Landscape ecology: an integrative discipline for sustainable development achievement

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Introduction: the case of agriculture in landscape ecology

Since human beings began to use and shape the land, their influence on their environment has kept on growing so that currently, little or no ecosystem in the world is now considered as untouched (Sanderson et al., 2002). For this reason, most landscapes are currently referred to as biocultural landscapes: generated by both natural and anthropogenic processes (Bogaert et al., 2014). Human activities have worldwide consequences on landscape structure as well as ecosystem functioning (Bogaert et al., 2014, Mazoyer and Roudart, 2006). This phenomenon is referred to as anthropisation, anthropogenic effect, as well as many other terms (Vranken et al., submitted). As agriculture represents one of the main land uses in the world, it is essential to understand its multiscalar impact on ecological processes in order to ensure the ability of the earth system to provide the necessary resources to human populations and ecosystem services (ES) over the long term (Fischer et al., 2014).

Agricultural land uses can be very disturbing to local ecosystem processes and strongly alter their naturalness (Vranken et al., submitted). Indeed, conventional agriculture transforms the environment in order to adapt it to agricultural production activities (Lemanceau et al., 2015). However, if the definition of naturalness that serves as a reference is based on analogous ecological processes to those occurring in natural ecosystems or across natural landscapes, it is possible to make agriculture more 'natural' and exploit ecosystem functioning to produce food sustainably (Altieri, 2002b, Lemanceau et al., 2015, Vranken et al., submitted), by adapting agriculture to its environment. This is one of the the central postulates of agroecology (AE). Within this view, agriculture can be seen as a form of environmental management. Environmental management is the process of enhancing an ecosystem towards less disrupted ecological processes and spatial patterns. Applying compensation or enhancement actions to disturbed ecosystems in order to develop their functional analogy to existing natural ecosystem, even exploit it, is a form of environmental management (Rajvanshi, 2008). This action is typically undertaken in AE. The analogous ecosystems have functionally analogous abiotic and biotic features to natural landscapes occurring in the same region (e.g. calcareous grasslands can be of natural origin or result from pasture) (Lundholm and Richardson, 2010, Piqueray et al., 2007). Therefore, eco-intensive agricultural practices (see "The way forward") can ensure similar, even enhanced ecosystem functioning compared to analogous natural land covers (Huang et al., 2015, Lundholm and Richardson, 2010, Rajvanshi, 2008).

Diagnosis: on the necessity of a landscape approach in agroecology

The ecological footprint of industrial agriculture

Agriculture is one of the foundations of human society and a major activity at the human-environment interface. Like other natural and semi-natural ecosystems, agroecosystems can provide ES, such as carbon sequestration, pollination, biological control, soil regeneration, biodiversity or water filtration. However, the capacity of agriculture to provide such services is not guaranteed (Doré et al., 2011). In fact, during the 20th century "modernisation" programmes of agriculture through industriualisation caused the development of adverse effects of agricultural practices on the environment, leading to multiple socio-ecological disservices of agriculture around the world (Matson et al., 1997, Swinton et al., 2007). Agriculture via the use of high-yielding crop varieties, fertilization, irrigation and pesticides indeed heavily impact on natural resources with serious health, socio-economical and environmental implications (Foley et al., 2011). Industrial agriculture has thus proven to be unfit to the actual and future food challenge in a world with a shrinking arable land base, with less, more expensive fuel, increasingly limited supplies of water and nitrogen, and within a scenario of a rapidly changing climate, social unrest and economic uncertainty (Foley et al., 2011, Godfray et al., 2010, Ploeg, 2008). The recent food price crisis (2008-2009 and 2012) has been an important catalyst for realizing that humankind needs an alternative agricultural development paradigm to foster food systems' transition towards strong sustainability (Altieri et al., 2012b, Godfray et al., 2010).

