Short communication

Assessing resilience and adaptability in agroecological transitions

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Keywords: State and transition models; Complex adaptive cycle; Indicator framework; Agroecology; Land use change

Highlights

- Theory is needed to support research and development on emerging agroecological transitions
- Sustainable transitions mean favouring pathways of increasing resilience and adaptability
- Transitions can be portrayed as alternative states of the agroecosystem along farming intensities
- Complex adaptive cycle is used to assess resilience and adaptability throughout the transition
- A real transitional gradient is examined to illustrate a simple multicriteria evaluation framework

Abstract

Guidelines are needed to support research and action on sustainable transitions towards more resilient and adaptable agroecosystems. Here I present an operationable and simple framework with theoretical underpinning to assess to what extent agroecological transitions propend to greater resilience and adaptability. Ecosystems may transition between alternative states defined by their structural and functional characteristics. Agroecological transitions are a special type of human-mediated transitions in which the various components of the agroecosystem and their interactions are reconfigured through a process of design. The concept of the complex adaptive cycle of social-ecological systems is used to propose a set of 10 criteria to monitor resilience and adaptability in agroecological transitions using a system of scores. They comprise: self-regulation, connectivity, functional diversity and redundancy, response diversity, space and time heterogeneity, building of natural capital, social self-organization, reflective learning and human capital, autonomy and local interdependency, and capitalising on local knowledge. The framework is illustrated with an example from Brazil, where national and local level socio-political drivers have supported a 25-year process of agroecological transition. Implications for policy monitoring, research for development and political discourses are discussed.

1. Introduction

Agroecology is gaining momentum worldwide as an approach to agriculture and food systems management that can contribute to addressing global food security and sovereignty, reducing environmental impacts, balancing production and biodiversity conservation and promoting equity and fairness in terms of wealth, value, knowledge and natural resources governance (e.g., Peeters et al., 2013; Duru et al., 2014; Jansen, 2015; Le Mire et al., 2016; Wezel et al., 2016; Meynard, 2017; Astier et al., 2017; Beudou et al., 2017; Khadse et al., 2018; FAO, 2018; HLPE, 2019; etc.). Agroecology is nowadays being promoted at both technical-institutional and political levels (e.g., Monteduro et al., 2015 – and references therein; Miles et al., 2017) and increasingly fostered by societal demands for healthier food and environments in different parts of the world (e.g., Guirado González et al., 2014; Hvitsand, 2016; Tornaghi, 2017; Dell´Olio et al., 2017). Yet the transition towards agroecological farming is slow, with barely 30% of the land worldwide being farmed following agroecological practices by one rough estimate (Gräub et al., 2016), and still more conspicuous among smallholder family farms than in large scale commercial crop and livestock farming (cf. Altieri and Nicholls, 2017; González de Molina and Guzmán, 2017; Teixeira et al., 2018; Wezel et al., 2018).

Change in terms of ecological functions and services is needed for agricultural systems to transition away from the dominant industrial agriculture paradigm towards more sustainable, self-sufficient, efficient, affordable, circular and inclusive production (Sevilla Guzmán and Woodgate, 2013; Prost et al., 2017; Salliou and Barnaud, 2017). Agroecological transitions, or the necessary social-ecological reconfiguration of agroecosystems to produce following agroecological principles, are in most cases driven by the motivation of individual producers, who are to assume the risks and transaction costs of the transition and hence put themselves in a situation of high vulnerability to failure (Tittonell, 2014a). Such risks and associated vulnerability are aggravated under ongoing global change, and the success in the agroecological transition towards more sustainable agriculture and food systems depends largely on the capacity of transitioning systems to become increasingly resilient and adaptive (Tomich et al., 2011; Bennett et al., 2014; Saj et al., 2017; Bullock et al., 2017). Besides, the necessary reconfiguration that the social-ecological system undergoes during a transition process often implies deep structural changes that involve diverse degrees of cooperation, but also conflict, among all actors involved (Shove and Walker, 2007). In other words, for agroecological transitions to be considered *sustainable* transitions, they need to favour trajectories of increasing resilience and adaptability in production landscapes and rural communities. But, how can resilience and adaptability be monitored during (or assessed after) a process of agroecological transition?

System transitions have been vastly studied through what is known as the sustainability transition theory, or the study and conceptual modelling of the socio-technical transformations necessary to promote more sustainable ways of production and consumption (Grin et al., 2010; Smith et al., 2010; Wieczorek and Hekkert, 2012; Markard et al., 2012; Hodson et al., 2013; Avelino et al., 2016). An application of the well-known multilevel socio-technical transition model (Geels, 2014) to understanding agroecology as a niche innovation that may or not find its place in the dominant socio-technical regimes has been presented and discussed in Tittonell et al. (2016). However, models based on socio-technical transitions, which have been initially developed for the energy sector, tend to ignore the ecological dimension of the transition (Ollivier et al., 2018). This theoretical framework contrasts with the social-ecological system framework developed by the resilience thinking community (e.g., Gunderson and Holling, 2002; Folke et al., 2010; etc.) to assess social-ecological transformations (cf. an application to studying trajectories and transformability of African rural livelihoods – Tittonell, 2014b). Instead of multi-level, unidirectional transitions, this approach considers dynamics as nested adaptive cycles (Walker et al., 2009) and attaches a physical materiality to the social-ecological system being studied (space-time delimitation at different scales) (EEA, 2018). But it has a narrower conception of the social dimension of the transition (Binder et al., 2013) and pays little of no attention to the role of technology.

It appears that these two major approaches to studying transitions – and transformation[1] – of complex systems offer both opportunity and limitations to assess agroecological transitions and their contribution to resilience and adaptability. Any attempt at merging both, however, needs to carefully consider their differential ontologies (cf. Ollivier et al., 2018). Here, and since I aim to develop a simple and

[1] The use of the term ´transformation´ is less strict in sustainability transition theory than it is in the realm of resilience thinking, where it refers to profound reconfigurations of systems, as opposed to transitions which imply gradual changes (cf. Tittonell, 2014b)

operationable framework to assess real, concrete systems, I will rely on the social-ecological approach yet emphasising on the social dimensions, and will draw comparisons with the sustainability transition theory when appropriate. Beyond notable exceptions (cf. Danrhoffer et al., 2016), the contribution of agroecological transitions specifically to building resilience and adaptability of production landscapes and communities has not been sufficiently studied from a theoretical perspective. Although indicator frameworks have been presented that compare resilience across different types of food systems (e.g. Jacobi et al., 2018), they have not been used to monitor transitioning systems. No specific indicator framework seems to exist to monitor the contribution of agroecological transitions to resilience and adaptability in real life transitions.

This short communication focuses on the social and ecological implications that agroecological transitions have at landscape and local community levels, and hence on the necessary transformations the production ecosystem needs to undergo to transition towards agroecology. Ecological, complex system theory is proposed here to describe and monitor agroecological transitions, resting on the hypotheses that (i) different steps in the transition can be understood and characterised from the perspective of the states and transition concepts used in ecology (cf. Bestelmeyer et al. 2010), and that (ii) the contribution of a given system transition, or transformation, to increasing resilience and adaptability can be described using the adaptive cycle of ecosystems (Gunderson and Holling, 2002). A simple indicator framework based on the one by Cabell and Oelofse (2012) is proposed to assess to what extent agroecological transitions may lead to greater resilience and adaptability, and its applicability illustrated using examples from actual transition landscapes in family agriculture. Agroecosystems or production ecosystems are considered here to be the smallest scale expression of social-ecological systems, and comprise rural households, local communities, farms and the landscape.

