemical products killing phytoseids have been banned by public authorities
Hoverflies (Syrphidae)	Aphids	Parasiting	3	
Neodryinus typhlocybae	Metcalfa pruinosa	Parasiting and predating	3	Official pest control institutions (FREDON) released it
Lacewings (Chrysopidae)	Aphids	Predating	2	Anti-insects nets may interfere
Trichogramma	Ostrinia nubilalis (European Corn borer)	Parasiting eggs	2	
Asobara japonica	Drosophila suzukii	Parasiting	1	Acclimation studied by researchers
Aphidoletes aphidimyza (Aphid midge)	Aphids	Predating	1	
Rhagonycha fulva (Common red soldier beetle)	Aphids	Predating	1	
Pear aphids	Cacopsylla pyrisuga	Niche competition	1	
Anthocoridae	Psyllids	Predating	1	
Forficula auricularia (Earwig)	Aphids	Predating	1	Anti-insects nets practices may interfere with them

3.1.1 IPM development identified natural enemies as key resources for pest control

In the 80's and 90's there was a significant development of the IPM approach to pest control. Orchard managers and especially fruit tree technicians involved in IPM development programs were encouraged by public policies to integrate this new perspective on pest control. As a consequence, many natural enemies were mentioned in fruit tree technician's mental models. This specialized knowledge is consistent with some farmers relying heavily on their technician for advice as they did not always acquire IPM techniques and thus knowledge of natural enemies individually.

Among producers, IPM development and the consideration and use of natural enemies in their farming practices was not driven by public intervention, but rather by personal experience that revealed the efficiency with which natural enemies can control some pests. For illustration, the most quoted story is related to the 1991 frost, which had a significant impact on the apple harvest. As a consequence, orchard managers applied minimal chemical treatment that year, and yet no damage from red acaris (locally called "red spiders"; a major pest in the area) was observed. Many orchard managers discovered at that moment the effectiveness of phytoseids (a family of mites that feed on thrips and other mite species) in regulating the pest. For example, one producer stated that: «We realized that there were no more spiders because they had been predated by acaris and phytoseids. So it's from this point that our approach started to change".

Red acaris predators clearly appear as a resource for many apple producers and technicians, but perceptions of how the resource was developed vary according to the perspective of different stakeholders. Individuals who were close to public IPM development programs described concrete actions that led to the use of natural predators on red acaris, such as chemical bans, machinery improvements and observation routines limiting systematic treatments. One individual close to local agricultural administrations illustrated this by stating that: "the evolution happened in the years 1985-90 when we adopted integrated pest control. Today, red spiders are not a problem anymore because we developed natural enemies". By contrast, for many apple producers, the strategy was happened upon by accident: "I went on holiday for a week and wasn't dealing with spiders. When I came back there were no spiders left".

In the 80's and 90's, public authorities took the lead in IPM development and the use of natural enemies within orchard production systems. Farmers were not directly included in the process, and so public institutions and farmers viewed natural enemies in this context as a public good, as the benefit from natural enemy action was for every farmer with no intention to prevent any potential user from benefitting. IPM development followed a top-down linear approach and farmers were not directly involved in the social construction of this resource.

3.1.2 Natural enemies as resources in response to a chemical product ban

Aphelinus mali is a parasitic wasp and natural enemy of the woolly aphid, which is a sap sucker that impacts apple quality through honeydew production and the subsequent development of Sooty mold. Woolly aphids were apparently not a problem for most of apple farmers until the pesticide Vamidothion was banned in 2003. As one technician stated: "it has become more difficult to control Woolly aphids since KILVAL [Vamidothion] was unexpectedly banned …overnight a product that had provided effective control was no longer available to us, presenting us with a new challenge".

