The original published PDF available in this website:
https://link.springer.com/chapter/10.1007%2F978-3-319-96229-0_15

Vulnerability of ecosystem services in farmland depends on landscape management

Jacqueline Loos[1], Péter Batáry[1,2], Ingo Grass[1], Catrin Westphal[1], Svenja Bänsch[1], Aliette Bosem Baillod[1,3], Annika Hass[1], Julia Rosa[1], Teja Tscharntke[1]*

[1]Agroecology, Department of Crop Science, Georg-August University of Goettingen, Goettingen, Germany

[2]GINOP Sustainable Ecosystems Group, MTA Centre for Ecological Research, Klebelsberg Kuno u. 3, 8237 Tihany, Hungary

[3]Agricultural Landscapes and Biodiversity Group, Research Station Agroscope Reckenholz-Taenikon ART,

Reckenholzstrasse 191, 8046 Zurich, Switzerland

**jloos@gwdg.de*

Key words

Agricultural intensification; Biodiversity; Landscape heterogeneity; Landscape complexity; Landscape composition; Landscape configuration; Pollination; Pest control; Semi-natural habitat; Spatial scale.

1.1 Introduction

Forty-four percent of Europe´s terrestrial surface is covered with agricultural land. Thus, agriculture strongly influences Europe´s environment, including ecological functions and processes. Agriculture provides direct benefits to humanity, such as food, feed, fuel and fiber. Besides agricultural production, farmland also plays an important role for regulating services, such as carbon sequestration, water capture and retention or biological pest control and pollination. As an interface between nature and human activities, agricultural landscapes fulfill people with a sense of place, enable livelihoods, employments and ways of living and offer space for recreation [1]. These and several other ecosystem services constitute the multifunctionality of the agricultural landscape that European agricultural policy seeks to achieve and maintain. Hence, ecosystem service management needs to navigate trade-offs between competing interests from local to landscape scales.

Mainly two processes, land use intensification and land abandonment, drive current changes in European agroecosystems. Fairly unexplored are the consequences of these changes for human well-being. On the one hand, production of agricultural goods increases, either through the expansion of agricultural land or, more frequently, by intensification on existing farms. This happens through the use of higher yielding crop varieties, increased input of agrochemicals and simplification and shortening of the crop rotation. Intensification also aims at higher cost-effectiveness in the short term, which involves consolidation of field sizes and the removal of semi-natural landscape elements such as hedgerows, field margins and tree lines [2]. The consequences of intensification include landscape simplification, nutrient leaching, soil compaction, loss of soil fertility and of biodiversity. On the other hand, land abandonment might also lead to a loss of landscape heterogeneity through biotic homogenization, thereby eroding habitats for open-land species.

1.2 Biodiversity as integral part of ecosystem services

Agroecosystems are pivotal for the conservation of biodiversity in Europe. Biodiversity, in terms of species richness, trait diversity and biotic interactions, affects ecosystem functions and their stability [3], e.g. by promoting soil supporting services, pollination or biological pest control. In a political context, biodiversity conservation is often justified to ensure human well-being via the supply of ecosystem services. Notwithstanding, conserving a wide range of species, including those that are rare and endangered, may serve as an insurance and complementation strategy for safeguarding ecosystem functions under changing environmental conditions. Despite a huge body of experimental approaches [3], our knowledge about the relationship between biodiversity, ecosystem functions and ecosystems services in agricultural landscapes is still fragmented and ambiguous. Most likely, this relationship is non-linear and depends upon interacting field and landscape-scale effects.

Pollination through insects and biological pest control are two ecologically and economically important agroecosystem services. Production of 75% of all major crops, especially fruits, nuts and vegetables, benefits from insect pollination or even relies on it. Wild pollinators such as bumblebees and solitary bees are usually the most effective pollinators for many economically important crops [4]. Pollination rates may increase with the number of species present in a site due to functional complementarity. However, the majority of pollination service is delivered through few common species [5]. Thus, the relationship between pollination rates and the number of species levels off at a particular point of the curve, which means that additional species only marginally increase the ecosystem service of interest. Under changing environmental conditions, however, these species may play an important role to maintain the resilience of the ecosystem.

For pest control, both success and failure are possible with increasing numbers of natural enemies, but despite the context dependency, enemy diversity appears to generally increase biocontrol [6]. In a systematic re-analyses of aphid pest control across Europe and North America, Rusch et al. [7] found consistent negative effect of landscape simplification on the level of natural pest control, despite interactions among enemies. Average level of pest control was 46% lower in homogeneous landscapes dominated by cultivated land, as compared with more complex landscapes. Thus, there is a huge potential to support natural pest control through counteracting homogenization of farmland.