2. (Agro-)ecosystem states and transitions

Agroecological transitions can be described using the analogy of state and transition models (cf. Easdale and López, 2016), but instead of depicting the various states of the ecosystem along gradients of structural and functional degradation, as in the original model, they can be represented in a gradient of farming intensity, as illustrated in Figure 1. The diagram assumes that greater farming intensity leads to loss of ecosystem service provision, due to loss of structural and functional integrity of the ecosystem. Within each state of the ecosystem, of which for simplicity´s sake only four were represented (Natural, Traditional, Industrial and Agroecological, plus a Degraded state), it is possible to recognise more than one system regime, of which only two are represented in Figure 1 (respectively, N_1, N_2; T_1, T_2; I_1, I_2; A_1, A_2 and D_1, D_2).

Natural ecosystem states are assumed to provide services at the highest rate based on the integrity of their ecological structures and functions (Fig. 1). They may still present alternative regimes (N_1, N_2) that in some cases could be actually far from being ´natural´. Yet ecosystem structures and functions are maintained to such an extent at the Natural state of the ecosystem that its capacity to deliver services fluctuates within acceptable ranges. Farming, *sensu stricto*, is not possible in the Natural state of the ecosystem, which is often a protected or legally conserved system state. However, a Natural ecosystem can accommodate human intervention in the form of management, extractive activities (e.g. wood, game, wild foods, feeds, ornamentals, soil, forages, etc.) or other human related activities, up to a certain critical threshold of intensity (Fig. 1), beyond which it shifts to alternative, less conservative states.

Figure 1 approximately here

Highly specialised systems, or the Industrial management or industrialised state of the agro-ecosystem, at the other end of the gradient (Fig. 1), may present alternative regimes (I_1, I_2) that privilege only one ecosystem function: economic productivity, in detriment of all other ecosystem services. At the Industrial state, ecosystem structure has been so profoundly modified that the functions necessary to sustain most other ecosystem services are lost or degraded. Industrial management of the ecosystem is highly dependent on external resources, including financial ones, and heavily subsidized through external energy, without which it is unable to deliver (productivity-related) services at any optimal level.

What is termed here Traditional management system state, for want of a more appropriate name, comprises a broad range of possible ecosystem configurations in between the Natural and Industrial management states that exhibit one common feature: more than one function is delivered but in all cases at sub-optimal levels (Fig. 1). This type of system state is often associated with ´traditional´ farming practices where not even economic productivity is optimal, and where farming is less intensive than under Industrial management, but not always necessarily less harmful to the environment. This is why this system state is described as sub-optimal multifunctional in Figure 1. Reasons for sub-optimality may be many and differ according to context and system properties, current or historical. Sub-optimal multifunctional system states are associated with extensive management, insufficient investment in terms of resources and knowledge, unequal access to and governance of natural resources, unfair distribution of profits, wealth and added value. Their level of delivery of ecosystem services is generally sub-optimal, low in some cases, and this situation is often hard to revert due to several (social-ecological) lock-ins (cf. Tittonell, 2014b). Yet in most cases the Traditional management state overlaps to some degree with the agroecological one, offers opportunity and room for improvement, often more than the Industrial state, as its ecological structures and functions may be less degraded.

The Agroecological is an alternative state of the ecosystem in which structures and functions are reconfigured – recovered - through re-*design* in order to optimise the provision of multiple ecosystem services simultaneously, including economic productivity (Fig. 1). Examples of multiple ecosystems services, though chiefly provisioning and regulating ones, associated with agroecological management abound in the literature (Palomo-Campesino et al.,2018). Yet multi-functional optimality as depicted in Fig. 1 does not rule out possible trade-offs between services (e.g., higher labour demands associated with ecologically intensive management – Aravindakshan et al., 2020), due to which it is virtually impossible to achieve the delivery of all services at the same time at optimal levels. At the Agroecological state, the best available knowledge (local and global) is mobilised to manage the system intensively but sustainably, reducing its dependence on external inputs and subsidies, restoring degraded resources, while new rules of the game are put in place to foster social inclusiveness, shared governance and fairness along value chains (Gliessman and Tittonell, 2015).

The Agroecological state does not occur ´naturally´, it is not reached ´by default´, simply by removing inputs and subsidies. It is intentionally designed and purposively managed (cf. Vandermeer and Perfecto, 2011). To arrive at the Agroecological system state it is necessary to actively transition from any of the other states of the ecosystem (i.e., transitions T -> A; I -> A; N -> A in Figure 1) by investing knowledge, time and resources, and often also by increasing the exposure to risks during the transition phase (Tittonell, 2014a). Depending on the initial configuration of a Traditional management ecosystem state, the transition from this to the Agroecological state (T -> A) may be relatively easier and shorter than the transition from an Industrial system state (I -> A), which may imply profound reconfigurations, or even transformations (cf. Tittonell, 2014b), before a stable Agroecological state is reached. Note in Figure 1 that the various intermediate sates during T->A and I->A are termed ´Agroecological´. I consider systems in transition to be already agroecological systems. The question is, to what extent such transitions lead to gradual increases in resilience and adaptability in order to endure, that is, to navigate and overcome risks associated with global change.

Finally, undesirable transitions are also possible, when systems degrade from either Traditional or Industrial management states. Degraded ecosystem states are characterised by low intensity management and poor service provision (although, granted, there are many possible degraded states and processes that make their representation in Fig. 1 almost impossible). The degradative transitions from T and I states are not labelled in Figure 1 as their treatment exceeds the aim of this article.

3. Resilience and the complex adaptive cycle

Although agroecological transitions (T->A and I->A) are represented as arrows in Figure 1, which may imply that they are linear and unidirectional, in reality they are complex trajectories that exhibit reversibility, non-linearity, discontinuity and hysteresis (cf. Tittonell, 2014b). In principle, transitions could be described simply using the analogy of the logistic S-shaped curve that describes succession in natural ecosystems. In other words, sufficient investments in terms of resources, management and knowledge are needed at the start of a transition in order for positive feedbacks to emerge that can set the system onto an upward trajectory or ´growth´ phase. An extension of the concept of logistic successional trajectories is the complex adaptive cycle proposed by Holling and Gunderson (2002) that describes ecosystem dynamics considering four stages: growth or exploitation (*r*), equilibrium or conservation (*K*), which are the two main phases of logistic succession, followed by phases of collapse or release (*Ω*) and reorientation or reorganization (*??*). The original version of the adaptive cycle was depicted as a ∞ sign. Resilient systems have been defined as those that are able to successfully navigate the four stages of the complex adaptive cycle (Fath et al., 2015). Later revisions, however, proposed to ´tilt´ the cycle left-wise to better represent ecosystem dynamics (Burkhart et al., 2011), and to consider the growth to conservation (r -> K) phase as a non-monotonic, yet upward trajectory as depicted in Figure 2 A. From a stage of equilibrium, or conservation (*K*), systems may describe a monotonic collapse (*Ω*) that brings them back to a reorganization stage (*??*) and potentially new growth (*r*).