As a result, *Aphelinus mali* has become a key resource that is under close scrutiny from local agricultural public institutions, fruit selling companies and experimental stations. *Aphelinus mali* is monitored in many different fields and experimental plots around the region. One technician from a fruit cooperative mentioned that "we try to pamper them as much as we can". Another stated that they "try to remove all pesticides which were negative to *Aphelinus mali*". In contrast to red acaris and phytoseids, the solution to woolly aphids was not developed by public authorities. On the contrary, the woolly aphid pest problem was initiated by public authorities through removing a pesticide from the market for toxicity reasons. *Aphelinus mali* is now a key resource because authorized chemical treatments are no longer sufficient to control the wooly aphid and significant investment has been put into *A. mali* monitoring and the integration of such practices into apple production systems. *Aphelinus Mali* as a resource is clearly a public good as provision of the aphid control service is not subtractable (use of the resource does not mean there will be less for someone else) or excludable (no one can exclude another person from using it).

3.1.3 Natural enemies as resources against increasing invasive pest pressure

Eight out of seventeen individuals involved in fruit tree production mentioned *Metcalfa pruinosa*, an invasive pest from North America, in their mental model. Three mentioned its natural enemy, *Neodryinus typhlocibae*, which was successfully introduced to control it (Malause *et al*., 2003). Its acclimation was managed and monitored in a top-down manner by public institutions. Even though pest invasion is not a new phenomenon, with increasing globalization in recent decades, its occurrence rate has increased significantly for invertebrates due to increased economic activity and transport efficiency (Hulme, 2009). The acclimation process of natural enemies for these invasive pests is also not new. For example, the acclimation of *Aphelinus mali* to limit woolly aphids was managed by an international network of researchers in the 1920's (Howard, 1929). Understandably, an increasing number of pest invasions puts increasing pressure on the need to introduce corresponding natural enemies.

Farmers themselves are not involved in the growing need for research on natural enemies for invasive pest control. Natural enemy introduction is mainly managed by researchers whose role is typically to identify and test the ability of natural enemies to adjust to a new environment (i.e. acclimation) and to regulate invasive pests. Public institutions then validate each approach and implement the most viable option. This process is a very clear resource construction process as there is significant investment from well identified agents (researchers and public institutions) into establishing a pest regulation resource. This type of resource is a public good as these pest control insects, once released and acclimated, are beneficial to whoever might need them and there is no exclusion from any potential beneficiary.

3.1.4 Natural enemies as part of a holistic view on pest control

Two interviewees had a holistic view of insect pest control and considered that efficient global ecosystem functioning would provide sufficient pest regulation. This type of thinking is consistent with perceptions expressed by farmers positively inclined towards organic production and who have a more complex and philosophical attitude towards biodiversity (Kelemen *et al*., 2013). For example, one respondent stated that "We're not alone on Earth (…) animals have a right to live and I think that if birds (…) and other organisms in the ecosystem that prey on leafhoppers were removed, we would be reliant on a lot more agro-chemical use"

In this regard these stakeholders with a holistic view of the environment have built a different type of relation with natural enemies as resources. Firstly they focus less on one species in particular and more on the belief that a global ecosystem can regulate invasive pests. Attitudes towards individual components of the system tend to be more ambivalent as an element can be perceived both as a benefit and a cost: "Falcons eat my chicks but also eat field mice and snakes… it's the circle of life". This trust in the ecosystem to balance out all the components is sometimes established through practices favouring global biodiversity. For example, an organic orchard manager provided food and egg-laying sites for natural enemy insects by maintaining a herbaceous inter-row in his orchards. For this type of actor investment in natural enemies is achieved by allowing ecosystems to reach a natural balance of species. This kind of perception is consistent with a less anthropocentric view of agriculture that considers elements of ecosystems not only as a support for production but as an integral part of the production process itself (Barbier and Goulet, 2013).

Many farmers with a holistic view of ecosystems were in part-time organic production and therefore, compared with conventional, full-time orchard managers, were less exposed to ecosystem and economic uncertainty due to price premiums provided by organic sales and/or from income security provided by having a secondary activity. By contrast, conventional producers generally felt more reluctant to rely on ecosystem services. For example, one conventional technician stated that: "Natural processes can be random and I don't like being reliant on a parasitic wasp (e.g. *Aphelinus mali*) to control aphids. One day, these wasps will prevent me from spraying against acaris and this will cost me money".

Stakeholders with a more holistic view considered the general ability of on-farm biodiversity to regulate pests and reduce pest damage to an acceptable level as a key farm resource and a public good. Furthermore, growers that perceived the environment in this way did not mention any aspect of their off-farm surroundings or neighbouring land that would impact on their ability to benefit from natural enemies, suggesting that there was no competition or subtractability associated with such a resource.