1.3 Landscape heterogeneity determines on-farm biodiversity and ecosystem services

The field and the landscape are intricately interconnected and constitute heterogeneity [8]. Both landscape compositional and configurational heterogeneity can affect biodiversity [9]. Landscape compositional heterogeneity increases with the diversity of habitat types, while landscape configurational heterogeneity increases with high amount of edges and small crop fields. Ongoing research shows that increasing configurational heterogeneity at a landscape scale is at least as important for keeping biodiversity as the switch to organic farming (Batary et al. 2017, Nature EcolEvol in press). Landscape composition and configuration at different spatial scales explained species richness of plants, bees and butterflies [8, 14], and the presence of pest enemies in agricultural landscapes [15]. Many other ecological studies confirm that landscape characteristics influence biodiversity patterns at different spatial scales [e.g. 8]. Moreover, heterogeneity can mitigate adverse effects of local land use intensification [10].

Semi-natural habitats and crop diversity are two important components of compositional and configurational heterogeneity in agricultural landscapes that affect biodiversity at the landscape scale [9]. Semi-natural habitats in agricultural landscapes play an important role for many species as source habitats, for example for wild bees that pollinate crops [11] and for natural enemies of pests [12]. However, not only the amount of semi-natural habitat determines biodiversity at a landscape scale, but the quality in terms of resource availability is an important consideration from an agroecological perspective. For example, conservation management of set-aside or fallows contributes to landscape complexity, but set-aside that is agronomically managed may not differ from cropland [13]. Enhancing functional biodiversity for pollination and biocontrol on a landscape scale requires a minimum of ca. 20% of semi-natural habitat, but improved cropland and fallow management may allow reducing this percentage (e.g. Tscharntke et al. 2011, AgEE).

The crop production area itself is often ignored and only considered as undifferentiated matrix [9], although it greatly varies in its heterogeneity (e.g. field size or diversity of crops). In a recent study, we found that both configurational and compositional heterogeneity of the cropland influence predation rates on aphids, which indicates a higher success of pest control in more heterogeneous cropland (Figure 1). Furthermore, fewer cereal aphids were present in farmland comprising spatial and temporal heterogeneity represented through small field sizes and high cover of field margins [18]. Consequently, ecological effectiveness, e.g. through pest control and pollination, interacts with heterogeneity of the landscape at local and landscape scales [16, 17] (Figure 2). However, measures to enhance biocontrol and pollination (e.g. by implementing field boundaries or hedges) are most efficient in simple, but not complex or fully cleared landscapes [16]. We assume that this positive relationship between landscape complexity (i.e. the presence of semi-natural habitats) and the presence of natural enemies and pollinators may proof beneficial for crop yield (Figure 2c).

Also other ecosystem services may be affected by landscape-scale characteristics and their interaction with local scale conditions [11]. Knowledge of such interacting effects can improve the planning of agriculture for specific ecosystem services of interest. Mass flowering crops, for example, may serve as complementary resource that enables pollinator increases. This complementarity effect, however, calls for assessments not only of local species richness and related ecosystem services, but for a stronger focus on larger-scale species turnover (beta-diversity) among habitats as well as total landscape diversity (gamma-diversity). Measures to increase semi-natural habitat and cropland heterogeneity across regions and countries promise to keep dissimilarity of communities (beta diversity). Higher beta diversity, in turn, increases the likelihood of functional redundancy and may increase the capacity of a system to sustain its service provision.

1.4 Local adaptation and targeted measures required for ecosystem service maintenance

The EU Common Agricultural Policy entails environmental measures applicable to the EU's farmland, which are intended to increase both biodiversity and ecosystem functions. As an example, management practices used in diversified farming systems result in more complex and heterogeneous agricultural landscapes and thereby have the potential to generate higher levels of biodiversity at the local scale. Flower strips represent such widely used agri-environment schemes, and benefits through pollination has the potential to outweigh the loss of area [19]. However, EU policies target mainly at farm and field levels and usually disregard the landscape context. The effectiveness of these measures, however, strongly depends on the landscape structure [20]. Thus, flower strips may or may not be beneficial for a specific conservation target. For example, perennial strips with few forbs may enhance the richness of soil-dwelling arthropod predators in the field margins, whereas nectar-rich flowers in annual field strip may be more beneficial to attract pollinators. Hence, a set of measures need to be implemented to enhance a diversity of important services. Moreover, these measures need to fit the biophysical and socio-economic conditions of the region in which they are to be applied.