I propose the use of this representation of the adaptive cycle to study agroecological transitions and whether or not they contribute to greater resilience and adaptability along the way. Figure 2B illustrates this using the indicator framework to assess agroecosystem resilience and adaptability proposed by Cabell and Oelofse (2012). Their definition of resilience is broad and includes also adaptability. Their framework proposes 14 behaviour-based indicators (originally 13), which were derived from an exhaustive review of the resilience literature, and each is coupled with the phases of the adaptive cycle adaptive at which it is most critical to occur (Fig. 2B). Successful transitions (r -> K) are those that propend to greater connectivity, spatial and temporal heterogeneity, to autonomy from global forces but with high degrees of local interconnectivity, to self-regulation in ecological terms, resting on functional and response diversity and building human capital, to achieve equilibrium stages that can be compatible with reasonable and responsible levels of economic profitability.

Figure 2 approximately here

Some degree of exposure to disturbances is desirable for systems to adapt and optimal levels of redundancy confer stability as well as the ability to turn collapse into reorganization (Figure 2B). Success at the reorganization (or, eventually, reorientation) stage depends largely on the capacity of social actors to self-organise, reflect, learn and be able to share their lessons, recouple their livelihood system responsibly with the natural capital, and honour legacy and tradition (knowledge, culture) while focusing in the future. Agroecosystems that engage in a gradual transition towards agroecological states need to be able to navigate all these phases and exhibit many – if not all – of these capacities in order to transition sustainably, while increasing resilience and adaptability. These properties form the conceptual basis to propose the indicator framework presented in the following section.

4. Assessing resilience and adaptability in agroecological transitions

Because transitions are not exclusive to agroecology, but to any socio-technological change (cf. Grin et al., 2010; Geels 2014; Avelino et al., 2016), and because not all the transitions that are presented as agroecological do really contribute to increasing resilience and adaptability, I propose to use the following ten indicators – more like criteria in a strict sense – to assess the contribution of any type of transition to building resilience and adaptability in agroecosystems:

(i) Self-regulation
(ii) Connectivity
(iii) Functional diversity and redundancy
(iv) Response diversity
(v) Space and time heterogeneity
(vi) Building of natural capital
(vii) Social self-organization
(viii) Reflective learning and human capital
(ix) Autonomy and local interdependency
(x) Capitalising local knowledge

Note that virtually all the resilience and adaptability properties highlighted by Cabell and Oelofse (2012 – cf. Fig. 2B) are captured through these ten indicators, albeit in a more condensed and semi-quantitative way (Table 1). Successful transitions are those that have a positive gradual impact on– most of – these characteristics of agroecosystems simultaneously. To keep it simple and operational, the contribution of a given pathway or strategy or actual trajectory of agroecological transition to enhancing the properties represented by these indicators can be scored using a scale from 0 to 4. Each indicator gets a score value of zero when the transition being evaluated does not contribute to building resilience and adaptability through the agroecosystem property each indicator represents. For example, a score of zero for the indicator *(ix) Autonomy and local interdependency*, means that the proposed transition pathway brings the agroecosystem towards an increasing dependence on external energy (including material inputs in general) and financial subsidies, relying on knowledge and genetic resources that are under external control, often protected through patents and subject to royalties, and towards an increasing isolation of farms and farmers from the local community and its organizations (Table 1).

A score value of four for any indicator, on the other hand, represents a sort of ideal situation for an agroecosystem from the perspective of resilience and adaptability. For example, a score of 4 for the same indicator illustrated above, *(ix) Autonomy and local interdependency*, means that the engaged transition pathway makes the agroecosystem increasingly autonomous in terms of energy, finance, knowledge and genetic resources, leads to local interdependency among social actors, propending to solidarity, as well as to increasing circularity in ecological and economic terms. These ten indicators exhibit also variable degrees of interdependency. For example, the indicator just discussed, is closely dependent on the agroecosystem properties represented by the indicator *(i) Self-regulation*, particularly when it comes to ecological processes. Self-regulation forms de basis of stabilizing feedback mechanisms, which result from intermediate functions and ecosystem services. These mechanisms sustain the recovery of the system after facing shocks and stress, as well as its ability to adapt to internal and external change.

Table 1 approximately here

Considering these ten indicators or criteria *simultaneously* is crucial to assess agroecological transitions. Transition trajectories are often complex. They tend to be exposed to risks, require learning, trial and error, or be subject to variable climate, or start from degraded soils and vegetation or from situations of serious indebtedness, or require extra training or research or knowledge, or adapted technologies and institutions (including markets), etcetera. This makes transition trajectories look actually quite tortuous, as illustrated in Figure 2A, especially when only one ecosystem function or service is considered in the assessment (e.g., economic profit). The trajectory from reorganization (redesign) to growth and conservation (development) may look smoother than in Fig. 2A when multiple aspects of the transition are considered simultaneously, as proposed in Table 1. Agroecosystems that would score 4 in all criteria, on the other hand, may be considered ideal – in the sense of non-existent – or archetypes – in the sense of being a reference point, a goal, to inspire and guide and to work towards. Using archetype analysis to assess transitions on the basis of scores for different indicators appears as a promising avenue to be further explored (cf. Tittonell et al., 2019).

An example

To illustrate how this framework can be applied to assess agroecological transitions, I chose the example of a well-documented agroecological transition by family farmers in the Zona da Mata of Minas Gerais, in Brazil. This is a conspicuous example of a complex 30-year old transition process that is the result of drivers operating at different levels, from national policies to local NGO support and farmer self-organization, all of them concurring towards a rather successful transition. The process has been well documented and described at its different stages by a.o. Cardozo et al (2001), van der Berg et al. (2018) and Teixeira et al. (2018). The various states of the agroecosystem using the state and transitions concept (cf. Fig. 1) are illustrated with pictures taken by the author in Araponga, a municipality of Zona da Mata, portraying examples of the natural, traditional and industrial states (Figure 3). The ´Natural´ state in Fig. 3 corresponds to a sector of the adjacent Serra do Brigadeiro National Reserve. The Traditional state is illustrated with an image from a mixed smallholder family farm, while the Industrial state corresponds to a highly intensive full-sun coffee plantation.

Figure 3 approximately here

Teixeira et al. (2018) revealed that challenges to agroecological transitions are not the same to all farmers in the region, and proposed a farm typology, without necessarily focusing on resilience and adaptability, combining quantitative farm information on 115 family farms with participatory methodologies to inquire about local farmers' perceptions and knowledge, and to generate hypotheses on farm diversity[2]. Other information used in the typology included household characteristics, production strategies, land use and management practices, participation in public policies and extension services. Farmers differ in their objectives, management strategies and actual adoption of agroecological practices and principles, which were promoted regionally by a network of rural families, church-based organisations, university groups and NGO`s. They identified three major types of family farms in the region, termed Conventional, Traditional and Agroecological, which are reminiscent of the three agroecosystem states proposed in Figure 1.

