Insect conservation in agricultural landscapes

An outlook for policy-relevant research

Insect populations decline, particularly in intensively managed agricultural landscapes. Insect communities are influenced by current agricultural practices, which are themselves determined by the economic, political and social frameworks. We highlight these direct and indirect drivers affecting insect communities, raise key research questions and discuss options for action to encourage a transformative change towards an economic, political and social system protecting biodiversity.

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Biological diversity is declining across the globe, resulting in the loss of ecosystem functioning and services (IPBES 2019). For insects, declining diversity has been shown in long-term studies, especially in areas with intensive agricultural land use (Beckmann et al. 2019, Homburg et al. 2019). A long-term record in Germany measuring the biomass of flying insects indicated a dramatic loss of flying insects in protected areas over the past 27 years (Hallmann et al. 2017).[1] Hallmann et al.'s publication has attracted worldwide public attention and led to a societal and professional debate on how to improve insect conservation. It supported conclusions from the first report from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES 2016) that had stirred discussion on insect conservation internationally. In Germany, these reports contributed to recent political action that extends existing efforts to protect biodiversity by programs focusing particularly on insect conservation, for example, the "action program for insect conservation" *(Aktionsprogramm Insektenschutz)* of the German Federal Government (BMU 2019).

Here we aim to give a perspective from a social-ecological and economic research experience on future research that is required to improve knowledge about declining insect populations in agricultural landscapes and to develop effective conservation strategies with a focus on Germany. To mitigate insect decline the drivers responsible for these losses need to be addressed. As drivers occur on different levels and manifest as direct or indirect influences on insect communities, we proceed as follows: first, we identify the potential drivers influencing insect communities and group them according to their type of impact (direct or indirect). Second, we raise research questions related to these drivers and define the prerequisites to answer them (research approach). Lastly, we suggest conservation measures based on knowledge that is currently available. In the following, we start by introducing the conservation target: insect communities.

Insect communities

Insects fulfill manifold ecosystem functions and develop various values for humans.[2] They provide ecosystem services, for example pollinating crops or decomposing litter and excrements (Klein et al. 2018). They can also harm human well-being, for example, as crop pests or vectors of disease (Schäckermann et al. 2015). Their decline can have tremendous effects on ecosystem functions and services.

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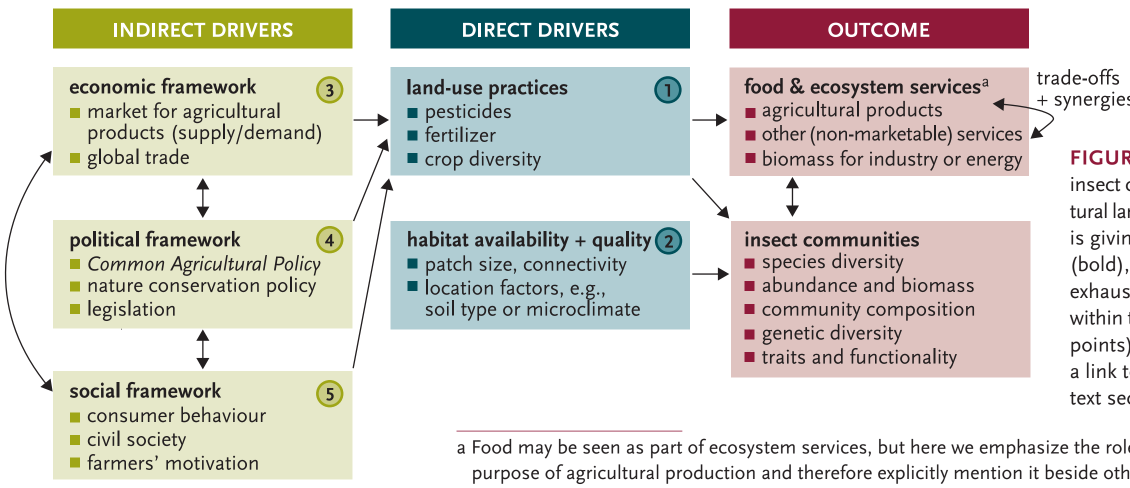

FIGURE 1: Drivers influencing insect communities in agricultural landscapes. The flowchart is giving broad categories (bold), specified by a non-exhaustive list with examples within these categories (bullet points). Numbers provide a link to equally numbered text sections.

a Food may be seen as part of ecosystem services, but here we emphasize the role of food as the main purpose of agricultural production and therefore explicitly mention it beside other ecosystem services.