The way forward

In response to the multidimensional and international crisis of food systems, farmers around the world developed more ecological, biodiverse, resilient, sustainable and socially fair forms of agriculture (Altieri et al., 2012b, Holt Giménez and Shattuck, 2011), by applying agroecological principles (Altieri, 2002a), AE emerged in the 1980s as a knowledge-intensive (rather than input-intensive) approach to revitalize the efficiency and the applicability of small farming (Altieri, 2002a). Defined as the application of ecological concepts and principles to the design and management of sustainable food production systems, AE aims to provide a transdisciplinary framework for how to study, design and manage agroecosystems that addresses both the current food crisis and the biodiversity crisis (Altieri, 2002a, Gliessman, 2006, Vandermeer and Perfecto, 2013). Other agricultural models regard themselves as sustainable – eg organic agriculture (IFOAM), eco-agriculture (Scherr and McNeely, 2008) or diversified systems (Kremen et al., 2012). But as these rely on similar principles as those that form the pillars of AE — diversity, efficiency, recycling, regulation – , unlike AE they are not necessarily linked to social movements and do not always have clear positions regarding polemic technologies such as genetically modified crops. AE stands out by embodying simultaneously a science, a practice and a social movement and we agree with Altieri et al. (2012a) by arguing that it is the most conspicuous model of sustainable agriculture in terms of both technological and institutional development. AE is increasingly acknowledged as having the potential to bring solutions to many uncertainties facing humanity in a peak oil era of global climate change and financial crisis (Altieri, 2004, Toledo and Barrera-Bassols, 2009).

Recent high-profile policy reports call for a urgent fundamental shift towards AE (De Schutter, 2014). AE has thus recently become an integral part of a wider agenda for food sovereignty (Arc et al., 2012, Ifoam, Nyeleni, 2011, Surin, 2012), and farmers involved in peasant movements have rapidly integrated agroecological principles in recent years (Via Campesina, 2013).

Path dependence and 'lock-in' situation.

Nevertheless, common agricultural and agronomic practices still largely ignore biological interactions in cultivated fields (Doré et al. 2011).

To study and understand the underlying factors that hamper the transition of our agricultural systems toward AE, insights from evolutionary economics have been of great use in describing and explaining the complexities of interdependent technological and socio-economic systems such as food systems (Kemp et al., 2007, Vanloqueren and Baret, 2009). Concepts such as "path dependency" and "lock-in" indeed allow to explain the stability of situations where among several competing paradigms, one paradigm becomes dominant even though it may have an inferior long-run potential (Arthur, 1989). Hence, despite the mainstreaming of AE and the harmful systemic footprint of industrial agriculture, the western socio-technical regime remains mired in an industrial path-dependence (Cowan and Gunby, 1996, Wolff and Recke, 2000). The concept of path dependence explains a situation where the set of decisions one faces for any given circumstance is limited by the decisions one has made in the past, even though past circumstances may no longer be relevant. Continued irrelant choices thus lead to outcomes that are regrettable and costly to change depite the existence of feasible arrangement for achieving preferred outcome (Liebowitz and Margolis, 1995).

This results in a systemic lock-in situation – ie an accumulation of obstacles – hampering the development of AE. A range of political, economic and institutional obstacles have been highlighted at the the macro socio-technical context level (Vanloqueren and Baret 2009; De Schutter 2014), influencing niches and regimes dynamics (cf Multi-level Perspective Framework (Geels and Schot 2007)). Yet some farmers overcome these macro barriers and design at farm scale sophisticated agroecological systems challenging the dominant agro-food regime. Hence we argue that the main ***lock in*** hindering AE is at **individual level** and is of cognitive nature (Louah et al. In press).

Theoretical frameworks: how to merge agroecology with landscape ecology

Landscape ecology is at the crossroads between Ecology and Geography. It aims at combining spatial structure, the scope of geography, and ecosystem processes, the scope of ecology (Burel and Baudry, 2003). In Landscape ecology, a landcape is then defined as a heterogeneous land area composed of a cluster of interacting ecosystems (Forman and Godron, 1986). Within this view, crops and pastures can also be considered as ecosystems: agroecosystems (Gliessman, 2007). This point of view will serve as a departure point to include AE in a landscape ecology perspective (Baudry et al., 2000, Vasseur et al., 2013).