Conventional farms represent the industrial state of the agroecosystem, where the ecosystem has been profoundly modified through the introduction of monocrops such as modern full-sun coffee plantations or monospecific tropical pastures (e.g. *Bracchiaria* sp.) to feed cattle. Traditional farms represent the traditional state of the agroecosystem in Fig. 1, following traditional practices and using local knowledge often due largely to lack of capacity to afford the technologies used by Conventional farmers. Yet, although their capacity for self-organisation was seen to be rather low, the Traditional type of farmer was characterised by profound cultural bonds with the rural way of life and traditions of their region, which they had in common with Agroecological farmers (cf. Teixeira et al., 2018). Agroecological farmers were those that used design principles and practices from agroecology. And, most importantly, they were engaged in social movements supporting agroecology in the region as well as other forms of associative networks, which strengthened their social capital and self-organisation capabilities. All of these attributes contributed to render their agroecosystems in an Agroecological state *sensu* Figure 1.

Applying the 10-indicator framework of Table 1 to assess resilience and adaptability to the three types of farms identified by Teixeira et al. (2018) – assuming they represent three distinct states of the agroecosystem – yielded the results presented in Figure 4. It must be noticed that this application of the framework was done, for illustrative purposes, using average farm types, and not on each individual farm visited in the field.

[2] Information and details on data collection and processing are provided in the original paper by Teixeira et al. (2018)

Although using individual farms may yield sharper differences for the various indicators, the interpretation of the results and the identification of clear patterns between agroecosystem states becomes difficult. This is why delineating a farm typology, preferably a functional one based on agroecosystem states (cf. Fig. 1), is recommended as a previous step to assessing agroecological transitions (when the number of cases is sufficiently large). The analysis presented in Figure 4 indicates that, in this particular case, T->A transitions appear to be more easily realisable than I->A ones, as suggested also in Fig. 1. In other words, traditional agroecosystem states appear to be closer to agroecological states in terms of resilience and adaptability attributes than industrial states are in this case.

Figure 4 approximately here

The greatest differences between agroecosystem states were observed in terms of autonomy, use of local knowledge, self-regulation, connectivity, social organisation, functional and response diversity. Traditional farms were close to Agroecological ones in terms of use of local knowledge, reflective learning and human capital, functional diversity and heterogeneity, and far from them specially in terms of building of natural capital, but also in terms of social organization, autonomy and self-regulation. Such findings, which decidedly highlight the importance of social capital and organisation as key levers in agroecological transitions, may help orient development efforts and policies to foster change towards more sustainable agriculture and food systems. In such sense, the framework could be useful for monitoring transition processes over time or to assess gradual and incremental effects of policies and development projects on building resilience and adaptability.

Discussion

Several examples of socio-technological transitions worldwide are nowadays presented as agroecological transitions (e.g., organic farming, national or regional agroecology policies, international development projects, etc.). Yet there is lack of common ground to define what an agroecological transition is, how ´agroecological´ is an agroecological system state, how far the baseline agroecosystem state is from an agroecological one, etc. All of which requires formal assessment using simple, applicable, common and generalizable methodologies. Let us focus on an actual case. The Ministry of Agriculture of the French Government, a pioneering state in terms of promoting wide scale agroecological transitions, claims in its website that there are some 4000 farms undergoing agroecological transition in France (www.agriculture.gouv.fr). Undoubtedly a promising result from an effort to undertake the challenge of mainstreaming agroecology in Europe. However, little is said on how the transition is being assessed, i.e. defined, referenced, measured, monitored. Neither is it clear what the ideal or model of an agroecological farm is for every region and/or production system in France, and thus it is hard to assess how far in the transition the claimed 4000 transitioning farms really are. Further, in a context of accelerating global change and uncertainty, and despite the growing positive evidence that abounds in the literature (e.g. Blesh and Wolf, 2014; Bonaudo et al., 2014; Duru et al., 2015; Gaba et al., 2015; Phocas et al., 2016; Berthet et al., 2017; Beudou et al., 2017; Dupré eta l., 2017; McCune et al., 2017; Prost et al., 2017), one may still wonder whether transitioning agroecosystem are better off than they were at the baseline situation in terms of resilience and adaptability. A framework to monitor transitions as the one presented here, operationalisable and simple, may contribute to start addressing these questions.

Existing indicator frameworks to monitor agroecological transitions have mostly emphasised measuring ´performances´ (e.g., Trabelsi et al., 2016). Others prefer to avoid the use of indicators which they see as too reductionistic and propose ´domains´ of transformation (in place of transition), but offer no practical application of their theoretical approach in real life circumstances (cf. Anderson et al., 2019). The framework I propose combines elements of state and transition theory with the concept of the complex adaptive cycle, and provides a minimum set of resilience and adaptability indicators for rapid – yet evidence-based – on the ground assessment of actual agroecological transitions (cf. Table 1; Figure 4). Although, for simplicity, the various criteria used in the framework were given the same importance, in the sense of receiving the same relative weight in the assessment, one may immediately think of examples where this is not the case. In fact, social organisation and building of natural capital are normally two key aspects of a successful transition.

The narratives provided in Table 1 are meant to limit the degree of unavoidable user subjectivity when scoring each indicator. Yet the actual score values will also depend on the context in which the framework is applied, terms of both social and ecological conditions and history. This may be a weakness of such a simple framework when the intention is to use it for comparative analysis across agroecosystems, as the assessment of resilience and adaptability is not only dependent on the intrinsic attributes of an agroecosystem but also, and fundamentally, on the nature, magnitude and risk of exposure to external shocks and stresses (e.g., Groot et al., 2016). In other words, the attributes that confer resilience and adaptability to droughts, to hurricanes or to price shocks differ, as do the magnitude and nature of the devastating effects associated with these shocks. Farmers and other rural actors also differ in the way they perceive such risks and in the way they act in response to them (e.g. Tittonell et al., 2019). In such sense, it cannot be simply assumed that any agroecosystem, subject to any external shock or stress, will always undergo the various steps of the complex adaptive cycle (cf. Fig. 2). In particular, not all agroecosystem will necessarily undergo collapse when facing disturbance, and for the same reason, collapse and reorganization, in a strict sense, are not strictly prerequisites for an agroecological transition.

A special case of transition that raises much controversy is the one depicted as N->A in Figure 1, representing a possible transition from a Natural to an Agroecological state of the ecosystem. To some, considering such a transition ´agroecological´ is simply an oxymoron, since fostering land conversion by bringing more forest, savannahs or natural rangelands into agricultural or livestock production is unsustainable, and hence not compatible with agroecological principles and practices. Others, who see land use conversion as an inevitable result of human population growth (e.g., the expansion of livestock and soybean production in the Amazon forest, of oil palm in South East Asia or Equatorial West Africa, of coffee plantations in Central American highlands, etc.) see agroecology as a viable way to design land sharing schemes where nature conservation and food production could be integrated and balanced, hence preventing further land conversion. This controversy is a hard one to solve, and the right answer may differ according to contextual conditions and specific circumstances, including notably policy environments and local societies´ own values and norms (Sayer et al., 2012).

Conceptualising transitions as shown in Figure 1 somehow challenges the well-established discourse of the agroecology movements worldwide – of which I am actively part – that typically opposes agroecological against conventional or industrial system states, highlighting an urgent need to undertake *I -> A* type of transitions (e.g., Levidow et al., 2014; Gliessman and Tittonell., 2015; Jansen, 2015; Timmerman and Félix, 2015; Nicholls and Altieri, 2018). In resource poor and/or marginal environments, such as in smallholder systems of sub-Saharan Africa for example, the initial conditions for the agroecological transition is not an Industrial state but often a Traditional management state (e.g., Félix et al., 2018). And the presumption that a traditional state is already an agroecological state is also often erroneous. In other words, and as Sartre once said, Paul Valéry may be a petit bourgeois intellectual, but not every petit bourgeois intellectual is like Paul Valéry. Although several traditional *campesino* systems follow the principles of agroecology (e.g., Altieri and Nicholls, 2017), it cannot be simply asserted that all smallholder traditional farms are agroecological.

