Chapter 6
Biodiversity friendly landscapes – A question with many solutions

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Abstract Building on some of Teja Tscharntke's key papers we discuss a number of complexities of farming systems and agricultural landscapes that we believe should be included in future studies of production landscapes. We contend that transformation of modern agricultural landscapes to biodiversity-friendly ones needs a combination of farming on-field measures, land-use practices and landscape measures, but also policies supporting less intensive production. We argue that in future research, landscape ecologists should acknowledge the multiple values of biodiversity, and abandon using simple species richness indicators for those values. Ecologists should rather focus on understanding what species and their interactions are actually doing in production ecosystems. Some myths in landscape ecology, such as global food scarcity, land sparing, and intensive farming being the benchmark for sustainable food production, are rejected. We show that the global agricultural system is entrenched in a productivist narrative that hinders development of more sustainable production systems. In order to change current agricultural systems towards sustainable production and biodiversity-friendly landscapes, we need a broader perspective that incorporates knowledge and understanding of social-ecological systems and processes. We exemplify this with four future scenarios for Swedish food systems that in different ways are suggested to contribute to biodiversity goals, though perhaps not exactly via the biodiversity-friendly landscapes envisioned by Teja and many other ecologists.

"*Answers live their time. Questions come again and again.*"
Samuli Paronen[1]

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[1] Paronen, S. (1974) Maailma on sana: Mietteitä. Translated from Finnish by Heljä-Sisko Helmisaari.

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6.1 Introduction

It is interesting how thoughts and ideas tend to develop in parallel in science. Starting from different points of departure we (Janne and Riccardo, together with a much missed Barbara Ekbom) developed an interest in agricultural landscape ecology in the mid to late 1990s. By the turn of the millennium we had discovered Teja Tscharntke who followed similar lines of thought.[2] What drew our attention and admiration was the ground-breaking paper in *Science* by Carsten Thies and Teja (Thies and Tscharntke 1999) that pointed towards research on how non-arable habitats in the agricultural landscape could be important for biological control of insect crop pests; a process now often called ecosystem service or Nature's Contributions to People (NCP), depending on the choice of conceptual framework.[3] However, examining our articles from that time, references to Teja are conspicuously rare until 2005, and if anything was cited, it was the Science paper. Teja was by then building his successful agroecological group in Göttingen with many interesting persons, and by 2006-08 we routinely referred to and were inspired by the quickly increasing body of excellent research led by Teja. When there was a EuroDiversity call for a "pan-European" project on biodiversity and ecosystem services from the now largely closed down European Science Foundation in 2004, it was an obvious choice to invite Teja and his group in Göttingen as a key partner. We called the project AGRIPOPES and we received funding for three years from late 2006.[4] It was during this time that we really

[2] It could have made us competitors, but instead we became collegues, collaborators and friends with Teja and many of the younger group of students and Ph Ds that he gathered around him in Göttingen. Janne came from a background in metapopulation ecology of waterfleas (*Daphnia*), being one in a long tradition of Swedish researchers who believed they could change the world with research in rockpools (see below), but happened to end up studying biodiversity and ecosystem services in forest and agricultural landscapes at the Swedish University of Agricultural Sciences by the late 1990s. Riccardo had a training in agronomy and had worked with crop protection and the population ecology of predators and their pest prey, and had initiated research on spatial ecology and the influence of landscape on population regulation in his PhD-studies mentored by Barbara Ekbom. (Rockpools are small waterfilled depressions in bedrock along large areas of the coasts of Sweden, Finland and Norway, but also other countries such as Russia and Canada, being perfect models for fragmented populations such as *Daphnia* metapopulations (e.g. Hanski and Ranta 1983; Bengtsson 1989; Bengtsson and Ebert 1998). Other Swedish researchers studying rockpools include Fredrik Wulff, Björn Ganning, Jon Norberg, Eva Lindström, Silke Langenheder and – amazingly – Janne's collaborators Örjan Östman and Lars Gamfeldt, to name a few).

[3] IPBES advocates that the term Nature's Contributions to People (NCP) is used rather than ecosystem services (e.g. Díaz et al. 2018). It is argued that this is a broader and more inclusive term that puts higher emphasis on cultural links between people and nature, and recognizes other knowledge and value systems, while the term ecosystem services is too much based in an western and economic world view. Here we use these terms interchangably as they have been used in the debates we refer to.

[4] The perhaps strange acronym AGRIPOPES stands for AGRIcultural POlicy-induced landscaPe changes: effects on biodiversity and Ecosystem Services. It's not been possible to trace exactly how the project emerged and how Teja got one of the key roles; the files on Janne's computers only date back to late 2004, when a full draft of thce application appears from the shadows. We believe that Michel Loreau's work in the ESF Linking Species and Ecosystems network played an important role, but the person who did most of the hard job to produce the apparently well-received application was Pablo Inchausti, then at CNRS in France. (As a side issue, the surprisingly positive reviewer comments included "a breath of scientific fresh air. The authors have a testable hypothesis, which, while not the most original, will certainly provide evidence for a much larger landscape of Europe than the typical country assessments'", "a novel, superior approach to anything I have seen at this level.'" and "a jewel to read … Amazing."). The project ran during

got to know Teja and his co-workers in Göttingen in person, with friendships that have continued. For example, Janne has a fond memory of a seminar and Christmas party in Göttingen in December 2008, and then taking a very early train back to Sweden the next morning. Riccardo vividly remembers the warm reception by Teja and his group at a visit in Göttingen. We remember Teja impressively balancing between on one hand scientific focus and high ambition, with on the other hand feasibility and pragmatic consideration of the students and available resources in AGRIPOPES.

Most of Teja's career, as we know it, has been built around questions on how to preserve, increase and use biodiversity and ecosystem services in managed landscapes – from landscape effects on natural enemies of crop pests and the dynamics of the trophic interactions involved (Thies and Tscharntke 1999), pollinators' use of landscapes (Steffan-Dewenter et al. 2002) and how this affects coffee pollination (Klein et al. 2003), to advantages (Gabriel et al. 2006; Holzschuh et al. 2008) and disadvantages (Tscharntke et al. 2021) of organic farming for increasing farmland biodiversity. These are all questions of high theoretical and practical importance that have inspired research globally, and are likely to have complex, localized or regionalized and often uncertain answers, partly because each answer is likely to represent particular perspectives, localizations, organism interactions, scales, times, and time-frames. To this is added the uncertainties of climate warming and the socio-political responses to climate change and biodiversity loss (IPCC 2014; IPBES 2019). Finally, the questions may also challenge many views on human-nature relationships in a fundamental way (Díaz et al. 2018; Biermann 2021).[5]

A reoccurring and important theme in Teja's research is the conviction that landscape composition, and especially the amount and quality of seminatural habitat outside arable crop land, is an important determinant of biodiversity in agricultural regions, together with farming practices and production systems on the arable land. This is especially emphasised in one of Teja's most cited papers (Tscharntke et al. 2005) in Ecology Letters,[6] in which most of the ideas were formulated that have been elaborated by him and many others for almost 20 years. Examples of still active research topics springing from this paper include the contrast between local and landscape intensification, the role of the landscape species pool and dispersal, and the varying effectiveness of agri-environmental schemes depending on landscape context. The latter suggests that farming system changes, such as transition to organic farming, will have larger effects on biodiversity and ecosystem services in simple than in complex landscapes. The article makes a strong case for both more extensive and traditional farming methods and land use systems, including benefits of managed non-crop areas, to increase biodiversity. In addition to more extensive farming methods, e.g. organic and regenerative practices, such managed semi-natural habitats have received large

2007-2010 and included field studies in a N-S gradient from Estonia and Sweden to Spain, and E-W from Poland to Ireland, with two sites in Germany (former West and former East) and one each in France and the Netherlands. Several other European countries were also involved. Work from the project is still being published, the most recent articles are Emmerson et al. (2016) and Carmona et al. (2020). Riccardo and Janne take this opportunity to thank Pablo, Teja and the other PIs for the privilege to have worked with you.