Within this view, the elementary unit of a landscape is an ecosystem different from its surroundings, i.e. a patch (Forman, 1995). The number and relative areal abundance of similar ecosystems (classes) in the landscape represent the compositional properties of the landscape spatial pattern. Patch shape, size and spatial arrangement represent the configurational component of the landscape spatial pattern.

The latest landscape ecology research also includes perception of the landscape, more specifically from the point of view of the species or group of species studied (Cale and Hobbs, 1994, McIntyre and Hobbs, 1999, Tischendorf and Fahrig, 2000). In the majority of cases, these groups will be defined according to species mobility and related functional traits. For example, in a field matrix with vegetation remnants, habitat has different compositional and configurational characteristics from the point of view of birds (Cale and Hobbs, 1994)\ compared to insects (Petit and Burel, 1998), even from pollinator insects than from insects that are natural ennemies of pests (Tscharntke et al., 2005). Indeed, trees, hedgerows, their sizes and proximity to similar habitat have different meanings for these two groups of species (Tscharntke et al., 2005). Functional aspects are then integrated to spatial pattern studies, like animal mobility to evaluate habitat connectivity (Lindenmayer and Fischer, 2013, Tischendorf and Fahrig, 2000). Such integration deepens the study of the link between spatial patterns and ecological processes. This analysis will serve as an entry to introduce a landscape perspective to agro-ecological considerations.

The central hypothesis of landscape ecology, the pattern / process paradigm, states that landscape spatial patterns (composition and configuration) are connected in causal relationships with the ecosystem processes occurring therein (Turner, 1989). This powerful connection allows to infer the impacts of the spatial structure of the landscape on the ecological processes occurring within and between the ecosystems (Turner, 1989), that determine the relative abundance and distribution of organisms (Fahrig, 2005). Landscape ecology is motivated by a need to understand the development and dynamics of pattern in ecological phenomena and the role of disturbance in ecosystems (Urban et al., 1987).

This discipline has a strong integrative nature due to its spatial-based explanatory power and its multiscalar approach, centred on the landscape. It also approaches the direct higher and lower organisational levels (Green and Sadedin, 2005). The ecosystems represent the lower levels (components, holons). The immediately higher level, the system environment or surroundings, is the region; this level represents the outer constraints encountered by the landscape (Li et al., 2004, Wu and Marceau, 2002). According to complexity theory, the processes regulating the system functioning are specific to each level (Green and Sadedin, 2005, Li et al., 2004, Wu and Marceau, 2002). This explains the importance, from an agroecological point of view, of studying agroecosystems as well as plant or animal communities and abiotic processes, as it is currently performed in agroecological studies, but also of studying the landscape context, that frames the two lower levels and follows its own rules.

As landscape ecology paradigms and methods make it suitable for combination with different disciplines and analysis frameworks, this discipline can be of major interest for the monitoring of anthropogenic disturbances, but also frames the responses to give to anthropogenic landscape change, addressing the challenge of sustainable development: preserving ecological functioning as well as human development. In the present approach, we propose to combine it with the Driver Pressure State impact on Ecosystem Service Response (DPSER) and multi-level perspective frameworks. We aim to combine these frameworks with landscape ecology, AE and related disciplines such as land planning, functional and restoration ecology into a comprehensive, logic and action-oriented analysis framework.

Some attempts to address agroecological issues with landscape ecology are already being performed (Baudry et al., 2000, Vasseur et al., 2013). Conversely, some attemps to address landscape aspects in agroecological studies are also emerging (Tscharntke et al., 2005, Tscharntke et al., 2012). However, little knowledge of the relative importance of local and landscape management for biodiversity and its relation to ES make reliable recommendations difficult (Tscharntke et al., 2005). This requires a multiscale approach (Fischer et al., 2014). If the presence of natural and semi-natural landscape elements and the effect of their configuration on multifunctional ecological processes and ES is more largely studied, the landscape effects of both crop practices and (semi)natural elements spatial distributions in the landscape on the different ES linked to agriculture and functional traits of the biotope / biocœnosis are still very embryonary.

The cornerstone of merging landscape ecology with AE is to integrate different organisational levels (both ecological and human) from a monitoring perspective into guidelines for response actions to enhance ES at landscape scale. From crop and hedgerow to crops and crop/hedgerow interface, then to tenure, then to landscape, even to region, into a consistent ecological network. The main focus of this cornerstone are presented in Figure 1.