Insect communities are characterized by their diversity, numbers of individuals and community composition. While general trends of diversity are known, there is less certainty about the long-term trends of specific species and the community composition (IPBES 2019, Basset and Lamarre 2019). It remains mostly unknown whether insect species that are beneficial or damaging for human well-being are more affected by decline (IPBES 2016). Beside changes in species diversity, traits and genetic diversity are lost (Pereira et al. 2012). Insect communities and their characteristic components are influenced by direct and indirect drivers (figure 1) – these are explained in the next step.

Direct drivers of insect losses

Direct drivers of insect losses comprise 1. habitat availability and quality, and 2. land-use practices.

Habitat availability and quality (1)

To maintain stable populations, insects require habitats depending on their species-specific needs. On a landscape scale, two components are important: first, the species-specific habitat needs to be large enough to host a viable population, and second, with increasing landscape diversity multiple species will find their habitat requirements. Isolated habitat patches resulting from homogenization of landscapes and fragmentation of natural habitats have negative effects on diversity (Rossetti et al. 2017). Habitat requirements for particular insect groups such as bees are known especially in regard to landscape elements such as hedges, field margins and extensively used meadows and pastures (Ponisio et al. 2019, Sands and Wall 2017) (figure 2, p. 345). Quantification of how many and what kind of landscape elements are required for conserving insects across taxa has been less investigated (e.g., Batáry et al. 2017). Habitat availability and quality are themselves influenced by various drivers, such as climate change or land-use practices. Land-use practices such as the application of pesticides can also directly influence insects.

Land-use practices (2)

Most typically, the decline in insect diversity is related to multiple processes of land-use intensification in agricultural landscapes (Beckmann et al. 2019). Intensification increases cultivation or livestock husbandry outputs (e.g., via fertilizer inputs) and narrows the variety of agricultural ecosystem services via specialization. Intensification also leads to a decrease in landscape elements, such as hedgerows (Van Vliet et al. 2015). Additionally, the abandonment of landscape management can be an important driver of diversity decline, for example, if extensively managed grasslands are given up and overgrown by scrub (Ernst et al. 2017). Location factors such as accessibility, soil quality or local climate explain why some regions are more prone to agricultural intensification or abandonment, while others have preserved higher shares of high nature value farming (Van Vliet et al. 2015).

Indirect drivers: political, economic and social factors

Agricultural practices are driven by economic, political, cultural and natural factors (Plieninger et al. 2016). *Economic* drivers (3) play an important role, as agricultural production is influenced by local, European and global markets. *Political* drivers (4) influence land use either by shaping the economy with income subsidies or support for production, or via laws for land consolidation or directly regulating management. The most important European Union policy is the Common Agricultural Policy (CAP) and the way it is implemented in national policies (Heinrich et al. 2013). Despite relating 30 percent of the direct payments to measures >

1 This was recently confirmed by an insect survey in 150 grassland sites covering ten years (Seibold et al. 2019).

2 Insects include very diverse taxonomic orders, such as beetles *(Coleoptera)*, butterflies and moths *(Lepidoptera)*, bees, wasps and ants *(Hymenoptera)* and flies *(Diptera)*.

intended to protect the environment ("greening") and offering payments for voluntary measures ("agri-environmental schemes"), the present CAP has shown substantial weaknesses in delivering public goods and sustaining biodiversity (Pe'er et al. 2017, Pe'er et al. 2019).