[5] Also discussed in relation to biodiversity by Bengtsson and Hilding-Rydevik (2021) (in Swedish. A pdf is available from the first author on request, but it is in Swedish, and will not really make sense if you Google-translate it!)

[6] This paper has around 4000 citations, depending on which source is being used.

attention both in biodiversity science and policy, local and landscape management being regarded as complementary for supporting biodiversity in agricultural landscapes (e.g. Tscharntke et al. 2005; Tuck et al. 2014). More extensive farming methods have also been argued to have a number of other environmental and social benefits (e.g. Gomiero et al. 2011; Reganold and Wachter 2016; Seufert and Ramankutty 2017; Elmqvist et al. 2022).

In view of a seemingly general agreement on the complementarity of these two approaches, it was somewhat surprising when Tscharntke et al. (2021) argued that measures and policies at the landscape level was the major or even overriding factor for supporting biodiversity in agricultural landscapes, in comparison with extensification of farming practices and farm production systems on the arable land. The 2021 article elaborated their view on how "biodiversity-friendly" landscapes can be created. We will use the 2005 and 2021 articles as starting points for a discussion of some problematic issues when dealing with conservation of biodiversity and ecosystem services in human-dominated production landscapes. We refer especially to landscapes dominated by western types of agriculture that have been overwhelmingly transformed since the 1950s into a productivist industrial agriculture, to a large extent driven by large agrobusinesses aligned with policies (or no-policies) that have favoured intensification (e.g. Clapp 2015, 2021b,a).

Our aim here is not to question Teja's work, but rather to build upon it by highlighting a number of unresolved and difficult issues that Teja in various and sometimes contradictory ways has addressed, but at times also avoided in his career. We discuss the directions and questions asked and not asked in agricultural landscape ecology that has grown to a large field of research globally, to a great extent inspired by the work and approaches of Teja and his students. The main point we make is that creation of the "biodiversity-friendly" landscapes suggested by Tscharntke et al. (2021) and many other landscape ecologists is unrealistic without a major change in *farming systems*. We argue that in fact it is only possible if combined with a socio-political transition towards environmentally sustainable farming, along with climate-smart diets, biodiversity-friendly landscape management and reduced and recirculated waste (e.g. Billen et al. 2021).[7]

6.2 What is this thing called a biodiversity-friendly landscape?

Tscharntke et al. (2021) discuss what a "biodiversity friendly" agricultural landscape should look like, by giving examples of features that such landscapes should contain. They divide these features into "measures essential for biodiversity-friendly *farming*", "*land-use* practices" and "*landscape* measures" (our italics). We find it useful to divide what can be done to enhance biodiversity into these categories, since the societal drivers and actors are different. However, their paper largely focused on – or was interpreted often as – contrasting organic farming and landscape measures for biodiversity as *opposing* strategies. We contend that

[7] We base our view on a system perspective that emphasises something that is hidden or even actively forgotten in the biodiversity-farming discourse, namely that the system we want to change is a social-ecological one. Since our view also implies some hypotheses about the future – which cannot be known and tested now, we can only provide a chain of arguments based on what we presently know about the ecology of agricultural landscapes and social-ecological food production systems. By necessity, but in our case explicitly, this is based on a political view on agriculture, food and biodiversity that, albeit vague, is transcending the organisation of the present agricultural systems. But in which direction?

this framing of the biodiversity-friendly landscapes question is misleading. It will most likely not provide the answers needed for enhancing biodiversity in modern agricultural landscapes.

Farming measures include *what farmers can do* on or in the direct vicinity of *their arable land*. Such practices include crop diversification and crop rotations, cover crops and green manure, intercropping, agroforestry (combining trees and crops in arable fields), reduced tillage and reduced pesticide use, fertilising with organic amendments, and integrating livestock into farming systems. All these have significant positive consequences for biodiversity.

Crop fields are key habitats for a large number of organisms, many of which contribute to a number of ecosystem services. In particular, soil organisms and insects with life stages in the soil contribute to processes beneficial for farmers, such as earthworm bioturbation and redistribution of organic material, microbial decomposition and nutrient release, biological regulation of pests, pollination, crop health, and regulation of water storage and purification (e.g. Brussaard et al. 2007; Hanson et al. 2016; Smith et al. 2021; for pollinators see Carvalheiro et al. 2021; Christmann 2022). These processes are mainly dependent on the organisms performing them being present right there in the soil *in the crop field*, where farming practices shape the local communities and how they function (e.g. Riggi and Bommarco 2019; Viketoft et al. 2021; Torppa and Taylor 2022; Heinen et al. 2023).

However, we know rather little about how farming practices affect biodiversity and ecosystem services when changed at larger spatial scales. More organic farming in the landscape can increase weed diversity (Rundlöf et al. 2010), and positively affect predatory insects and predation rates (Inclán et al. 2015; Muneret et al. 2018), but sometimes only marginally (Petit et al. 2018). It also increases diversity of pollinators such as butterflies (Rundlöf et al. 2008). Because of the positive effects on biodiversity and ecosystem services of local field management, it is likely that landscape effects of biodiversity-friendly farming practices will emerge if implemented at larger scales than fields and farms. Indeed, recent research demonstrates that increasing crop diversity in the landscape can enhance pollinators and predatory arthropods and the pest suppression they provide (Redlich et al. 2018; Raderschall et al. 2021). Such positive effects on beneficial organisms could be further enhanced if landscape level crop diversity is combined with establishing or restoring seminatural habitats such as hedges, grasslands or non-arable vegetation near the arable land (Aguilera et al. 2020). Research on up-scaled farming practices beyond organic farming and diversified cropping would shed light on the main hypothesis of Tscharntke et al. (2021) that landscape effects of non-crop habitats is the main driver of biodiversity in agricultural landscapes.

While changes in many of the biodiversity-friendly farming measures sound simple, they are in practice difficult to achieve in the short term, because most farmers are locked in their present farming systems and their practices (see section 6.4 below). Rather than simple policy changes, they often need larger incentives and support to move away from an input-intensive production with few annual crops to a more diverse production system, which all alternatives compatible with biodiversity-friendly and sustainable farming are likely to be (Tamburini et al. 2020). Farmers need support with, for example, knowledge, infrastructure, breeding and genetics, suitable technologies and markets for a greater diversity of crops and agricultural products. Also, biodiversity-friendly farming measures are (and can only be) related to actual practices on either arable fields or adjacent semi-natural managed habitats such as grasslands. Such grasslands need to be incorporated in the farm management to be maintained in the landscape (cf. Bengtsson et al. 2019).

Land-use practices, on the other hand, are only partly under the control of farmers. One reason is the fact that farmers are restricted to certain ways of farming because of market forces and policies, and hence land use is difficult to change. Also, practices are often determined by local factors, such as soil type, topography and the presence of other biotopes that cannot be converted to arable fields, such as dry meadows, semi-natural grasslands, riparian elements and forests. Land use is greatly affected by the governing socio-economic milieu – how farming is expected to be made by the farmer, neighbouring farmers and larger society, and how farmers perceive their own role and identity (e.g. Ahnström et al. 2013; Ortman et al. 2023). Larger changes in land use usually require changes in farmers' mind-sets. They are more likely either towards the end of investment periods for buildings and machinery (often around 20 years), when farms are transferred to a new generation, or if societal and other external pressures are large enough to shift the farmers' views on how their farming should be made. Hence, policies need to be aligned with strong incentives (or regulations) and investments in knowledge and infrastructure to produce a transition. We have a role model for such changes in the relative success of organic farming since the 1980s to transform farming systems at the farm level.[8]

Finally, *landscape composition* and configuration are even more difficult to change by individual farmers. Farms are placed in particular landscapes that determine what is possible to do and what can be changed. Landscapes in plains and prairies are fundamentally different from landscapes with hills and river valleys or mountain landscapes, and farming needs different measures and policies to be changed. The ecological consequences of such differences were thoroughly discussed in Tscharntke et al. (2012), but they did not discuss the policy requirements for transformation in different landscapes. And this was not discussed much in Tscharntke et al. (2021) either. Landscapes often determine what types of farming that can be performed under particular socio-economic, environmental and climatic conditions. Despite all the machinery and technology available, to accomplish large transitions into biodiversity-friendly landscapes requires a coordinated effort at the societal level, often invoking changes in culture, ideology, society and relations between humans and nature, and adaptation to local conditions. Such changes in societal and farmer minds-sets will take time, often decades. Tscharntke et al. (2021) had some suggestions for positive changes within present landscapes, i.e. within present farming systems, such as increasing the amount of semi-natural habitats mainly by decreasing arable field size, and supporting traditional but "uneconomic" land uses such as semi-natural grasslands. However, larger landscape transformations require substantial concomitant changes in farming and food systems, which their and many other ecologists' framing of the issue

[8] It can be discussed how successful this transformation was, and if organic farming can manage to break out of the general intensification trap. Note that organics, like other suggested sustainable farming systems, such as regenerative, permaculture, etc. is only concerned with the farmed area, i.e. arable fields and grasslands, and can hardly be anything else. While these systems affect how agricultural landscapes look, they do not have prescriptions that extend outside the agricultural land to how other biotopes are managed.