Explanation of the data

The DPSIR framework is increasingly used in research related to environmental regarding the relationship between the ecological and human dynamics in a comprehensive and transdisciplinary analysis (Ness et al., 2010, Smeets and Weterings, 1999). According to this system analysis view, the Drivers (distant causes, demographic, social and economic development) exert Pressures on the environment, which modifies the State of the environment, such as the provision of adequate conditions for health, resources availability and biodiversity (Smeets and

Weterings, 1999). This leads to Impacts on human and ecosystem health that may elicit a societal Response to address those problems(Smeets and Weterings, 1999). This response can be directed towards any step of the causal chain, though addressing distant causes such as economic context is often more difficult to achieve (Vranken et al., submitted). Here we will use an ES-oriented version of the DPSIR: the DPSER framework (where E stands for ecosystem services) (Kelble et al., 2013).

To explore the socio-economic context in which these actions can be undertaken, the Multi-level perspective is used. As landscape ecology focuses on the landscape and the upper (region) and lower (ecosystem) scales, the multi-level perspective studies how societal changes, that can drive, for example, responses to environmental issues at different DPSER stages, develop from niche behaviours to broader habits over the longer term (cultural change)(Geels, 2002, Kemp et al., 2007).

To understand the process of socio-technical transition, the multi-level perspective framework (MLP) presents the interplay between three levels of heuristic, analytical concepts : niches interact with established regimes within a "macro-landscape". Transitions being defined as changes from one socio-technical regime to another, the MLP focuses on the regime level and interactions with the other two levels. The socio-technical regime forms the meso-level and refers to shared rules in a broad community of social groups. It explains their alignment of activities along socio-technical trajectories and account for the stability of existing socio-technical systems. Socio-technological Niches are viewed as a micro-level phenomenon where radical novelties emerge, carried and developed by small networks of dedicated actors. The socio-technical "landscape" forms the macro-level and refers to heterogeneous aspects of the exogenous environment that is beyond the direct influence of actors – eg economic growth, broad political coalitions, cultural values, environmental problems and resource scarcities.

The multi-level perspective argues that transitions come about through the interplay between processes at these three levels in different phases. In the first phase, radical innovations emerge in niches, often outside or on the fringe of the existing regime, without (yet) forming a threat to the existing regime. In the second phase, the new innovation is used in small-specialized market, still forming no major threat to the regime. The third phase is characterized by changes at the landscape level creating pressure on the regime and thus opening windows of opportunity for niche innovations. The alignment of these processes enables a wider breakthrough of the new technology and competition with established regime, followed by stabilization and new types of structuring.

On the other hand, we believe that the ***optimization*** of existing agroecological systems greatly depends on the landscape level, including not only the wider sociotechnical context but also the landscape *sensu* landscape ecology. In this paper, we focus on the link between current agroecological systems optimization and the landscape spatial structure. Indeed, it seems particularly relevant to explore the idea that, once a farmer is "cognitively unlocked" and applies agroecological principles, the maximalization of ecosystemic services potential at farm level involves a carefully planned and managed pattern design ensuring (agro)ecosystems connectivity at landscape level.