Heterogeneity of agricultural landscapes has often been found beneficial for biodiversity, however, diversification of cropland proved to impact biodiversity most in simplified landscapes [20]. Moreover, not all functional groups of species may be similarly affected by variables at the field or at the landscape scales. For example, small solitary bees forage at small ranges, whereas large bumblebees (and honeybees) on large scales [21]. Generalist predators of cereal aphids, however, benefited from simplified cereal-dominated landscapes (but not specialist enemies; [22]). In contrast, earthworms and other organisms that increase soil quality and long-term soil fertility, thrive best through on-site management, such as tilling and crop rotation. Rare or endangered species and species which fulfill keystone functions in an ecosystem may need specific and targeted conservation measures in order to support their contribution to ecosystem services.

1.5 Conclusion

Neither single agri-environment measure nor single conservation action targets the range of benefits that humans derive from agricultural land. Maintaining or restoring the ability of agricultural landscapes to provide various ecosystem services requires regionally adapted schemes, which are most effective if embedded not only at the farm but also at the landscape level. To ensure the provisioning of many different ecosystem services in a landscape, allocating priorities for smaller units of the landscape may be helpful in order to navigate potential trade-offs between ecosystem services. One well-known trade-off between different ecosystem services is yield increase through intensification on the one hand and increases of semi-natural habitats for pollinators and natural pest enemies on the other hand. However, it is possible to balance these trade-offs through appropriate management. The implementation of flower strips at the local scale and increasing heterogeneity at the landscape scale are promising strategies to allow spillover of functionally important biodiversity between local and landscape habitats.

In combination, these measures reduce the hostility of cropland and achieve synergy effects between facilitation of pollination and increased yield. Consequently, use of agrochemicals can be minimized, which goes along with less detrimental impact on important soil functions, for example. More research on identifying synergies between apparently conflicting ecosystem services is needed in order to inform the management of multifunctional landscapes. Moreover, farmland should be recognized as social-ecological systems that are strongly influenced both by the local society and by contextual legislation, spanning from local to EU policies. Eventually, a comprehensive management for the maintenance of multifunctional landscapes needs to tackle meaningful ecological scales and match various governance levels.

Acknowledgements

ABB was supported by a scholarship from the German Academic Exchange Service (DAAD), SB acknowledges her scholarship by the German Federal Environmental Foundation (DBU) and PB was funded through the DFG (BA 4438/2-1) and by the Economic Development and Innovation Operational Programme of Hungary (GINOP–2.3.2–15–2016–00019). ABB and AH were supported by the ERA-Net BiodivERsA project “FarmLand” funded by the BMBF (German Ministry of Research and Education, FKZ: 01LC1104A).

References:

1. Plieninger T, Schleyer C, Schaich H, Ohnesorge B, Gerdes H, Hernández-Morcillo M, Bieling C: Mainstreaming ecosystem services through reformed European agricultural policies. Conservation Letters 2012, 5(4):281-288.

2. Plieninger T, Draux H, Fagerholm N, Bieling C, Bürgi M, Kizos T, Kuemmerle T, Primdahl J, Verburg PH: The driving forces of landscape change in Europe: A systematic review of the evidence. Land Use Policy 2016, 57:204-214.

3. Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, Narwani A, Mace GM, Tilman D, Wardle DA: Biodiversity loss and its impact on humanity. Nature 2012, 486(7401):59-67.

4. Garibaldi LA, Steffan-Dewenter I, Winfree R, Aizen MA, Bommarco R, Cunningham SA, Kremen C, Carvalheiro LG, Harder LD, Afik O: Wild pollinators enhance fruit set of crops regardless of honey bee abundance. Science 2013, 339(6127):1608-1611.

5. Kleijn D, Winfree R, Bartomeus I, Carvalheiro LG, Henry M, Isaacs R, Klein A-M, Kremen C, M'gonigle LK, Rader R: Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. Nature Communications 2015, 6:7414.

6. Jonsson M, Kaartinen R, Straub CS. Relationships between natural enemy diversity and biological control. Current Opinion in Insect Science 2017, 20:1-6.