— (organic) farming measures vs. landscape measures -– does not recognize.[9] Landscape transformation entails a transformation of farming systems and society because it requires breaking out of the straitjacket of intensified agricultural systems. It is time that ecologists working in agricultural landscapes begin to grapple with these issues.

What this useful distinction of measures for biodiversity-friendly landscapes implies is that transformation of agriculture to become biodiversity-friendly needs a set of complementary actions and policies that ensure that farming measures, land-use practices and landscape measures are aligned with each other. They are complementary approaches and hence not useful to contrast against each other. Many of the comments on the Tscharntke et al. (2021) article in Trends in Ecology & Evolution (e.g. Brühl et al. 2022, Marrec et al. 2022, Stein-Bachinger et al. 2022; see also Mupepele et al. 2021) hint at this, but it needs to be more explicitly stated. *If transformation of agricultural systems to biodiversity-friendly landscapes is the goal, there is no conflict between farming on-field measures, land-use practices and landscape measures.* All are needed since they complement and will strengthen in each other during transformations to future sustainable farming systems.

Most of the landscape and farming elements and practices that can be considered for making landscapes more biodiversity friendly are nicely summarized by Tscharntke et al. (2021, their tables 1 and 2): a larger diversity of biotopes in the agricultural landscape, de-intensification of farming through crop diversification and less use of fertilizers, using pesticides, herbicides and antibiotics only as a last resort, increased use of semi-natural and semi-managed habitats such as less productive grasslands and woodlands for livestock (many grazing animals like feeding on young trees), expanded areas of field edges, and so on. So what's the problem? It is that the 2021 paper, in contrast to many earlier of Teja's writings, seems to drive a wedge between landscape composition and biodiversity-friendly farming. It does so by constructing a narrative of opposition, or trade-off, between biodiversity increase from existing (albeit imperfect) organic farming and other on-farm practices vs. a non-existing conventional intensified farming system, in which measures increasing landscape complexity are hypothesised to be possible to add within the present production systems.

In many ways the farming systems that would be most likely to fit with the landscape vision of the "biodiversity-friendly" landscapes are deceptively similar to organic farming in mixed landscapes (Tscharntke et al. 2021). But alas no! The authors distance themselves from organic farming, implicitly arguing for intensified farming[10] and extensification at the landscape level. Their arguments are ambiguous and seem to us a combination of wishful thinking – intensification of farming can actually provide more space for biodiversity – and unsupported suggestions, such as pesticide use being as common in organic farming as in conventional, that crop rotations are similar in conventional and organic farming, that organic yields have to be consistently lower than conventional, and that less intensive farm-

[9] We use organic farming as representative for several alternative farming systems to intensive industrial farming dependent on fertilizers, pesticides, herbicides, and technology machinery, entailing monocultures and large farming units. Organic is – for good and bad – the most articulated system among these alternatives, but not the only one, neither necessarily the desired endpoint.

[10] At least keeping the present level of intensification on the arable areas, which to us is contradictory to the tables 1 and 2 in Tscharntke et al. (2021).

ing systems, in contrast to conventional ones, are immutable and impossible to improve.[11] A friendly interpretation is that the authors really wanted to emphasize their point about landscape being important for biodiversity, which we basically agree with. This point was also made by (Estrada-Carmona et al. 2022), who highlighted that multifunctional agriculture at the farm as well as landscape levels is needed for biodiversity and ecosystem

[11] The critical remarks on the TREE paper from others (Brühl et al. 2022; Marrec et al. 2022; Stein-Bachinger et al. 2022) discuss this in more detail, but the replies to the criticisms from Tscharntke et al. (2022c,a,b) are in our view weak and defensive, written to maintain the priority of their landscape view while de-emphasizing farming and land-use practices. Also, some of the propositions of Tscharntke et al. (2021) rest on a selective reading of the literature, which for some issues is in conflict with their propositions. Some examples are:

1. As Brühl et al. (2022) and Stein-Bachinger et al. (2022) point out, while organic farming uses pesticides, levels are much lower and of qualitatively different types which, apart from copper, are less negative for the environment and human health. Pesticide residues in organic products are much lower than in conventional ones (Mie et al. 2017; Benbrook et al. 2021), but not zero. Their response (Tscharntke et al. 2022b) just dismisses this point by juxtaposing pesticide use and landscape effects, as if a choice has to be made between one or the other (see also point 5 below).
2. Crop rotations of organic farming were stated to be only slightly longer than conventional (15%), but selecting this figure misses the point that crop rotations in organic farming usually is more functionally diverse and includes leys which enhance both soil carbon and soil biodiversity (obvious in Figs 1 and 2 in Barbieri et al. (2017). Also, crop rotations are locally adapted in ways not captured by regional means. For example, in agriculture-dominated landscapes in Sweden typical organic crop sequences are 5-7 years long (Cederberg et al. 2011: `https://www.diva-portal.org/smash/get/diva2:943924/FULLTEXT01.pdf`), but sometimes slightly shorter, on average 4.8 years in Chongtham et al. (2017), compared to common conventional rotations in the same areas which are usually 3 years with functionally more similar crops (cereals and oilcrops but rarely leys or legumes). In addition, organic crop rotations in marginal regions are often short because farming largely consist of leys (feed for animals) interspersed with annual crops, resulting in low crop diversity and rotation length but a less intensively managed and more biodiversity-friendly landscape overall.
3. The higher food production argument for conventional farming is only true if we accept that conventional intensive farming is the baseline, as discussed in the main text. This inconsistent logic should at least have raised a warning sign. Crop diversification can, as actually mentioned in Tscharntke et al. (2021), to a large extent decrease the yield differences (see above).
4. We do not downplay the worry about organic intensification mentioned by Tscharntke et al. (2021). That conventionalization breaks with "organic principles" should obviously be a matter of concern, and has been discussed by researchers (e.g. Darnhofer et al. 2010; Chongtham et al. 2017). We believe it can be explained as part of the lock-in problem discussed later in this chapter (section 4). The present food system, in which organic food production is embedded, is rigged for intensification no matter the farming methods.
5. As a side issue on pesticides, there is probably a pervasive influence of landscape-wide use of pesticides, as suggested by the results in Geiger et al. (2010). After this study was published, Janne and Barbara Ekbom were invited to the Swedish Chemical Inspection (Kemikalieinspektionen), because it was one of the first studies that had examined landscape-wide negative effects of pesticide use. They told us that 'no studies underlying the registration and permission for pesticides were done at larger scales such as landscapes, and most were short time plot studies'. Janne was surprised while Barbara stoically agreed. However, the Geiger et al. (2010) study was not designed to answer exactly that question, although it suggests landscape-wide effects of pesticides across the nine European landscapes studied. This point is reinforced by Brühl et al. (2022) and Stein-Bachinger et al. (2022). The landscape-wide effects of pesticides on biodiversity and ecosystem services deserve more research, as does the landscape-wide effects of organic or regenerative farming.

services. However, relationships between agricultural practices and landscape measures on biodiversity are likely to be complex,[12] and need a more in-depth analysis than the simple species richness comparisons in the 2021 article.