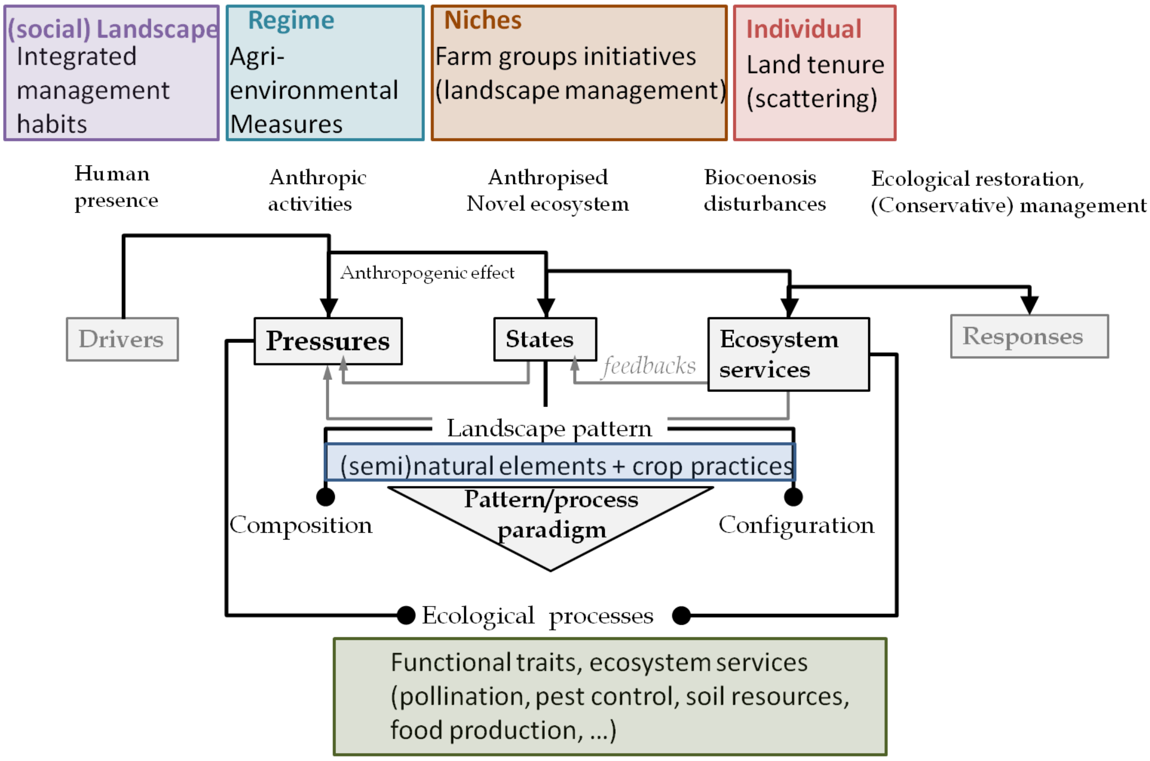

Figure 1: cornerstones of merging landscape ecology with agroecology

The main issues linked to merging the disciplines relies within creating ecological networks at multiple scales. As shown in Figure 1, the objects to be studied in landscape AE are related to both the landscape spatial structure and processes (analysed through the pattern / process paradigm) and socio-economic context (analysed through the DPSER / MLP frameworks). Ecological processes are affected by pressures and provide ES. In the case of agriculture, both agroecosystems (through cropping practices) and (semi-)natural landscape elements should be studied as for their spatial patterns and ecosystem processes interactions. Each function should be distinctly studied because spatial patterns do not have the same effect on ecological processes depending on the functional groups studied, as presented in the previous section (Cale and Hobbs, 1994, Tscharntke et al., 2012). As for the spatial and institutional scales of patterns and processes, we consider that smaller institutional scales act at smaller spatial scales. For example, at individual level, from the farmer's point of view, managing agricultural landscape spatial structure can only happen at the scale of his/her own exploitation, depending on its land tenure structure. In the case of transition initiatives, the MLP framework describes that a bottom-up change process occurs. Combining it to a landscape ecological perspective, centred on landscape spatial structure, we tend to see that, without integrated sub-level initiatives, regime-level initiatives, such as agri-environmental measures (AEM) in the European Union, are less effective to build consistent ecological networks, for ecological corridors appear dispersed and disconnected, as they do not result from integrated initiatives but scattered opportunities (see "positive experiences"). This shows the importance of integrating multiscale approaches and MLP to response actions to environmental pressures and to maximise ES.