Society (5) influences political action and agricultural production for example through consumer behavior (Seufert and Ramankutty 2017). Agricultural practices are also influenced by attitudes and motivations of farmers. Farmers either focus on production, emphasize their role in conserving biodiversity, or have a more holistic understanding of being conservationists, primary producers, and managers of a range of ecosystem services. Individual farmers' motivations have so far not been sufficiently considered for the success of the implementation of some public policies (Dessart et al. 2019), although these policies are key to place farmland biodiversity "in the hands and minds of farmers" (De Snoo et al. 2013). Motivations and practices of farmers are themselves influenced by markets, social acceptance and the regulations set up by the political frame. Effective insect conservation requires management changes at the scale of landscapes, hence the degree of collaboration between farmers in a landscape is also an important driver (Prager et al. 2012).

Research outlook

Successful conservation of insects requires strong knowledge pertaining to the direct and indirect drivers as well as their complex interactions, and about the design and implementation of comprehensive action as informed by transformation research. Based on the experience of the authors, we suggest exemplary research questions that would improve the understanding of these relationships in the following:

Research on direct drivers:

1. How does the above- and belowground insect community composition and their traits in agricultural landscapes change with quantity, quality and configuration of landscape elements?
2. How does the management of permanent grasslands and croplands affect insect communities and their diversity on different landscape scales?
3. How do beneficial insects and pest species interact and influence each other?
4. How does the equilibrium between beneficial insects and pests change related to land use and various landscape elements?
5. How do different pesticides and their combinations (including livestock medication) affect different insect species and their ecological interactions?
6. How much of which pesticide is retained in the soils?
7. What are suitable indicators to monitor biodiversity on farmland and how can the indicators successfully be linked to drivers?

Research on indirect drivers:

1. How can we organize transformation processes within industrialized societies to a more sustainable farming and economic system, where externalities are priced into the regular market?
2. How can we identify most effective leverage points to transform a system of natural and social components towards a more sustainable system?
3. How do different actors, such as farmers, consumers and the civil society, influence each other in their direct or indirect impacts on insect populations?
4. How can we organize or support collaborative actions between farmers and citizens through, for example, community-supported agriculture, which can also support biodiversity-friendly systems?
5. How do political measures, including incentives (subsidies) and obligations (regulations), lead to changes in insect communities?
6. How will measures in the CAP, such as the eco-schemes and conditionality, presumably replacing the "greening" after 2020, impact insect conservation?
7. How can the link between incentive-based schemes and conservation targets be improved while simultaneously considering and leaving space to farmers' intrinsic motivation?
8. How can agricultural policy incentivize a diversification of farms regarding the provision of biodiversity as a regular part of their business and support investments into farm resources (labor, machinery, land) being necessary for such diversification?

All the drivers mentioned interact in multiple ways, so that an integrative research approach including production, economics, politics, legislation, biodiversity and society is needed to accommodate the complexities among them (figure 1). So far, mainly individual links, for example, between political activities and land use, have been investigated (Batáry et al. 2015). An integrative approach requires an interdisciplinary research design, where different disciplines collaborate in design, implementation and evaluation, such as in Rosa-Schleich et al. (2019). This can be achieved by integrating socio-cultural, economic and ecological methodologies at the farm level offering the opportunity to gain valuable insights for sustainable production systems (Poudel et al. 2002, Lakner and Breustedt 2017).[3]

Research approaches to gain knowledge

Research to fill the previously outlined knowledge gaps needs different approaches. Transdisciplinary research, linking science and practice, is based on integrative approaches (Pohl et al. 2017). Given the complexity of the interaction of drivers, transformation research can help navigate the process, including balancing trade-offs between multiple stakeholders affected and monitoring and evaluating the impact of measures undertaken (Loorbach et al.

2017). Assessing and synthesizing the available knowledge related to one research question can be best done by a systematic review, as it was realized for example in an analysis on the effectiveness of agri-environmental management on pollinators (Marja et al. 2019) or the effects of schooling on farming practices (Waddington et al. 2014).

Primary studies in research are most commonly based on short funding phases. The link between particular species and the effect of a driver (e. g., pesticides) can be investigated in short term at best through experimental studies, but changes in communities may be found only over longer time scales, and extinctions occur with a delay. Long-term social-ecological research can reveal the long-term impact on species groups and communities resulting from an experimental manipulation. In Germany, long-term (social-)ecological research is organized as part of a European and global network, with most prominent sites being the *Biodiversity Exploratories*[4] and the *Jena Experiment*[5], both supported by Deutsche Forschungsgemeinschaft (DFG).