6.2.1 Some productivist agriculture myths — food scarcity, land sparing, and non-sustainable baselines

Global food scarcity is often invoked as an argument for further agricultural intensification, contrasting yield deficits in especially organic farming compared to present intensive farming. However, the argument is not used when discussing other issues, such as grain or soybean being used as feed for pigs and poultry, when it could be used for humans directly. It assumes that present yields from intensive farming are sustainable, despite the fact that enough food is produced globally, but the distribution is unequal (Holt-Giménez and Altieri 2013)[13]. Almost a billion people are too poor to obtain food at the same time as up to 50% of the arable land area is producing feed for animals in the developed world (Öborn et al. 2011; Poore and Nemecek 2018; Harwatt et al. 2023); up to 70% of soy bean production is fed to pigs and poultry (*ibid.*). Hence food scarcity and yield arguments for intensification fail, at least in the short run and given that we can control climate change, which of course is uncertain but another story.[14] In this intensification narrative it is common to reject any alternative farming system as not being able to meet a purported "need" for more food production.

Another myth that has engaged landscape ecologists and agricultural researchers for too long is that intensifying agriculture will make it possible to spare more land for biodiversity, often framed as a land sparing–land sharing dichotomy (Green et al. 2005; Fischer et al. 2014; Kremen 2015). However, the land sparing–sharing debate should be laid to rest for several reasons: The conflict is largely constructed and usually poorly conceptualized because these choices are not mutually exclusive and outcomes depend on context, scale and on the subject of interest – biodiversity, ecosystem services, other environmental and social consequences (Fischer et al. 2014; Kremen 2015; Grass et al. 2019; Billen et al. 2021; Sidemo-Holm et al. 2021). In addition, different actors in the debate have communicated mainly within their "closed clusters", i.e. on one hand a land sparing group, better funded and with a philosophy dominated by biodiversity conservation, associated industry and practices of intensive agriculture, and on the other hand a land sharing group emphasising

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[12] The AGRIPOPES project did analyse the effects of landscape complexity and farming intensity on biodiversity as species richness at local and landscape levels (e.g. Flohre et al. 2011). The results were indeed complex and varied between the three organism groups, i.e. birds, carabids and plants. On the other hand, and not consistent with Tscharntke et al. (2021), Carmona et al. (2020) found that functional diversity of plants was more affected by intensification at the field scale than at the landscape scale. There is scope for more research on these issues. Marja et al. (2022) to some extent refuted the basic hypothesis in the 2021 article, but also highlights that different taxa respond in different ways to landscape and management.

[13] Holt-Gimenez reports that around 50% more food was produced than needed to feed everyone by 2008 (quoting FAO figures). This is still reported by the UN (`https://news.un.org/en/story/2019/10/1048452`) and consistent with the per capita figures in Our world in data (`https://ourworldindata.org/food-supply`). However, it may not be the case in a warmer world with approx. 10 billion people by 2050.

[14] See the current IPCC report, and the fact that CO_2-emissions still are increasing (Liu et al. 2023).

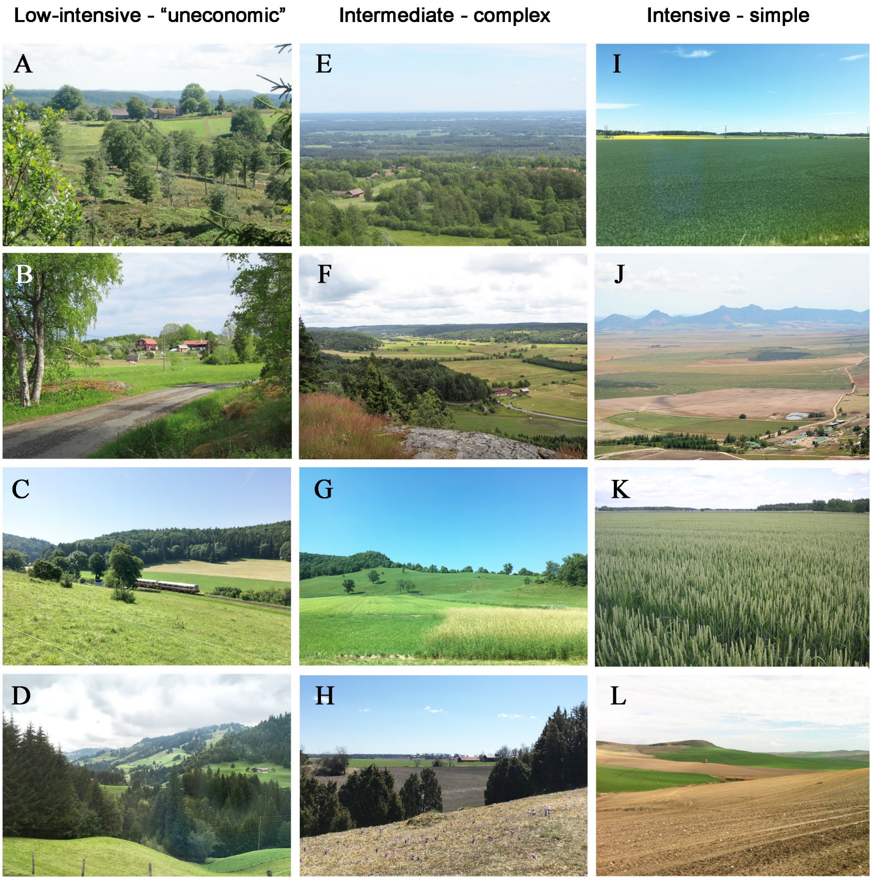

Fig. 6.1: Examples of landscapes managed with different intensities and different landscape composition, from older, low-intensive and “uneconomic” management (left column, A-D), modern landscapes in areas with more complex underlying natural conditions (mid column, E-H) to intensively managed industrial agriculture landscapes (right column, I-L).
Left column: A, recreated old landscape in SW Sweden. B, mosaic coastal landscape in E Sweden. C, grasslands in SW Germany. D, mountain landscape in central Switzerland.
Mid column: E, mosaic landscape with managed forest and intensively managed arable areas in Västergötland, Sweden. F. mosaic rift valley landscape with agriculture along rivers, and forest on the hills where arable cropping is impossible, SW Sweden. G, mosaic landscape with forest and medium intensive agriculture, Driftless area, Wisconsin, US. H, mosaic landscape with semi-natural grasslands on sandy soils and intensive agriculture on adjacent clay soils close to Uppsala, Sweden.
Right column: I, intensive conventionally managed landscape on fertile clay soils, SE of Uppsala, Sweden. J, wheat production landscape with small remnants of threatened renosterveld vegetation, north of Capetown, South Africa. K, wheat fields somewhere in Uppland, Sweden. L, cereal production landscape with no natural biotopes left, near Cordoba, Spain. [Photos by Jan Bengtsson, except J (Suzaan Kritzinger-Klopper) and K (Johan Bengtsson-Palme/Camilla Winqvist)].

ecosystem management, ecosystem services and functions, and sustainable agriculture (Loconto et al. 2020). Furthermore, and importantly, intensification sold as efficiency suffers from the problem of the rebound effect or "Jevons paradox". By increasing land-use "efficiency", the actual outcome of land sparing intensification will likely be that *more land is intensified* to produce even cheaper food, and hence even less land will be available to set aside for biodiversity (see also next paragraph). This was pointed out already by Perfecto and Vandermeer (2008), and the general concept of decoupling has been efficiently debunked by e.g. Parrique et al. (2019) and Vadén et al. (2020). Without strong regulation (Wackernagel and Rees 1997) the intensification in land sparing scenarios will just lead to more sections of the landscape becoming intensified.[15] Clearly, other solutions are needed for modern industrial agricultural landscapes to be transformed to sustainability and biodiversity-friendliness. We need to move away from deceptively straight-forward and elegant, but empirically unfounded, trade-offs which has proliferated especially around the selected contrast between conventional and organic agriculture, but not between other forms of agriculture for which such trade-offs may be equally strong if not stronger.