Therefore, at the uppel level of individuals, that is, the niche, integrated landscape agroecological management can be performed in concerted groups of farmers having adjacent exploitations. Such actions would reorganise the state of the landscape system, due to changing pressures and with stronger impacts on ES due to the creation of ecological networks. This is what is currently done in the Netherlands, as explained in the next section). At the next level, such initiatives should influence the (socio-technical) landscape and favour developing them accross the region and coordinate them from landscape to landscape. Here, the socio-technical landscape corresponds to which practices (pressures or responses addressing them) will be performed and where, at large scale. Therefore, it represents the proximal drivers of anthropogenic effects on landscapes. Over the longer term, the regime will be in turn be influenced by such ecosystem service-optimizing initiatives based on both pratices and their spatial distribution. Once it is integrated in the general habits, the culture, at even broader spatial scale and embracing from individual from institutional levels, it represents distant drivers. It then corresponds to a system shift.

Positive experiences

Farming practice vs. hedgerow contributions to pest control at parcel and landscape scales

In the example of Puech et al. (2015), both landscape (semi)-natural elements and farming practices (organic vs. conventional) are tested at local and landscape scale, but only the natural ennemies of crop pests are studied. They found out distinct influences at landscape and at parcel scale. The farming practice influence the diversity and abundance of natural ennemies at parcel scale, but at landscape scale, it was the hedgerow network that influenced diversity and abundance of natural ennemies across the landscape.

Tillage, cattle health and hedgerows: an example of niche initiatives

An ethnographical study of farmers' novelty production provides many examples of these attempts (Delobel, 2014). For instance, stock farmers tackled ruminant parasitism by connecting their feeding practices to surrounding hedges, and by valuing the botanical diversity of their different pastures. Stockless farmers developed an integrated fertility and pest management of their crops by building an ecological infrastructure (beetle banks, grass strips, trees and hedges, woodchip compost production), associating different species (fodder legumes, living mulches), increasing crop genetic diversity (variety mixtures, populations), reducing soil tillage and including complex green manure mixes in their crop rotation. At a higher scale, cooperation between farmers (e.g. exchanges of feed, straw and manure) connects their different agroecosystems. Thus, building new connections between agroecosystems and cooperating with actors of surrounding villages, cities and industries allow these farmers not only to solve problems but also to operate actual farm transitions towards low-till cropping systems, achieve feed autonomy and to integrate short food supply chains.

Agri-environmental measures and the landscape

The main goal of AEM of the European Union is to encourage farmers to preserve and enhance the environment beyond legal obligations. Therefore, they provide financial aid to farmers that apply definite environmental-friendly practices on a specific field for a minimum period of five years. Which AEMs are subsidized is defined by the EU-member states and can vary on a regional scale.

Since the farmers individually apply for the AEMs, there is not necessarily continuity in space. Hence, the overall landscape-aspect is not necessarily/mandatorily considered, as already mentioned. This is one of the major criticisms to the AEMs of the EU. Indeed, the environmental benefits of several AEMs can only be obtained on the landscape-level, for instance for the AEMs to enhance biodiversity (Kleijn et al., 2011, McKenzie et al., 2013, Ricketts et al., 2001, Tscharntke et al., 2005, Tscharntke et al., 2012, van Dijk et al., 2013). Recently, a meta-analysis on the effectiveness of AEMs on biodiversity showed a significant, positive correlation between measures that enhance landscape complexity and both species richness of invertebrates and vertebrates (Gonthier et al., 2014). Hence, ES such related to agriculture and biodiversity, can be boosted by collaborative AEMs that consider the landscape-level.

Therefore, in the Netherlands, from 2016 onwards only collectives of farmers can apply for AEMs (Subsidiestelsel Agrarisch Natuur- en Landschapsbeheer ANLb2016, http://www.portaalnatuurenlandschap.nl). Hence, farmers that want to apply for AEMs must join a regional environmental cooperative. The first environmental cooperative was created by farmers themselves in 1991 as a criticism on the top-down approach of the Dutch agri-environment policy (Franks and Mc Gloin, 2007, Groeneveld et al., 2004, Oerlemans et al., 2006). Since 2000 the Netherlands created the possibility to apply collectively for AEMs by those environmental cooperatives (van Dijk et al. 2015). This Dutch model of farmers cooperatives has been proposed in other countries like the UK (Emery and Franks, 2012, Mills et al., 2011), on a European level (Burton and Schwarz, 2013) and in other continents (Attwood et al., 2009). At the moment, several EU-member states are investigating whether and how they could implement collaborative AEMs in their countries.

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