In addition to long-term social-ecological research, monitoring is required as it provides information on a longer scale and with a better coverage in space. It takes place to report the state of landscapes and society. So far, the coordination of comparable monitoring schemes covering a large space (across Germany, Europe or even globally) and a broad range of taxonomic groups is missing (see also Geschke et al. 2019).

Insect conservation measures

Beside the identification of the drivers and their interaction responsible for insect decline, immediate changes need to and can be instigated to reach a transformation towards a more favorable environment for insect communities (Leopoldina et al. 2018, SRU 2018, Forister et al. 2019, BMU 2019). The current knowledge offers multiple leverage points to foster insect conservation in agricultural landscapes and each of them is ideally monitored and evaluated.

Key arenas for action are:

Agricultural policy: In 2018, the European Commission launched a new reform proposal for their CAP post 2020 (Pe'er et al. 2019). To become a central instrument to mitigate biodiversity decline, the link between subsidies and good practice prioritizing environmental protection and the adaptability to local conditions needs fundamental improvement, for example, by strengthening and simplifying agri-environmental measures emphasizing specific targeted measures, instead of a one-size-fits-all approach like

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3 Ecosystem services provide a good common framework to investigate trade-offs between ecological, economic and social interests.
4 *www.biodiversity-exploratories.de*
5 *www.the-jena-experiment.de*

FIGURE 2: An ivy bee *(Colletes hederae)* collecting pollen from ivy *(Hedera helix)* at Kaiserstuhl in Southern Germany. The ivy bee nests in coarse clay and sandy soils and is mainly oligolectic, which means it requires particular plants as food source.

"greening" (see Pe'er et al. 2017). This requires knowledge on specific relationships such as between agri-environmental practices and resulting impacts on insect populations, and how to embed measures in farming cultures to be sustained self-evidently as part of conventional "good farming" practice (Burton and Paragahawewa 2011).

2 ***Law enforcement:*** The number of laws and regulations to sustain biodiversity has substantially increased over the past decades, but there is a lack of implementation of existing laws and controls, typically due to missing financial and staff resources (LANA 2016). Especially at the level of local administration, a lack of priority and financial means can hamper the implementation of regulations (Haupt et al. 2010).

3 ***Trade and markets:*** Incorporating non-marketable services into the market, for example, by taxing or subsidizing through payments of ecosystem services, potentially protects habitats required for insect conservation. Creating markets for regional products will support local value chains. The market for organic products with its established certification system for a more environmental-friendly farming process might serve as a guide to incorporate "biodiversity-friendly" products into respective certification systems. There are some promising first approaches to develop and test such a certification scheme together with the food retailers (Stein-Bachinger and Gottwald 2016). But here, particular social-ecological impacts of different certification systems, direct and indirect land-use changes resulting from certification, and a potential "consumer fatigue" regarding new certificates and labels need further investigation.

4 ***Civil society:*** Civil society plays an important role to realize initiatives from bottom-up. These serve as multipliers and can influence public opinion and politics, such as recently seen in the popular petition to conserve biodiversity in Bavaria.[6] The engagement of society in research activities (citizen science) can empower citizens' scientific competences and simultaneously support science by voluntary labor and outreach. As a relatively new research area, little is known about the mechanisms underlying a successful citizen science initiative.

Sustaining insect diversity and mitigating losses of insect populations requires a transformative change towards an economic, political and social system protecting biodiversity. Transformative change ideally starts at several leverage points simultaneously, and the above-mentioned key arenas demand action from multiple stakeholder groups. Action needs to be coordinated on a landscape scale, while constantly monitoring the impact of change and acting based on continuously updated, best available evidence.

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6 *www.sueddeutsche.de/bayern/artenschutz-bienen-volksbegehren-csu-freie-waehler-1.4394525*

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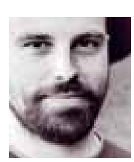

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