7. Rusch A, Chaplin-Kramer R, Gardiner MM, Hawro V, Holland J, Landis D, Thies C, Tscharntke T, Weisser WW, Winqvist C, Woltz M. Agricultural landscape simplification reduces natural pest control: A quantitative synthesis. Agriculture, Ecosystems & Environment. 2016, 221:198-204.

8. Loos J, Turtureanu PD, Wehrden Hv, Hanspach J, Dorresteijn I, Frink JP, Fischer J: Plant diversity in a changing agricultural landscape mosaic in Southern Transylvania (Romania). Agriculture, Ecosystems & Environment 2014, 199(0):350-357.

9. Fahrig L, Baudry J, Brotons L, Burel FG, Crist TO, Fuller RJ, Sirami C, Siriwardena GM, Martin JL: Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecol Lett 2011, 14(2):101-112.

10. Gámez-Virués S, Perović DJ, Gossner MM, Börschig C, Blüthgen N, De Jong H, Simons NK, Klein AM, Krauss J, Maier G, Scherber C. Landscape simplification filters species traits and drives biotic homogenization. Nature communications. 2015, 20;6.

11. Ricketts TH, Regetz J, Steffan-Dewenter I, Cunningham SA, Kremen C, Bogdanski A, Gemmill-Herren B, Greenleaf SS, Klein AM, Mayfield MM et al: Landscape effects on crop pollination services: are there general patterns? Ecology Letters 2008, 11(5):499-515.

12. Bianchi FJJA, Booij CJH, Tscharntke T: Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proceedings of the Royal Society B: Biological Sciences 2006, 273(1595):1715-1727.

13. Tscharntke T, Batáry P, Dormann CF: Set-aside management: How do succession, sowing patterns and landscape context affect biodiversity? Agriculture, Ecosystems & Environment 2011, 143(1):37-44.

14. Kennedy CM, Lonsdorf E, Neel MC, Williams NM, Ricketts TH, Winfree R, Bommarco R, Brittain C, Burley AL, Cariveau D, Carvalheiro LG (2013). A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. Ecology Letters, 16, 584–599.

15. Chaplin-Kramer R, O'Rourke ME, Blitzer EJ, Kremen C: A meta-analysis of crop pest and natural enemy response to landscape complexity. Ecol Lett 2011, 14(9):922-932.

16. Tscharntke T, Klein AM, Kruess A, Steffan-Dewenter I, Thies C: Landscape perspectives on agricultural intensification and biodiversity - ecosystem service management. Ecol Lett 2005, 8(8):857-874.

17. Shackelford G, Steward PR, Benton TG, Kunin WE, Potts SG, Biesmeijer JC, Sait SM. Comparison of pollinators and natural enemies: a meta-analysis of landscape and local effects on abundance and richness in crops. Biological Reviews. 2013 Nov 1;88(4):1002-21.

18. Bosem Baillod A, Tscharntke T, Clough Y, Batáry P. Landscape-scale interactions of spatial and temporal cropland heterogeneity drive biological control of cereal aphids. Journal of Applied Ecology. 2017.

19. Pywell RF, Heard MS, Woodcock BA, Hinsley S, Ridding L, Nowakowski M, Bullock JM: Wildlife-friendly farming increases crop yield: evidence for ecological intensification. Proceedings of the Royal Society B: Biological Sciences 2015, 282(1816): 20151740.

20. Batáry P, Báldi A, Kleijn D, Tscharntke T: Landscape-moderated biodiversity effects of agri-environmental management: a meta-analysis. Proceedings of the Royal Society of London B: Biological Sciences 2011, 278(1713):1894-1902.

21. Steffan-Dewenter I, Münzenberg U, Bürger C, Thies C, Tscharntke T. Scale-dependent effects of landscape context on three pollinator guilds. Ecology 2002, 83(5):1421-32.

22. Rand TA, Tscharntke T: Contrasting effects of natural habitat loss on generalist and specialist aphid natural enemies. Oikos 2007, 116(8):1353-1362.

Figure legends:

Figure 1: Predicted predation effectivity in 52 agricultural landscapes in the Leinetal, Lower Saxony. The prediction is based on a comprehensive study on aphid predation rates in 104 cereal and 52 oilseed rape fields with different compositional and configurational heterogeneity of crops in the surrounding (Bosem Baillod & Hass unpubl. data). Information on the predation rates of aphid cards were collected during the summers 2013 and 2014. Predation rate was used as a response variable in a generalized linear mixed model using the landscape as random effect and heterogeneity of the landscape as predictors. The results of this model were then extrapolated to the entire agricultural landscape in the Leinetal to predict pest control based on landscape heterogeneity.