A final comment on land sparing and intensification is appropriate. It relates to the food production question, and whether alternative systems such as organic or regenerative or even low-pesticide/herbicide farming systems can produce the amount of food "needed" in the future. It assumes that intensified systems – monocultures that are fertilized, sprayed, mechanized and supposedly efficient – are the benchmark that all other farming systems should be compared with.[16] But this requires, firstly, that we do not count the disservices or externalities of the intensified systems, such as eutrophication by dumping nitrogen and phosphorus into inland waters and the sea, contributing to global warming by releasing greenhouse gases into the atmosphere,[17] and exposure to pesticides and herbicides to human and non-human life.[18] And secondly, that we believe that continued intensification is a possibility in an increasingly resource scarce world (Moore 2008; Cordell et al. 2009; Herrington 2021).

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[15] Land sparing proponents may argue that such regulations are possible, but it's hard to see how this can occur in the current situation of policies and land use lock-in, so this remains pure speculation, but maybe possible under a transformed food and land use system. Note that decoupling arguments are assuming that Jevons paradox won't happen, which is why these arguments are valid for both issues.

[16] To this can be added the proposition by (Benton and Bailey 2019) that the current food system is inefficient because of the drive for efficiency at the farm level (interpreted as yields), meaning that changes in diets could free up very significant natural resources and reduce agriculture's impact on both environment and human health. So efficiency arguments are dubious when discussing yields vs. biodiversity, because efficiency is a contested issue and depends on which system level you are analysing (see also van der Werf et al. 2020, as regards LCA and biodiversity).

[17] Agriculture, not only but mainly modern farming systems and land use changes, contributes to approximately 30-40% of total GHG emissions, of which more than half is linked to animal production (Xu et al. 2021; Lynch et al. 2021). Past land-use change from forests to agricultural land has also contributed to the present high CO_2-levels.

[18] It is sometimes argued that pesticide risks for humans are negligible, but this is not the case for those who work with or are repeatedly in contact with pesticides or herbicides, as the recent debates about glyphosate shows. See also Mie et al. (2017).

6.3 Biodiversity is multifaceted and multidimensional

Landscape ecology and especially policy addressing biodiversity continues to be largely based on diversity measured as species richness of different taxa. However, while richness appears relatively simple to measure and give a value – much of the lay and public discussion on biodiversity is based on this notion – it is also deceptive. It suggests that biodiversity is one measurable thing, when it is actually extremely complex, composed of thousands of species and other taxa with different requirements on the environment, with interactions dependent on local and landscape features, and having different effects on each other and the environment. There are many facets to this questions. We focus on two, firstly on which biodiversity we might be interested to preserve and secondly how to account for organisms and taxa having different requirements.

The reasons to be concerned about biodiversity can be many, and varies among individuals and actors in society. A primary reason can be that biodiversity and the species and populations that make it up has intrinsic existential value, even if we cannot find any human values for it. This is a valid argument, although it still forces us to discuss what it means in practice when we work in production landscapes dominated by agriculture or forestry.

A related argument for safeguarding biodiversity is the value we ascribe to biodiversity as rare, threatened or red-listed species, not for their intrinsic value but for some possible human benefits of this part of biodiversity in an uncertain future. For example, they contribute to option, insurance or resilience value, or many species, including rare ones, may be needed for ecosystems to function well in a future that we cannot know and therefore not tell exactly which species will be needed. These species have also been argued to be evidence that our landscapes are managed sustainably and well.[19] This view of biodiversity values of rare species is quite common among ecologists and biologists, who often also ascribe to a pure existential value of biodiversity.

Another reason, more oriented towards direct human benefits, for conservation of biodiversity is related to the part of biodiversity that contributes ecosystem services (NCPs) of benefit to farmers and society, for example, food production and the regulation and maintenance of underlying ecosystem services. Among those are biological control and pollination, where the research of Teja and his colleagues has been pioneering. Some of these ecosystem services are dependent on species that are common in other landscape elements than arable land, that are not or less intensively managed. However, other ecosystem services beneficial for farmers, landowners and society are not primarily sustained by species in non-farmed habitats. In particular, many soil processes are dependent on the organisms performing them being present and sustained right there in the soil, on the field. These processes and organisms play an important role in sustainable farming methods (e.g. Brussaard et al. 2007).

Still another argument for the usefulness of biodiversity is related to the *planned diversity* that farmers, forestry or urban planners can be interested in, often in terms of yield, biomass production or environmental benefits when plant diversity is increased. Examples include longer and more complex crop rotations, mixtures, agroforestry, intercropping,

[19] By e.g. Carl Folke in discussions at scientific meetings, and it is a compelling argument.

the use of catch and cover crops, integration of leys and grassland in the farming system, or diversification of crop species at the farm level. Here potentially common species can be used by farmers for higher yields or other benefits by smart farming or forestry practices (see above; also e.g. Gamfeldt et al. 2013; Jonsson et al. 2019, as regards forestry).

Finally, as highlighted during the Covid-19 pandemic (2020-2022), many humans use nature and hence parts of biodiversity for recreation and health reasons, in far-away national parks and nature reserves as well as urban, near-urban and countryside nature areas. These reasons for biodiversity conservation have – just like ecosystem services –been undervalued in economic valuation (TEEB 2010; UK National Ecosystem Assessment 2011; IPBES 2019, 2022), as well as planning.

All these arguments are valid and matter. Many of the arguments for biodiversity conservation pertain to both red-listed and common species, including organisms of importance for ecosystem functioning and ecosystem services. The different aspects of biodiversity are poorly captured by single measures of species richness of an unspecified part of its components. This problem has several aspects: Should we still emphasize species richness, but acknowledge the different components of richness? Or should we rather question species richness as a useful indicator of biodiversity as well as ecosystem services?

Which of all organism groups and their species richness should be our concern? Any choice between, e.g., birds, vascular plants, bees, earthworms, springtails, amphibians, insects, etc., is fraught with difficulties, implicit value statements and trade-offs between the richness of various taxa. Even simplistic indicators such as “total richness” or “phylogenetic variation” are value statements that favour some organism groups above others, without specification. Furthermore, since organisms respond differently to environmental conditions or human activities, relationships between species richness of different taxa or other biodiversity indicators are unlikely to be strong, and also vary spatially and temporally. Wolters et al. (2006) found an average correlation (r-value) of 0.374 among richness correlations gathered from the literature, with a large variation spanning from strongly negative to strongly positive, the latter being more common than the former. This pattern has been corroborated by e.g. Pearman and Weber (2007) and Ekroos et al. (2013).[20] These results suggest that it is unlikely that conservation efforts based on certain taxa, like butterflies, birds, plants or bees, will result in ubiquitous increases in species richness of many other taxa. There will be trade-offs between focusing on certain groups vs. other groups.

In addition, the diversity of rare or red-listed species is – by necessity in many cases – not related to the delivery of most ecosystem services, which are often driven by either biomass (abundance) or strong interactions between common species. For rare species to have measurable effects on ecosystem functioning, they need to be either top predators or ecosystem engineers, be able to become more common under certain ecological conditions, or affect functioning under or following disturbances to the ecosystem. Species can also be rare in fundamentally different ways — having one or combinations of the characteristics

[20] Janne once suspected that the trend towards positive correlations could be an effect of choosing taxa that were already expected to be correlated, such as plants and insects. Therefore, a student of his instead calculated richness correlations from the residuals from species-area relations, log-log transformed, assuming that these taxa had not been chosen according to this expectation. Surprisingly, this independent data set had a mean r-value of 0.373! (Ström 2006) Available from `https://stud.epsilon.slu.se/12425` or if this doesn’t work, by sending a mail to the first author.

small local population size, small geographic range or restricted habitat niche (Rabinowitz 2014). Apart from key top predators or ecosystem engineers, it has been difficult to find evidence that rare species are important for ecosystem functioning[21] (see e.g. Ridder 2008; but also Dee et al. 2019 for an interesting discussion). Placing too much emphasis and policies on conservation of threatened species risks ending up in the bizarre situation that we spend most of our time and resources on rare species of, say, pin lichens or soil mites of negligible value for humans while losing ecosystem service providing species when industrial agriculture and forestry wreak havoc in the production ecosystems around the globe. We should be able to do both, but for different reasons and with a diversity of actions and policies. Unfortunately, species richness measures often include many rare species and are less likely to relate to the delivery of ecosystem services.[22]

In accordance with the above, Birkhofer et al. (2018) found low correlations in species richness of a number of organism groups in south Swedish landscapes – birds, plants, spiders, beetles and hoverflies. They also examined how richness correlated with ecosystem service potentials. Biological pest control, pollination, conservation and yield were correlated with each other, but usually not with the diversity of the organism groups assumed to be responsible for these services. Although for one region only, these results indicate that relations between biodiversity and ecosystem services are complex, probably driven by abundances of species or groups, habitat structures and farming practices that vary over small as well as large scales.