In fact, the use of agrochemicals, for example, may be common among some smallholder family farmers when they are able to afford them. Battharai et al. (2015) in Costa Rica found that traditional smallholder family farmers prefer to use pesticides or chemical fertilizers if they can afford them – which is mostly not the case. Similar results were observed by Caulfield et al. (2018) in Ecuador, by Alomia-Hinojosa et al. (2017) in Nepal, by Castellanos-Navarrete et al. (2014) in Kenya, by Hauswirth et al. (2015) in Vietnam, by Cortez-Arriola et al. (2016) in Mexico, by Teixeira et al. (2018) in Brazil, or by Paresys et al. (2018) in Benin. No use of chemical inputs in such cases cannot be associated with purposeful agroecological management, but often simply with lack of cash to afford them. This form of low or no input farming, common among smallholder families, has been ironically termed ´organic by default´ (Tittonell, 2013). Yet agroecology is much more than that; much more than agriculture without inputs. It requires design, ecological replacement, specific knowledge and technologies on the farm, plus interconnectivity, solidarity and associative action within the broader community. A singular finding in the study of Teixeira et al. (2018) in Zona da Mata of Brazil is that several management practices, even those deemed to be agroecological, were to some extent adopted by the three types of farmers identified. This suggests that the actual differences between the Traditional, Industrial and Agroecological states of the agroecosystem would not always be as sharp in reality as suggested by Fig. 1, and that assessing the number of agroecological practices being adopted or implemented is not enough to identify agroecological transitions.

Note further, that both types of transitions in Figure 1, T -> A and I -> A, are represented as rightwards trajectories, i.e. trajectories that imply initial phases of intensification, not of ´extensification´ as it is often assumed when talking about agroecological transitions. For example, farmers who are averse to engaging in an agroecological transition often argue that agroecology implies more labour intensity than what their current systems demand (e.g., Alomia-Hinojosa et al., 2018). Initial intensification may be reverted in subsequent stages of the transition, as indicated for I -> A in Figure 1. Although the diagram presented in Figure 1 assumes that Natural states of the ecosystem are those that provide services at the highest rates, this assumption may not be correct when agroecosystems evolve from the modification of marginal or fragile environments such as drylands or marshlands. Often poorly productive rangelands in arid environments are turned through human agency into highly productive multi-storey systems by means of irrigation, agroforestry and conservation farming techniques, as can be seen in many parts of the world (e.g. Blanco et al., 2017). In such cases, the level of provision of certain ecosystem services (e.g., carbon sequestration) may be higher under human management than in natural circumstances.

Although for illustrative purposes transitions are depicted as trajectories of farming intensity in Figure 1, and although the framework presented here focuses strongly on the agroecosystem scale (Table 1), the actual transition process implies much more than that: adaptive cycles are nested in a hierarchy of space and time scales (i.e., a *Panarchy* – Gunderson and Holling, 2002). Transitions require social interactions, engagement of a diversity of actors operating in a territory, and enabling policy and institutional (including markets) environments (Newig et al., 2007). For example, in the case of the Zona da Mata of Brazil examined here (cf. Figure 3 and 4), the agroecological transition has been the result of the concomitant action of individual farming families, social movements and NGOs, church organizations, a local farmer union and municipal support (van den Berg et al., 2018) as well as national policies (Wittman and Blesh, 2017). The agency of these organizations, sometimes termed ´intermediaries´, is also crucial during the phase of reorganization following collapse (cf. Figure 2). Intermediary actors have been repeatedly shown as catalysts of transitions towards more sustainable socio-technical systems (e.g. Hodson et al., 2013; Wieczorek and Hekkert, 2012). The process of transitions is turbulent (cf. Figure 2A) and implies shifts in the relationship between actors, deep structural changes, and changes in the relationship between communities and their natural environment. All of which may lead to cooperation, but also to conflict between actors that needs to be addressed in order to ensure the success of the transition towards more sustainable (equitable, fair, inclusive) realities. This is why the transition towards agroecology must be understood as the consequence of both technological *and* institutional innovation (cf. Tittonell, 2014a), and not as unilinear, monotonic and irreversible but as complex, adaptive, reversible, gradual, and often discontinuous trajectories of change.

Acknowledgements

I thank Prof. Irene Cardoso for inspiration and for sharing her vast knowledge on the complex agroecological transition process that took place in the Zona de Mata of Minas Gerais, Brazil. I thank my colleague Dr. Marcos Easdale for very inspiring discussions and for sharing his ideas on how state-and-transition models could be used to depict agroecosystem transitions.

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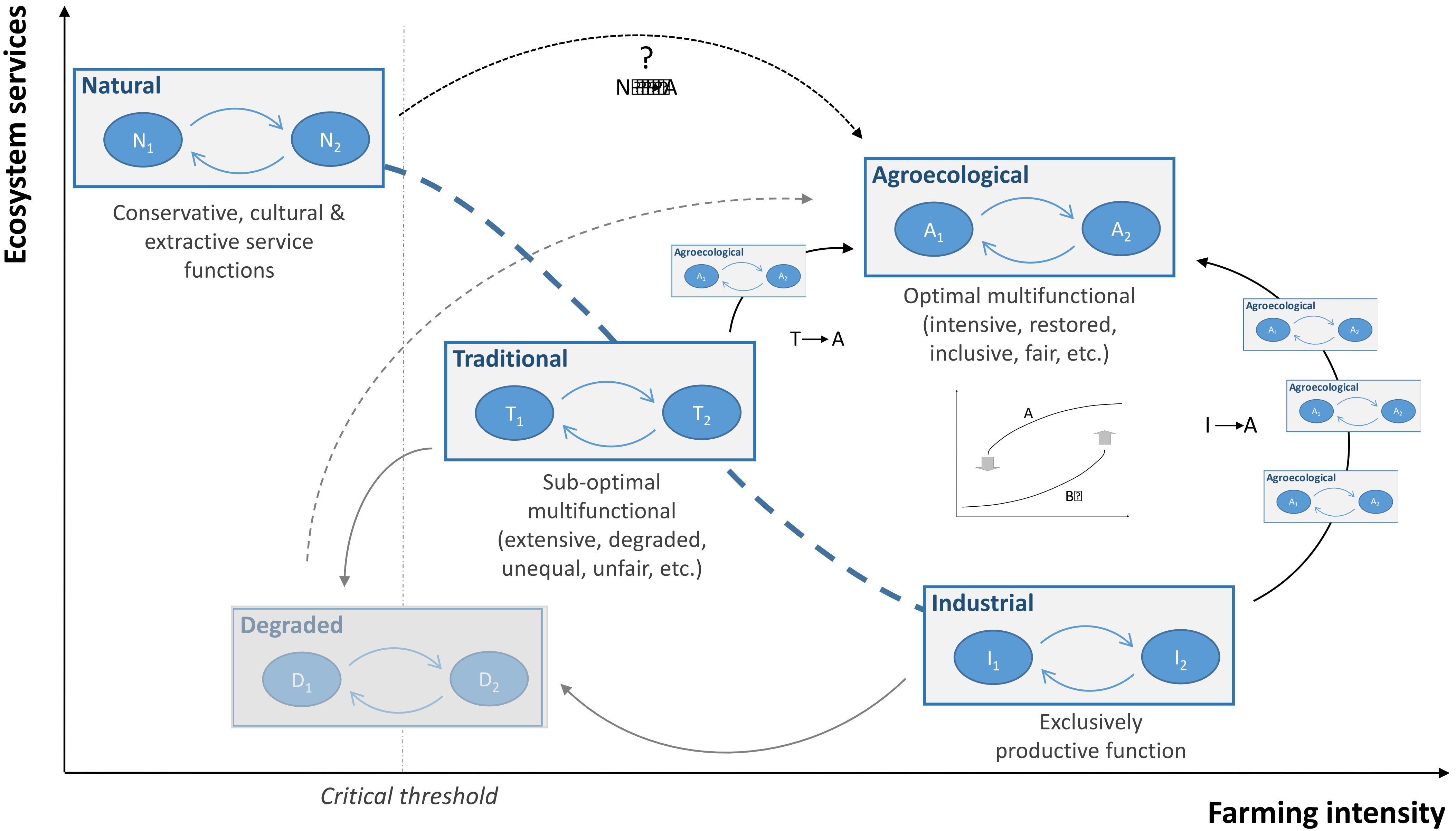
Figure captions