Figure 2: Hypothesized consequences of landscape complexity for ecosystem service delivery and crop yield. (1) Pest damage to apple fruits is often caused by the codling moth (*Cydia pomonella*). (2) Insectivorous birds can suppress adult codling moths. (3) Similarly, *Trichogramma* wasps are egg-parasitoids of codling moths, reducing codling moth damage in apple orchards when released. (4) Trees and hedges in the landscape surroundings provide nesting habitat and food for insectivorous birds, increasing their biological control potential. (5) Similarly, high-value habitats in the landscape surroundings as well as (6) local establishment of flower strips benefits parasitoids as well as wild bee pollinators. (7) Particularly wild bees are often more efficient pollinators of crops than commercial honeybees. While (a) complex landscapes provide ecosystem services, (b) landscape simplification results in losses of these services, which at the same time leads to higher pest outbreaks. Consequently, (c) complex landscapes should benefit crop yields at the farm-level by increasing ecosystem service provisioning.

Figure 3: Pollination and natural pest control are two important ecosystem services in agricultural landscapes. a) While the majority of pollination service is delivered through few common species (such as the honeybee *Apis mellifera*), rare pollinators are more efficient pollinators and may play an

important role under changing environmental conditions. b) the configuration and composition of cropland and the surrounding landscape influences the effectivity of natural pest control, as provided by parasitoids like parasitic wasps.