Hence, simple measures of richness are usually not adequate indicators of this elusive thing we call biodiversity, biodiversity-friendliness, or ecosystem services. The research agenda on relations between biodiversity and ecosystem functioning (and services) has been questioned along these lines (e.g. deLaplante and Picasso 2011; Frank 2022).[23] In fact, species richness does not do anything, it is just a usually poor indicator of something that we in fact do not know much about. If it is species that do the job in ecosystems – what we call ecosystem functioning – we need to abandon species richness as a useful concept and instead think about the species and their interactions, i.e. composition of ecological communities and ecosystems (Bengtsson 1998; Gagic et al. 2015).

We should instead focus on how species respond to environmental conditions, interactions between species and how these are affected by human activities, and the effects

[21] It is possible that when rare species have unique niches, or support functions that may become important under new environmental conditions, they are important for ecosystem functioning -– but evidence for large effects on ecosystem functioning is lacking, maybe because the time scales involved for this to show are longer than most ecological studies.

[22] However, this does not negate the validity of existential arguments for biodiversity, nor the possibility that rare species may be useful for functional ecosystems under novel environmental conditions in the future, i.e. option, insurance or resilience value (see above). Nevertheless, these arguments are based on a possible future value and hence not possible to measure until it's too late, a dilemma for all decision-making.

[23] On a course on the history of ecological ideas, one of the bright students asked Janne "… you have been active in Biodiversity and Ecosystem Services research for 20 years. What's your opinion? Was it a waste of time?". Janne had to ask for a night's grace. He came back the next morning thinking that "it was not a complete waste of time, but we forgot the key question asked by John Lawton 'What do species do in ecosystems?' 1994 and framed the problem as a diversity/species richness question. Which was the wrong framing to study the importance of organisms for ecosystem functioning. So it took us in the wrong direction for a decade or so."

of such interactions on the systems that the species are part of. This is what community ecology has been doing for several decades by studying traits (including functional traits; e.g. Loreau et al. 2001; Lavorel and Garnier 2002; Suding et al. 2008). It is by understanding the complexity of ecological communities that we can understand what species do in ecosystems (Lawton 1994), and which species are important for what we would like ecosystems to do — be it benefits to humans, society or just sustain nature in a state less impacted by humans. A potential and unsolved problem is that communities and ecosystems may be examples "middle number systems" that are too complex to find simple and general patterns in (Lawton 2000). Ecological generalities may be few and often valid only for restricted systems in space and time. Consequently questions and answers need to be anchored in local conditions and are subject to temporal (historical) contingencies.

A consequence of all this is that the question whether we should focus on biodiversity in the farmed areas, or on biodiversity in the non-farmed or less intensively managed landscape elements, is probably the wrong question. This on the surface simple question does not have a simple answer – if any answer at all.[24] Answers will depend on which organism groups or taxa that are studied, how the species are interacting in the local context, and the intensity of land use in different habitat types. In addition, the broad term "landscape" harbours large complexity in itself. A "forest" landscape element can be anything from an insect-rich old-growth southern deciduous forest with a soft edge towards arable land, to a planted monoculture of spruce or fast growing Eucalyptus trees, in which insects usually are few and when abundant mainly a few pest species.[25] In the former case, landscape elements not part of the farming system may contribute overwhelmingly to community composition and biodiversity at the landscape level and potentially influence farmed areas, while in the latter case such elements will be of no or very little consequence compared to a lower intensification and diversification of the farming systems, i.e. how we "choose" to farm the available land to produce food and other things that we "need".[26]

For these reasons, to focus biodiversity policies and research primarily on species richness is narrow-minded, to be blunt, and especially Janne has been guilty of this.[27] Biodiversity policies are supposed to conserve, support and sustain both biodiversity as such and

[24] Paul Keddy, in his book Competition (Keddy 1989), suggested that some, perhaps many, ecological questions are framed in the wrong way. Referring to Buddhism he suggested that answers could be neither "yes" nor "no", but "mu", implying that the questions are put in the wrong way, cannot have a clear answer and need to be re-framed.

[25] On one hand, most ecologists already know this, but it is still not enough put into practice. Most analyses of landscape retort to simple measures of landscape complexity or heterogeneity that suffer from similar problems as species richness measures. The measures don't catch the complexity of landscapes, their various elements and social-ecological relations very well. Some examples are the landscape measures used in Persson et al. (2010), Birkhofer et al. (2018), and Marja et al. (2022).

[26] These choices and needs do not, of course, have a common "we" – our choices and needs are dependent on the society that we are part of (see below) and who has the power to impose choices and needs on an "us" that is diverse, unequal and often powerless until a social movement hints otherwise or turns the world upside down.

[27] Janne refrains from adding any references to support this claim of guilt; anyone interested can go through most agricultural ecologists' publications and find ample evidence for such intellectual sloppiness.

ecosystem services, the use of biodiversity for human benefits (e.g. IPBES 2019, 2022).[28] As summarised by Emmerson et al. (2016), "focusing only on species richness might not provide sufficient detail regarding the effects of land-use intensification on biodiversity in and around agricultural land. In contrast, in-depth analyses within groups of species with different traits and conservation value would significantly advance our understanding of agriculture related drivers of biodiversity change".

Hence the question raised in Tscharntke et al. (2021) whether farming system or landscape contributes most to biodiversity is important, but only if we broaden our views. The answers will depend on context, on which organisms the researchers value or are interested in (which is an implicit value judgement that we as scientists sometimes don't want to discuss, but should give more consideration), and on whether we can leave the diversity as richness issue behind and start asking questions about the composition of and interactions in the communities and ecosystems that we are concerned with and worried about. In that process much of the work of Teja provides a foundation from which research can find new directions.

However, if the goal is to change production systems such as agriculture, farming and food production, it is not enough to understand ecology. If we want to transform systems we must understand the complex social-ecological food systems and what maintains them in the present unsustainable state. Which takes us outside the purity of ecology and biodiversity and into the world of interdisciplinarity, a place where they do things differently from what most ecologists are used to.

6.4 The nature of modern agricultural systems

Our social science colleagues working on understanding agricultural systems and landscapes have criticised, in our view rightly so, ecologists as often being overly meticulous when measuring landscapes and diversity, but largely ignorant of what farmers do and can do, and of the implicit assumptions we make about how production systems are shaped. Examples are our views on if and how policies can change behaviour of actors in the food systems, the impact of purely ecological and often top-down advice to policy-makers and practitioners, and our assumptions about trade-offs between, for example, food production and biodiversity, or land sparing and land sharing (see above). A basic question that many landscape ecologists, including us, has not addressed very clearly is what it is that drives agricultural systems and food production towards intensification, in particular in the Western world but also globally.

6.4.1 Locked in intensification

A large amount of research on intensification of agricultural and food systems has been performed, largely outside the narrow scope of biodiversity, ecosystem services, and landscape ecology, but anchored in perspectives from sociology or agroecology (Vanloqueren and Baret 2009; Clapp 2015; Kuokkanen et al. 2017; Anderson et al. 2020; Mortensen and Smith

[28] This has been important for policy ever since the 1992 Rio Convention (CBD) – to *conserve* and *sustainably use* biodiversity.