Figure 1: States and transitions in (agro-)ecosystems represented along a gradient of increasing farming intensity. Not all possible states (Natural, Traditional, Industrial, Agroecological and Degraded) and transitions (N->A; T->A; I->A) are represented. The inset graph depicted in between Agroecological and Industrial states indicates that shifts between system states (A, B) may not be linear nor continuous, and that they may exhibit hysteresis (cf. Tittonell, 2014b). The Degraded state is grey-shaded as it is not dealt with in this study, but D->A transitions (grey dotted line), although not represented here, are also possible and highly desirable. Black full and dotted arrows indicate possible transitions. Blue, dotted background line illustrates the stability landscape used in state-and-transition models (cf. López et al., 2011).

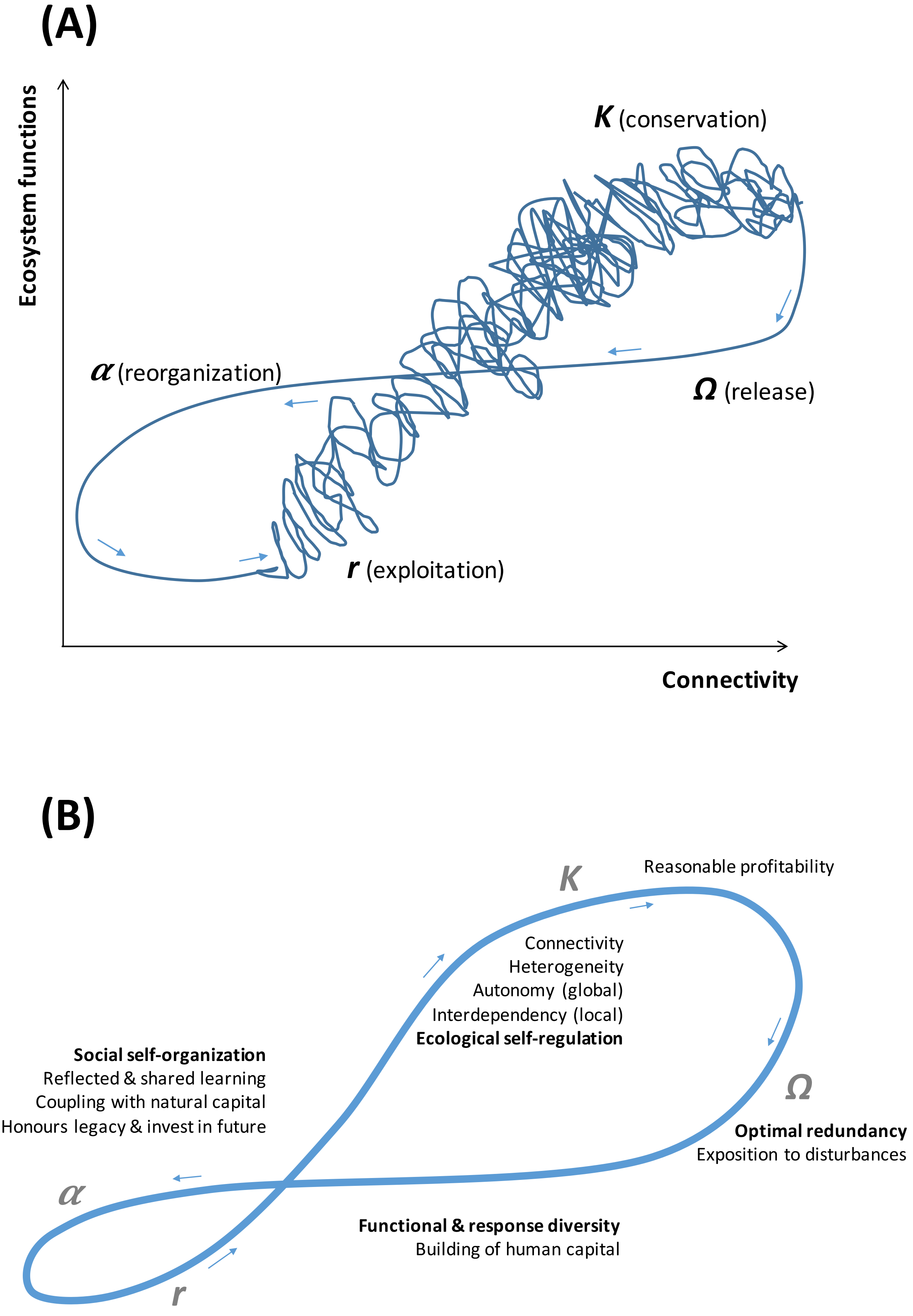
Figure 2: (A) A modified representation of Holling´s Adaptive Cycle of ecosystems as proposed by Burkhard et al. (2011), in which the cycle is tilted leftwards and the growth phase is shown as a tortuous pathway but with an overall upward trajectory. (B) The ´tilted´ adaptive cycle and the most relevant indicators of resilience and adaptability (following Cabell and Oelofse, 2012) associated with each phase of the cycle. Functional and response diversity, as well as building of human capital, are relevant throughout the cycle.

Figure 3: Pictures taken in Araponga, Zona da Mata of Minas Gerais, Brazil illustrating the various states of the agroecosystem using the concept of state and transitions (photos: P. Tittonell, 2015).