3.1.5 Natural enemies as a symbolic resource in communication with their buyers

Natural enemies were occasionally mentioned as a symbolic resource by small scale growers selling their fruits in open-air and farmers' markets. Some growers saw the use of natural enemies as an opportunity to differentiate their produce from growers that are reliant on agro-chemicals, thereby appealing to consumers concerned with biodiversity and health issues associated with pesticide use. Some growers even used features associated with natural enemies to market their produce to customers. For example, one grower highlighted lacewing eggs on peaches and apples as symbols of care for the environment, stating that "lacewing threads and eggs are a common feature of my top fruit. In the open-air market they ask me -what is that? – and I explain that these are natural enemies that protect my fruit from pests, and without them I would have to use products that would kill the pests and their natural enemies and leave residues on the fruit". Such dialogue is not possible within longer supply chains as producers are separated from their consumers.

Natural enemies as a symbolic resource for communication or marketing purposes are a public good as they are not subtractable or excludable. The use of a natural enemy feature does not mean there will be less for someone else and does not prevent anybody else from using it.

3.1.6 Natural enemies for biological control by augmentation

Some interviewees mentioned the use of natural enemies by augmentation, meaning the practice of releasing natural enemies on a farm to boost its population. For example, as part of the production contract with a seed buying company, some corn seed producers are required to release trichogrammas (a parasitic wasp of Lepidoptera eggs). Another example is a market gardener who uses a local company specialized in biological control to release diverse natural enemies in his greenhouses. Both examples illustrate that a certain degree of isolation is required to ensure the maximum efficiency of the release. For example, a corn field targeting seed production must be isolated from conventional corn fields to limit corn hybridization and to increase the likelihood of the trichogramma remaining in the field. For the market gardener, the greenhouse plastic creates a boundary that prevents any "dilution" of natural enemy insects in the surroundings.

This perspective on natural enemies clearly indicates that this type of resource is a private good, because farmers mentioning them explicitly try to limit their neighbours' access to the resource by creating some kind of boundary or buffer. Their mention of a risk of "dilution" indicates that they perceived the scarcity of natural enemies released as a threat to efficacy, and that to maximize effectiveness the intention is for the natural enemies to be focused on their crop rather than a neighbour's crop. The private nature of this natural enemy augmentation is consistent with an “input” approach of natural enemies and by the presence of private companies organizing their supply and sales.

Biological control by augmentation could herald a significant development in the study area with the introduction of anti-insect nets that entirely surround orchards to focus the activity and intensity of natural enemies and avoid dilution into surrounding neighbours’ plots. It is quite possible, following the “isolation” rationale for biological control by augmentation that anti-insect nets could become a general feature of orchards in the area.

Table 2 : Overview of the context of natural enemy seen as resources

Type of resource	Social Construction of the resource	Actors for whom it's a resource	Type of good
Natural enemy against invasive pests	Study by research institutions Acclimation by public institutions	Researchers Technicians	Public
Natural enemy as a tool within IPM program	Public policy for IPM development	Administration Technicians	Public
Natural enemy as secondary solution to pesticide bans	Pesticide ban by public authorities Monitoring from technicians	Technicians Orchard manager	Public
Natural enemy as an element of a holistic view of pest control	Philosophical relationship to nature and ecosystems	Organic producers	Public
Natural enemy as a symbolic resource	Marketing argument	Small scale growers involved in direct sales	Public
Natural enemy for biological control by augmentation	Companies selling natural enemies Companies imposing Natural enemies in production contracts	Farmers Grain companies Natural enemy sellers	Private

3.2 Landscape as a resource in pest management?

Findings in landscape ecology suggest that complex landscapes can enhance biological control (Thies, 1999). The landscape itself can therefore be considered as a resource that needs to be managed to favour the proliferation of natural enemies. In this section we analyze whether the landscape is perceived as a resource by the interviewees.

3.2.1 Landscape mainly perceived as a threat in pest management

One of the most surprising results of this study was that landscape elements were almost never perceived by any of the interviewees as having a positive influence on natural enemies and thus bringing a benefit. This result was not consistent with scientific findings of landscape ecologists suggesting that landscape complexity can enhance pest control (Bianchi *et al*., 2006).