2020).[29] It is well established that major parts of agricultural policy (including the policy to leave it to the market), farming methods and composition of agricultural landscapes are driven by agrobusinesses and multinational companies, with lobbying connections extending deep into, e.g., EU decision making institutions.[30] This has led to a rigidity or lock-in of modern agricultural and food systems, built on a productivist view of agriculture that perhaps was an appropriate policy in the 1950s after World War II, but is increasingly questioned (e.g. Vanloqueren and Baret 2009; Kuokkanen et al. 2017; Mortensen and Smith 2020; Goldstein et al. 2023). The productivist narrative is emphasizing the necessity of continuing intensification and industrialisation of agriculture, based on increased use of large-scale technology and inputs, such as energy, fertilizers, pesticides and herbicides, to meet a projected increased global demand for more food, usually more meat and processed food, and industrial profitability. It has been contrasted to a sufficiency narrative which argues that such an intensification will undermine the ecosystems that support food production and also generate unacceptable environmental externalities, including exacerbated climate warming (Freibauer et al. 2011; Allaire and Daviron 2020). The sufficiency narrative emphasises a need for large structural changes in farming and food systems, including changes in demand towards more plant foods and less meat consumption in the richer world, a general progress towards less impact on ecosystems, less consumption, and a lower human footprint, especially from the western lifestyle. It could be characterized as a controlled sustainable de-growth of agriculture (Gomiero 2018; Otero et al. 2020; Moranta et al. 2022), but its connection to de-growth remains to be further explored.

The lock-in perspective describes how today's agriculture is following an entrenched path characterized by fossil energy dependent infrastructure, pesticide-herbicide-fertilizer farming and a cognitive technology-dependent trap that — from a social-ecological perspective — impedes transformation to other, more socially, environmentally and ecologically sustainable system configurations (e.g. Mortensen and Smith 2020). While there is a kind of transformation present also in the productivist narrative, the transformations discussed are rooted in a modernity framework that is culturally, technologically and economically determined by the powerful businesses and actors in the present system; actors profiting from certain technological transformations that sustain profits but not much else, and do not threaten the status quo (Patel and Moore 2020; Béné 2022).[31] The power over this

[29] However, these perspectives have only to a limited extent, if at all, included the knowledge of landscape ecologists in their analyses, which shows how relevant disciplines for agricultural sustainability often have had too little contact with each other.

[30] This can be clearly seen in the discussions on the EU Farm-to-fork and Biodiversity strategies and how they relate to agricultural landscapes, where each take produced increasingly watered down versions of the initially quite radical propositions on agroecology and regenerative agriculture (e.g. Elmqvist et al. 2022); for critical discussion see, e.g. Corporate Europe Observatory (2022-03-17) `https://corporateeurope.org/en/2022/03/agribusiness-lobby-against-eu-farm-fork-strategy-amplified-ukraine-war`, Rudquist G. Bglc eye (2021-09-15) `https://www.su.se/stockholm-university-baltic-sea-centre/web-magazine-baltic-eye/eutrophication/the-eu-farm-to-fork-strategy-what-is-happening-1.606756`, and Askew K. Food Navigator (2023-03-13) `https://www.foodnavigator.com/Article/2023/02/13/Is-Europe-s-Farm-to-Fork-strategy-in-trouble-Political-resistance-is-threatening-to-derail-the-process` (All accessed in May 2023).

[31] This of course implies that the term economic sustainability needs to be relegated from the pillars of sustainability to one of many tools in our toolbox, as our friend Thomas Hahn has often emphasised in

system is unevenly distributed, with the actions of individual farmers being coerced by powerful agents further up in the food chains. This narrows their choices and how they can transform farming on their piece of land.

Within the productivist narrative the obvious need for some kind of transition to a believed (or hoped for) sustainable food system or society is discussed in different ways. Within the constraints of the present corporate-driven system, we can find those believing that capitalism can be harnessed to do the job to solve the problems it created, such as ecological modernisation (Mol et al. 2014; but see Foster et al. 2010) and ideas similar to Robert Reich's 'saving capitalism' from itself (2015). Others discuss more drastic and radical changes in farming systems and policies. These range from, for example, agroecology as an adaptive approach in pursuit of a more just and sustainable food system (Anderson and Rivera-Ferre 2021), organic agriculture in all its colours from intensified grey to outstanding green (Reganold and Wachter 2016; Seufert and Ramankutty 2017), regenerative agriculture – whatever meaning it has (Giller et al. 2021; Elmqvist et al. 2022) – all the way to more utopian ideas of leaving the imperative of continued growth behind through de-growth, producing food systems that are vaguely formulated (Svenfelt et al. 2019), or leaving the capitalist system for … yes, for what? The track record of past socialist or communist agriculture warn us that these did not leave the productivist paradigm at all, exacerbating the human-nature conflict rather than finding a solution.

The consequence of this large-scale lock-in is that in order to change current agricultural systems towards more sustainable ones, a broader perspective than a purely biodiversity-friendly landscape one is needed. This entails a more in-depth understanding of the drivers of biodiversity loss and possible ameliorative policies in production landscapes in general – agricultural as well as forestry landscapes. It has been highlighted in the IPBES reports (2019; 2022) as well as by IPCC (2014) that biodiversity loss and climate change have similar underlying drivers, namely the last 50-100 years of increased resource use, a growth and consumption oriented global economy, and intensification of land use. This means that the drivers are to a large extent social, and that solutions are complex and need to be based on analyses and understanding of social-ecological systems.

The concept of lock-in or path dependence implies that the present drivers of biodiversity loss are more or less stuck in the present situation. The powerful actors are likely to have no intention or incentive to change except along the present trajectory, i.e. continuing along an intensification and technological innovation path. It also means that they are unlikely to show much interest in contrasting perspectives on agriculture, neither listening to them nor taking them into consideration when they plan ahead, make or give advice on investments. They are likely to grab any argument for staying on this path, no matter whether these are based on reality and facts or not.

lectures and conversations. The economic drivers of the globalized food and agriculture systems have the goal to make profits, they do not wish us well, and they are unlikely sustainable socially and environmentally (e.g. Patel and Moore 2020).

6.5 Some possible futures for agricultural biodiversity

Much of the preceding discussion is oriented towards future agricultural systems and landscapes, and how well they might conserve and utilize biodiversity, and ecosystem services related to parts of that biodiversity. Many ecologists, including Teja, seem to assume that there can be a good future for biodiversity, and implicitly that policymakers and agrobusinesses will listen to the advice from landscape and agro-ecologists. We agree that this is desirable, although we have problematized some of the recommendations that seem to emerge from Teja's and others' work. Here we want to end by pointing out that future agricultural production systems can, for better or worse, handle and utilize biodiversity and ecosystem services in very different ways, depending on how society and production is organised and the responses to the climate and biodiversity crises at regional, national or European (continental) levels. The question then becomes which of these systems – if any – best combine biodiversity goals with social and environmental sustainability goals.

The Swedish research program Mistra Food Futures is developing a set of goal-seeking scenarios for Swedish food production that can meet multiple goals by 2045 (Gordon et al. 2022). The goals are related to climate (net zero emissions by 2045, i.e. meeting the Paris agreement of no more than 1.5°C warming), biodiversity (basically, no further reductions in birds and pollinators, and reduced pesticide use) and health (diet according to EAT-Lancet).[32]

Scenarios are meant to open up a discussion about possible futures. However, since scenarios are also about taking power over the future, they also close or hide futures by implicit or explicit selection of which factors and alternative scenarios are included in the discussion. They are not predictions, but possible trajectories into the future, and hence anchored in today's discourses rather than in all possible futures. Scenarios can be based on today's societal structures to protect the status quo and prevent transformations, or emphasize alternatives to today's society and policies. The latter type of transformative scenarios have been characterized as acts of "imagination, love and resistance" and of care toward future generations (Andersson 2018). Therefore, scenarios may say more about today's views of the world than what future generations may think, but still scenarios like these are structured considerations of the future that hopefully include important aspects such as climate change, food systems, limits to resource use as well as the future for biodiversity, a combination that is hitherto quite rare in the present menagerie of scenarios.[33]

[32] The targets for the goals were pragmatically set to be able to follow indicators for them. For biodiversity in Sweden, birds are monitored by a national program since 1975, pollinators were supposed to get a national monitoring program but this was recently (early 2023) halted by the new right-wing government drastically reducing funding for environmental monitoring. Pesticide use is also monitored nationally. The targets can be questioned but reflect global targets, the state of the art of monitoring and to some degree ecological importance in agriculture. See Gordon et al. (2022).