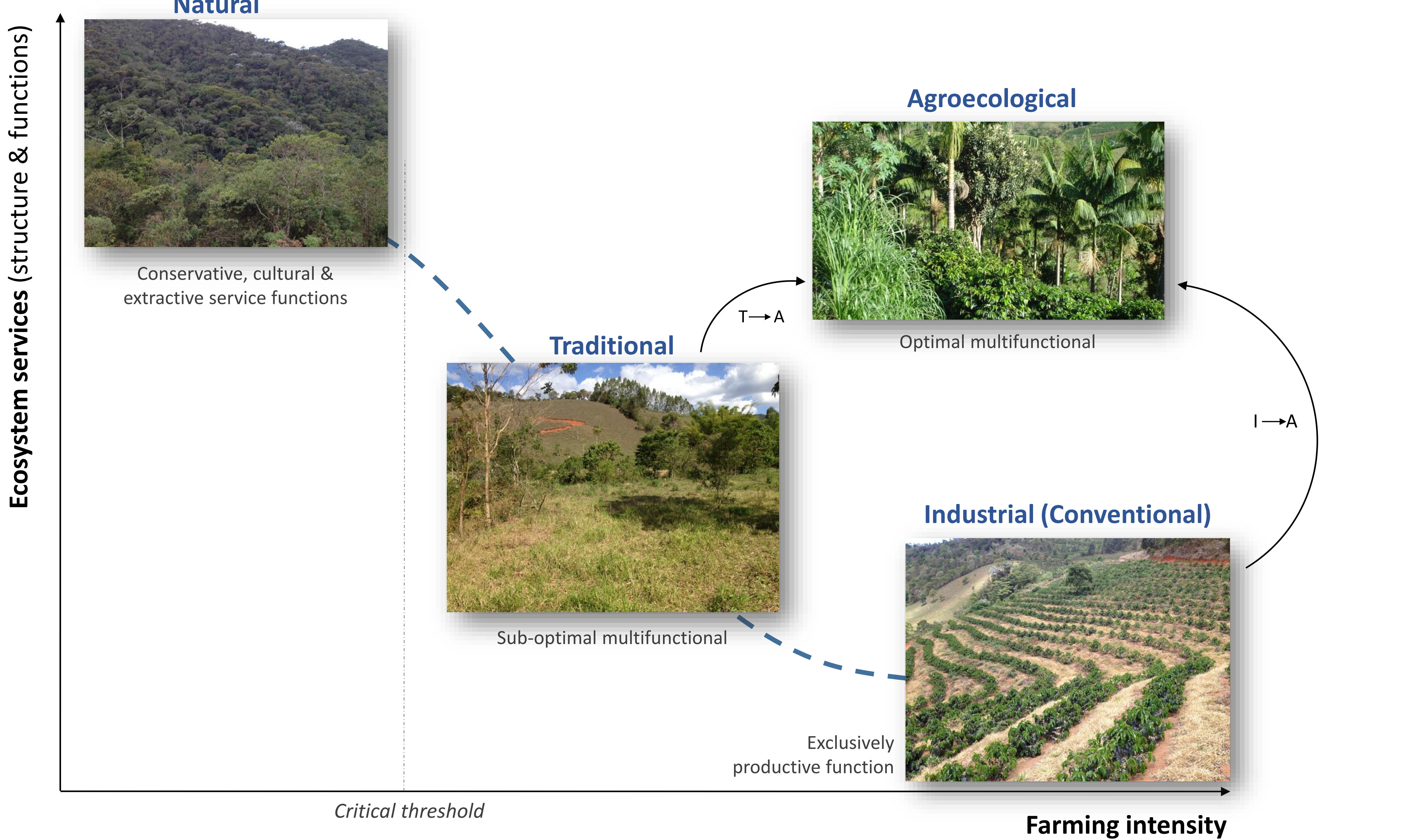
Figure 4: Application of the framework to assess resilience and adaptability (cf. Table 1) to case study farms from Zona da Mata (Brazil – Teixeira et al., 2018) assuming that they correspond to the three states of the agroecosystem described earlier (Fig. 1): Agroecological, Traditional and Industrial (Conventional). Indicator scores were assigned to ´average´ farms per farm type.



Ecosystem services
Natural
N1
N2
Conservative, cultural & extractive service functions
?
Agroecological
A1
A2
Optimal multifunctional (intensive, restored, inclusive, fair, etc.)
T→A
Traditional
T1
T2
Sub-optimal multifunctional (extensive, degraded, unequal, unfair, etc.)
A
B
I→A
Industrial
I1
I2
Exclusively productive function
Degraded
D1
D2
Critical threshold
Farming intensity



(A)
Ecosystem functions
K (conservation)
α (reorganization)
Ω (release)
r (exploitation)
Connectivity
(B)
K
Reasonable profitability
Connectivity
Heterogeneity
Autonomy (global)
Interdependency (local)
Ecological self-regulation
Social self-organization
Reflected & shared learning
Coupling with natural capital
Honours legacy & invest in future
Ω
Optimal redundancy
Exposition to disturbances
α
Functional & response diversity
Building of human capital
r



Natural
Conservative, cultural &
extractive service functions
Agroecological
Optimal multifunctional
T → A
Traditional
Sub-optimal multifunctional
I → A
Industrial (Conventional)
Exclusively
productive function
Ecosystem services (structure & functions)
Critical threshold
Farming intensity