One hypothesis could be that stakeholders only have a plot or farm scale perception range and do not perceive a landscape effect. This was supported by the fact that the only positive landscape elements mentioned were on-farm hedgerows that provide habitats for generalist predators. However, many stakeholders also mentioned that their off-farm surroundings could have a modest negative effect by stimulating diverse pests (see Table 3). However, negative effects were not always considered to be modest; in the case of *Drosophila suzukii* (fruit flies), landscape elements were thought to favour significant and uncontrollable damage to cherry trees.

Some technicians who regularly visited growers across various sectors mentioned that they saw no difference in pest pressure or natural enemy presence when they compared farms in different areas with contrasting landscapes (e.g. in terms of the proportion of semi-natural habitat). Other technicians shared experiences with establishing hedgerows in terms of their ability to increase natural enemy numbers with the effect being relatively disappointing. For example, one fruit tree technician stated that: “It was very fashionable in the 90’s to establish hedgerows (…) there was a great push for integrated pest management and hedgerows to shelter a wide variety of things (…) everybody, including myself, thought the method had great potential to increase natural enemy populations and many hedgerows were planted but many were not effective; there are even some places where hedgerows have been removed. What seems straightforward in the literature does not necessarily materialize in reality”.

Table 3 : Synthesis of landscape elements mentioned during individual interviews and their effect on insect populations

Landscape mentioned	Effect on insect populations	Effect of insects mentionned	Instances in interviews
Uncultivated land and hedgerows especially with nettles and blackberries, kiwi trees	Favours Metcalfa pruinosa	Honeydew production favors fungus damage on fruits	4
Woods	Favors Rynchites	Sting fruits	3
Hedgerows, woods and fallows	Favours Drosophila Suzukii	Sting fruits and lay eggs in diverse fruits (cherries, strawberries, raspberries)	2
Walnuts	Favours codling moth	Eat and dig apples	2
Absence of orchards around an orchard	Limit general insect pest pressure in the orchard	Less attacks on orchards	2
Peach orchards	source of Grapholita molesta to neighbouring apple orchards	Attack peaches and apples	2
Uncultivated land	Favours rose tortrix (archips rosana)	Attack young fruits	1
Acacia hedgerow	Favours Scaphoideus titanus (American grapevine leafhopper)	Attack grapes	1
Dead tree	Shelter Xyléborus dispar	Attack weak orchards trunks	1
Corn field	Source of Corn borer attacks on low apple tree branches	Attack apples on low branches	1
Poplars and willow	favors Zeuzera pyrina	Dig young trees trunks	1
Forest	favours Anthonomus pomorum (apple weevil)	Eats and lay eggs in apple flower buds	1
Malus in hedgerows	Source of woolly aphids	Suck apple sap, honeydew production favors fungus damage on fruits	1
Wheat field	Flows of ladybugs in July after harvest	no particular effect noted	1
Meadow	shelter Ladybugs	no particular effect noted	1
Hedgerows without rosacea	shelter, feed and provide egg-laying sites for generalist predators	Eat aphids sucking apple tree sap	

3.2.2 The perception of landscape diversity as a threat stimulates enclosure

As stated above, the landscape was mostly perceived as a threat to the farm (Table 3). As a consequence, isolation from negative landscape effects was sometimes perceived as a benefit, because pest pressure was perceived to be reduced when neighbouring fields were not growing the same crop. As one orchard manager stated: “15 to 20 years ago there were 110 hectares of orchards round here; whereas now the area is much reduced… for a very, very long time I was under very, very strong pressure from pest insects”. In this regard, isolation from fields producing the same crop was perceived to be a benefit due to reduced pest pressure, although not many growers actively sought this situation. By contrast, the use of anti-insect nets to completely surround an orchard is on the rise in the area because it opens up deliberate action from farmers to isolate their plots from external negative influence. A local perspective is quite clear on this prospect: "More and more new plantations, and even old ones, are covered with anti-insect nets… to suppress insects…and reduce insecticide use (…) I think this trend for using protection nets against insects will continue".