[33] This paragraph is partly based on a book chapter in Swedish (Bengtsson 2021), available from the first author on request.

Fig. 6.2: Summary of four scenarios for Swedish agriculture 2045, with major factors related to biodiversity goals indicated. For details, see text and Gordon et al. (2022).

Four scenarios were developed (Fig. 6.2). They represent different ways in which a national food system might simultaneously aim to meet the three goals of climate, biodiversity and healthy diets. They can be briefly summarized as:

1. *Food as industry*, in which Swedish agricultural products are marketed globally as "outstandingly sustainably produced", with support from the government and private sector. This implies a special kind of intensified agriculture and larger food industries in Sweden, improvements in productivity and technology, but at the same time less Swedish meat consumption. Thus it requires that Swedish meat and dairy replaces less environmentally friendly production, mainly in other EU member states, which makes it possible to reach climate goals through substitution effects. The health goal is met by lower meat consumption nationally and more plant food. Biodiversity goals are reached by increasing meat and dairy production from semi-natural grasslands, but the intensification of farming systems makes it problematic to enhance diversity and ecosystem services in arable land, reminiscent of a policy that probably will focus on landscape complexity. Whether this qualifies as sustainable production is unclear, and may rely on marketing rather than real biodiversity and ecosystem service friendly farming. This scenario is largely a continuation of present trends in Swedish agriculture, and hence represents a business-as-usual scenario embraced by many (but not all) mainstream food system stakeholders.
2. In *Food as technology*, diet change by technology innovation has transformed food systems. Power belongs to the transnational corporations that produce, process and sell novel foods. New technologies such as artificial meat, microbial proteins, and food printing allow personalized diets, and plant-based products replace "old foods". While

Swedish food processing increases, agricultural production declines, which opens up for reduced agricultural land area, less meat production mainly from semi-natural grasslands, and rewilding at the same time as plant production for the novel foods intensifies. Whether this will lead to land sparing or land sharing landscapes is unclear. National governments have less power over land use, and the idea of rewilding might be usurped as an excuse for more intensive forestry, since climate goals are fulfilled by a combination of less livestock, low-carbon transportation, carbon farming, rewilding and forest growth. Health goals are met with new diets and artificial products, which have to submit to some regulation at the EU level since national governments are weak. The major contribution to biodiversity goals comes from rewilding, grass-fed meat, and regenerative farming on parts of the arable land, all of which contain plenty contradictions that might be resolved by policies and regulations. However, governments and the public have little power in this scenario.

3. *Food as culture* assumes that Swedish and international food systems drastically transform by social movement responses to climate disasters and the biodiversity crisis. These changes are brought about by an emphasis on global and national equity, self-sufficiency and environmental justice, and placing food, farming and nature at the centre of local and regional culture and identity. The transition involves new rural-urban and human-nature interactions, movement to smaller cities around which peri-urban and rural living is supported by social policies. Food and food production is diversifying locally and regionally, less intensive agroecological farming systems are supported by the public and agricultural policies. With the help of technologies such as digitalization, rural jobs and multifunctional landscapes have been created. Climate goals are reached in agricultural landscapes through regenerative farming, agroforestry, less consumption of meat and dairy, which is mainly produced on permanent and semi-natural grasslands that sequester carbon. This diversification of farming, and a general decrease in intensification across whole landscapes, including more permanent biotopes, fulfils ambitious biodiversity goals. In this rather rosy scenario technologies that support better work conditions and environmentally friendly farming are prioritized, but it can also contain elements of de-growth (Svenfelt et al. 2019). It requires that governments and especially public social movements become stronger than today.
4. In the *Food forgotten* scenario, EU-driven climate policies drive European food systems. Food and how it is produced is constrained by the necessity for large-scale climate mitigation. Farming and food industry in Sweden are of little political and social importance. Climate taxes change diets towards less meat and dairy and more plant-based food, and land use focuses on climate mitigation and carbon sequestration. Some agricultural land is converted to bioenergy production. Afforestation and wetland restoration further decreases the area of arable land. Farming likely becomes a kind of intensive regenerative agriculture with large areas of permanent crops, depending on regional and local landscapes. Biodiversity goals are not prioritized but still met, mainly through restoration of wetlands, grasslands and forests. The latter two may have low or medium biodiversity value, but C-sequestration of forests implies longer rotation periods which enhances biodiversity and several ecosystem services (Jonsson et al. 2019), introducing a partial rewilding that increases diversity of forest species which may or may not be regarded to compensate for losses of biodiversity on arable land.

While none of these scenarios may be realized,[34] they show that it is fairly easy to imagine several drastically different agricultural landscapes for biodiversity by 2050, driven by different combinations of governmental policies and regulations, technological change, industry and market forces, and social movements. The biodiversity targets are met in different ways in different scenarios, for example larger areas of grazed grasslands (scenario 1 and 3, and perhaps 4), less intensive farming and new farming systems (3), restoration and rewilding (2, 4; partly dumping biodiversity responsibility on the forest sector). The ensuing uncertainty and local specificity of future landscapes caution against thinking about future biodiversity-friendly landscapes without taking society and its development and relation to ecosystems and nature into account. Although the scenarios suggest that the future is open, the realized future may not be decided by those who understand or care about biodiversity at all. It is up to ecologists and environmentalists to make an active choice to influence how future landscapes will develop as social-ecological systems. At the very least, scenarios like these force us to discuss what kinds of futures that our often unspecified "we" want, and perhaps more importantly which futures that can be considered as clearly undesirable.[35]

6.6 Final comments

We hope to have shown that the questions on farming systems and agricultural landscapes asked by Teja in his research have been important to ask. They have driven a lot of excellent agroecological and landscape research, even though many of the questions remain to be answered. We have highlighted some complexities of farming systems and agricultural landscapes that we believe should be included in future studies of how to transition to biodiversity-friendly production landscapes, and emphasized the importance of expanding our view on landscapes as parts of social-ecological systems.

Important remaining questions concern, for example, the importance of farming practices for biodiversity-based food production, how different local farming practices can be scaled up to agricultural landscapes, and what the landscape-wide ecological effects of such expansion might be. We also need a better understanding of how the qualities of seminatural habitats, grasslands and crop fields affect biodiversity, and how farming practices and landscape management complement each other. Biodiversity studies need to focus more on the species that make up biodiversity, their traits and interactions in food webs, and thus the role of species and community composition for ecosystem functioning, rather than on simplistic measures of taxonomic richness.

[34] The scenarios can be questioned as they make a number of simplifying assumptions, of which some are important to state: All of them assume continued economic growth, although this is less prominent in Food as culture; they also assume that no rebellion or migration from the global south in response to increased global warming will take place. More scenario-specific assumptions are that: Policies are possible and do the right thing(s); Social movements can make a difference; Novel technologies will fix the climate and sustainability; Technology food will be socially accepted; Electrification of Swedish society is possible (but none considered electrification in the rest of the world).

[35] For food systems, the French Agrimonde scenarios are exemplary in their discussion of scenarios that are clearly unsustainable, hence undesirable, and which futures that may be sustainable (Le Mouel et al. 2018).

Finally, ecologists working in agriculture and other production landscapes should account for and better understand how society, people and ecology interact, primarily through working together with scientists from other disciplines, especially social sciences. By incorporating important social and political drivers in our studies, ecologists can ensure that ecological knowledge is used in social discourses and policies, rather than remaining at the margins of decision-making. Hence Teja's questions will require further work and re-framing, presumably for generations, before they can be answered – we live in exciting but also depressing as well as hopeful times.

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Note: This pdf-version of our chapter has been edited by JB, by adding the full reference on p. 83 and correcting a number of minor errors throughout the text.