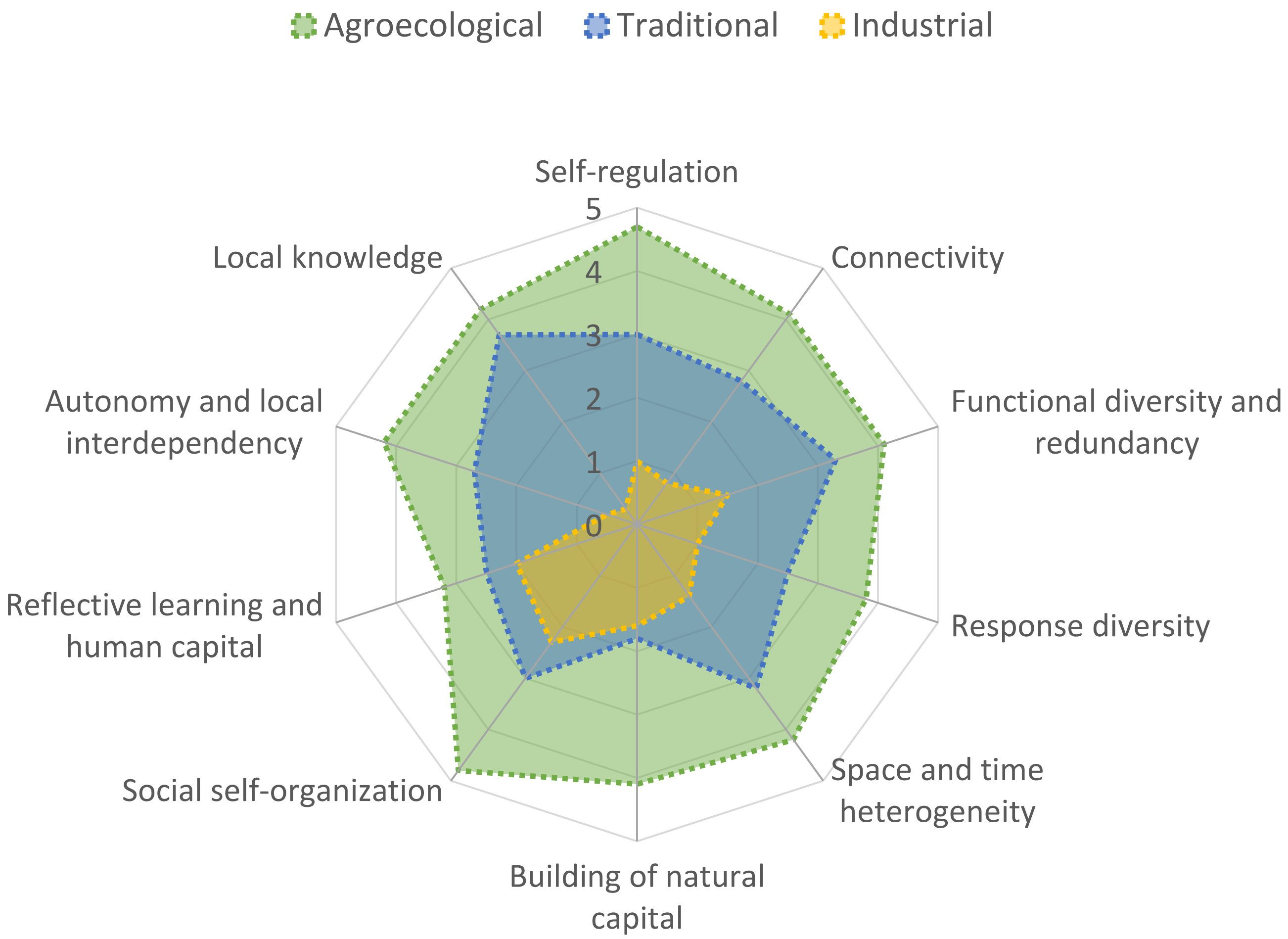

Agroecological
Traditional
Industrial
Self-regulation
Connectivity
Functional diversity and redundancy
Response diversity
Space and time heterogeneity
Building of natural capital
Social self-organization
Reflective learning and human capital
Autonomy and local interdependency
Local knowledge
5
4
3
2
1
0

Table 1: Ten indicators of agroecosystem (AES) resilience and adaptability to assess agroecological transitions, and the narrative behind the scores (0 to 4) for each of them. Only the two extreme (0, 4) and the intermediate (2) scores are described.

Indicator	**Score 0**	**Score 2**	**Score 4**
Self-regulation	The AES exhibits no or little ability to self-regulate, resulting in positive feedbacks (explosive behaviour, downward spirals) and heavy dependence on external inputs of nutrients, water, toxins, energy and control-based management.	The AES exhibits moderate self-regulation and limited connectivity and communication between its components, both positive and negative feedbacks coexist, and managers combine control-based measurements with regulating social and social-ecological interactions	The AES exhibits internal mechanisms of self-regulation (negative feedbacks) in the form of biotic (e.g. pest biocontrol) or abiotic interactions (e.g. water flow), mediated by social and social-ecological interactions (e.g. communal grazing bylaws).
Connectivity	Poor and strong connectivity (or none) between its components, and often fewer components, resulting in rigidity and dependency	Moderate number and strength of connections between AES components, moderate diversity, dependency and flexibility	High and weak connectivity between its components, often numerous, resulting in diversity and flexibility
Functional diversity and redundancy	The AES has been simplified and provides a narrow range of ecosystem services through a few highly controlled mechanisms (specialization); essential functions are provided by a limited set of elements or structures which exposes the system to risks and high vulnerability	The AES retains a minimum structure that allows providing a range of ecosystem services through multiple mechanisms operating at sub-optimal level (sub-optimally multifunctional); essential functions are provided by a limited set of elements or structures which exposes the system to risks and moderate vulnerability	The AES exhibits ability to provide a diversity of essential ecosystem services through multiple mechanisms (optimally multifunctional); essential functions are provided by a diversity of elements or structures which provides buffering capacity (duplicate functions or redundancy)
Response diversity	The AES exhibits no ability to respond or adapt to external shocks and stresses, little or no technical and organizational innovation emerges, and response capacity is hampered by insufficient functional diversity, connectivity, social organization or natural capital	The AES exhibits limited ability to respond or adapt to external shocks and stresses through alternative technical and organizational innovations, due to limited functional diversity, connectivity, social organization of natural capital	The AES is able to withstand critical periods and exhibits ability to respond and adapt to external shocks and stresses through multiple alternative mechanisms that imply technical and organizational innovation, supported by its functional diversity, connectivity, social organization and natural capital

Space and time heterogeneity	The AES is homogeneous in space and time, specialised, exhibits little patchiness, and changes in time are often repetitive and predictable (e.g. sowing dates, concentrated flowering, etc.); no buffering nor renewal capacity after disturbance, unless externally subsidised	The AES exhibits moderate levels of patchiness and change relatively little over time, which compromises buffering functions and provides limited seeds of renewal after disturbance or degradation	The AES exhibits patchiness at landscape level (habitats) and change over time (cyclical, evolutionary, reversible, hysteretic), which allows buffering functions and provides seeds of renewal after disturbance or degradation
Building of natural capital	The AES destroys, exhausts or degrades its natural capital in terms of soil organic matter and nutrients, vegetation structure, cover and diversity, water storage capacity and water availability, agrobiodiversity and crop and livestock (incl. fish) genetic resources, etc., with every production cycle, so that it decapitalises and reduces its capacity to restore capital.	The AES slightly decreases or maintains its natural capital with every production cycle, so that it slightly degrades or maintains its stocks and/or its ability to restore them.	The AES builds natural capital in terms of soil organic matter and nutrients, vegetation structure, cover and diversity, water storage capacity and water availability, agrobiodiversity and crop and livestock (incl. fish) genetic resources, associated biodiversity and wild life, etc., with every production cycle, so that it capitalises year after year.
Social self-organization	Individual and/or foreign enterprising dominates the modes of production (absent producers, often urban residents, land hired out to investment companies, etc.), no local social organization or just transitory ones, geared by short term goals (e.g. political claims and protests).	Short-lived or temporary organizations with specific or multiple objectives, initiated and supported through the initiative of a few community members as facilitators and motivators; limited ability to network outside the local community	Local community self-organization and cooperation, and networks with other communities and organisations, including rural-urban networks (e.g. direct markets); organizations are permanent or long living, with multiple objectives.
Reflective learning and human capital	Individual managers do not capitalise on past and current experience nor invest in human capital but rely on foreign knowledge, leading to repetitive behaviour and implementation of ´packages´, recipes or standard practices	Individuals within communities capitalise on past and current experience to adapt and create change, but sharing of such knowledge is limited among the community, leading to poor overall adaptive capacity	Communities (both individuals and local institutions) learn from past and current experience and share this knowledge, thereby creating human capital that allows to anticipate future dynamics and adapt their behaviour to create the necessary change
Autonomy and local interdependency	The AES depends entirely on external energy and financial subsidies, knowledge and genetic resources under external control, locally isolated and independent	The AES depends on external sources of energy, finance, and knowledge but shows increasing autonomy, maintenance of local genetic resources	The AES is globally autonomous in terms of energy, finance, knowledge and genetic resources and exhibits high degree of local interdependency among

	from other components		its (social and ecological) components
Local knowledge	Local knowledge is neglected and/or ignored, replaced by other sources of knowledge (often deemed ´modern´), and eventually forgotten, lost to next generations	Local knowledge still present in the community and used by some, seen as backwards and not well integrated with other sources of knowledge, neither documented nor past to next generations	Local knowledge is honoured, critically revisited, merged with other sources of knowledge and information, put in practice, documented and passed on through generations