The use of anti-insect nets creates a new resource which is an air space surrounding the crop in which pest insects are controlled. Through insect-nets, producers can control insect flows in and out of their plot and monitor pest pressure. Enclosure of the air space above plots opens up new biological control strategies because natural enemy releases can be more effective if they are guaranteed to stay within the plot. As one farmer stated: "For this fly [*Drosophila suzukii*], I don't know any predators. If there were any I would release them inside my nets. In this situation I would be confident of my strategy". The use of nets favours a strategy oriented towards privatization of the environment surrounding the crop, which can be complemented by an economic sector selling natural enemies as described above in 3.1.6.

4. Discussion: perception analysis as a reflexive tool for action-researchers

Exploring perceptions and the social construction of resources revealed a significant knowledge/perception gap between fruit producers and landscape ecology scientists. While the latter regularly demonstrate the positive influence of landscape complexity on natural enemies (Bianchi *et al.*, 2006), the former, as we have reported, do not perceive this benefit and on the contrary rather state a regular positive influence of the landscape on their different pests.

The results of this research significantly changed the focus we had on using enhanced landscape complexity to control pest pressures as a potential innovation. While we thought initially that our action-research process was a means of opening up stakeholders to a potentially useful piece of knowledge to innovate in biological pest control it turned out to reveal divergent perceptions between scientists and local stakeholders about the effects of landscape complexity on pest populations.

Participatory research is about including stakeholders to guarantee the best outcome possible for those who participate. The prospect is about the production of knowledge adapted to the stakeholders' situation and needs. However, in this case the stakeholders' perception shifted our research towards the exploration of this knowledge gap. This shift not only changed our focus, but also had significant influence on our methodology. While our research was first engaged in a companion modelling process (Etienne *et al.*, 2010) in which perception analysis was a first step prior to participatory modelling with the objective of stakeholders discussing coordination to achieve better pest control through employing and enhancing the landscape factor, we had to turn to different tools to explore this knowledge/perception gap.

The uncertainty between scientists' and local stakeholders' points of view about landscape effects oriented us towards uncertainty exploration tools. In this regard, participatory belief Bayesian networks are widely recognized for their ability to "represent and integrate knowledge and spheres, explicitly support the inclusion of stakeholder knowledge and perspectives, and take into account the uncertainty of knowledge" (Düspohl *et al.*, 2012).

Clarification of perceptions between those who hold a potential innovation and potential stakeholders benefiting from it appears to be a key step in engaging both on similar ground in an action-research process by eventually disambiguating uncertain knowledge, if possible, or at least identifying the root of the perception gap thus eventually clarifying the science behind the landscape pest control innovation. Science questioning science is an important part of a functioning action research agenda (McNiff, 2013).

To do so, we will assist local stakeholders as well as landscape ecologists in modelling a common Bayesian network structure about biological pest control. We will assist each participating individual in order to calibrate a common network with their personal knowledge on biological pest control and landscape effect. Individual networks will be compared and uncertainties discussed among participants.

5. Conclusion

It is clear that top fruit producers perceived natural enemies as a valuable resource in biological pest control. However, they did not consider that biological control could be enhanced by the nature, connectivity and diversity of landscape elements. Most stakeholders perceived the landscape as a threat and a source of pests. The absence (within stakeholders' perceptions) of the landscape or its elements as a resource in biological pest control challenges scientific findings that highlight the potential for using landscape complexity to enhance pest control, especially as mostly disservices were described by interviewees. The action-research framework will therefore need to be adapted to allow scientists to question the scientific knowledge at the root of their action and to integrate stakeholder feedback.

None of the stakeholders mentioned natural enemies as common pool resources (CPR), but rather as private or public goods. Technology and public policies seemed to be the main drivers of resource construction in the study area. Innovations such as anti-insect nets and the localized release of natural enemies (within enclosed plots) distance stakeholders from collective landscape management as they encourage the private management of individual plots within the landscape.

Public policies may eventually provoke a change in perception regarding the effect of landscape elements on natural enemies. This could potentially result from the promotion and adoption of biodiversity-focused agri-environment schemes or the withdrawal of some agro-chemicals, which might encourage greater reliance on natural enemies for pest control.

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