Figure 1

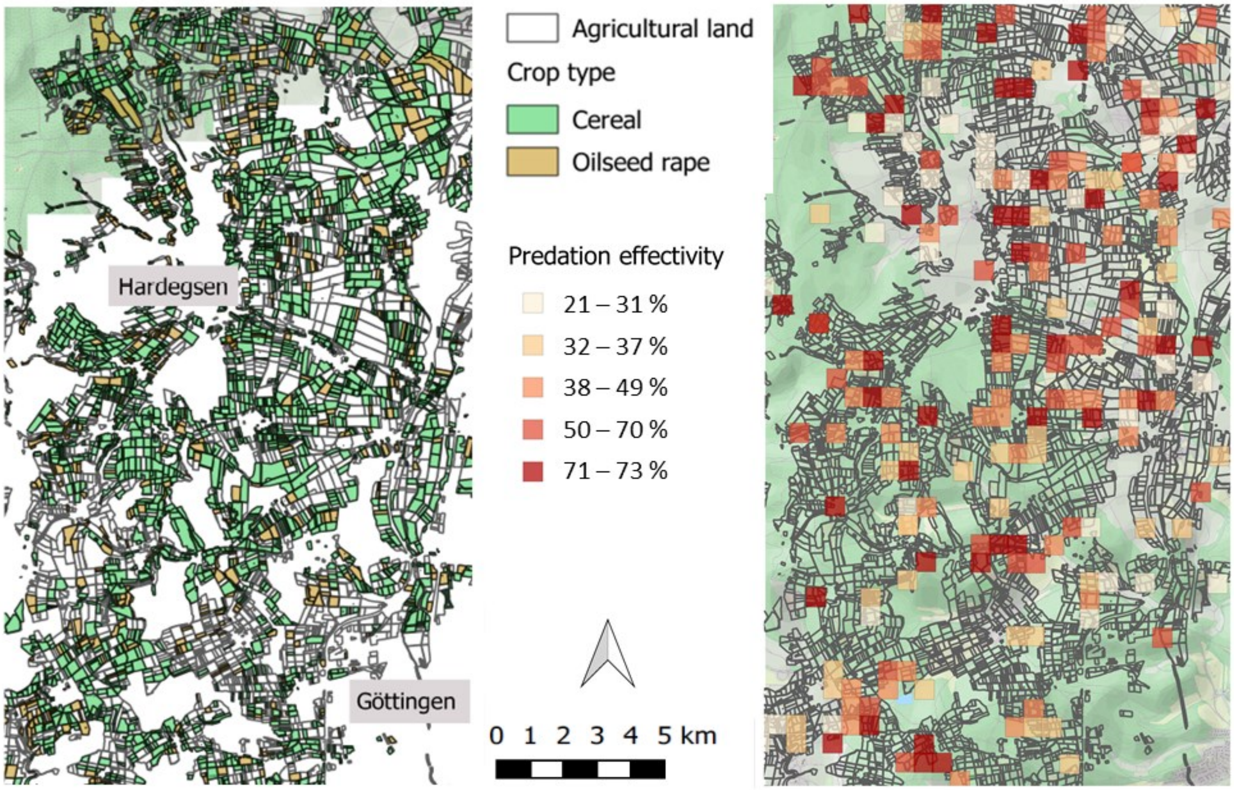

Figure 2

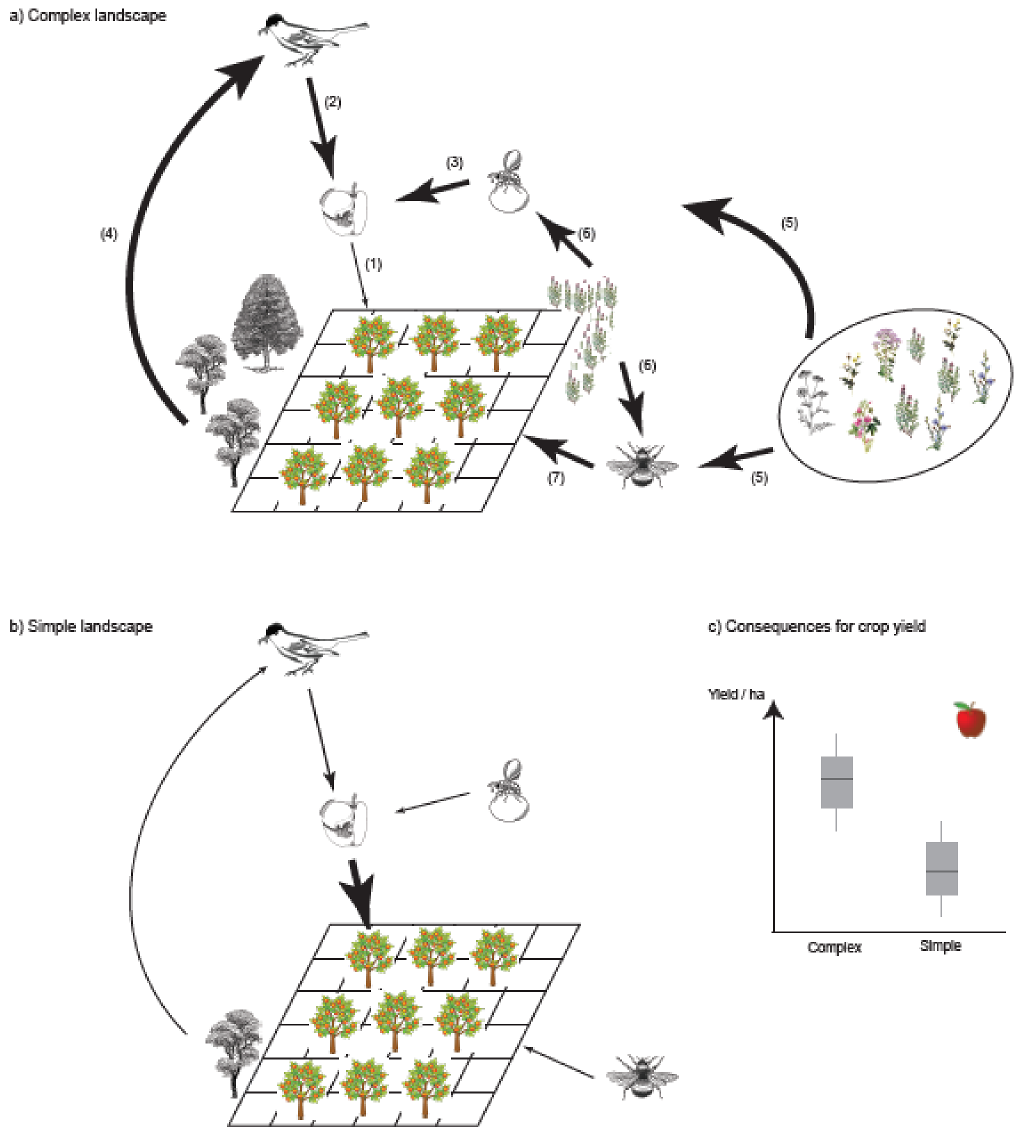
a) Complex landscape
(2)
(3)
(4)
(6)
(5)
(1)
(6)
(7)
(5)
b) Simple landscape
c) Consequences for crop yield
Yield / ha
Complex
Simple

Figure 3