Long-term monitoring of insects in agricultural landscapes

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Zusammenfassung: Standardisierte Langzeitmonitoring-Programme sind von erheblicher Bedeutung in der Bewertung komplexer Wirkungsgefüge zwischen Landschaftsstrukturen und Insekten. Neben wertvollen Datensätzen zur Auswertung von Ursache-Wirkungsbeziehungen bilden sie ein wichtiges Instrument zur Früherkennung von Risiken oder grundlegenden Verschiebungen in Lebensgemeinschaften auf regionaler Ebene. Das Monitoring der Insektenvielfalt in Agrarlandschaften und die Etablierung bundesweiter Erfassungsdaten durch standardisierte Verfahren sind Teil des „Bundesprogramms Biologische Vielfalt" – ‚Aktionsprogramm Insektenschutz'. Bislang existieren jedoch nur wenige Informationen zu Langzeittrends wichtiger Indikatorengruppen oder Artengemeinschaften, welche umfassend den allgemeinen Rückgang der Insekten in Agrarlandschaften dokumentieren. In dieser Studie nutzen wir Daten einer stationären Saugfalle (12,2 m Höhe), welche 1985 errichtet wurde und verschiedene Ordnungen flugaktiver Insekten und Spinnen in hoher zeitlicher Auflösung sammelt. Die seither nahezu unveränderte Methode ermöglicht die Abbildung und Bewertung von Langzeittrends in ausgewählten Insektengruppen.

Abstract: There is widespread concern about recent biodiversity and invertebrate biomass losses and the general public pays increased attention to the consequences in agricultural landscapes and finally the functioning of ecosystems. There are very few standardised, long-term datasets on insect populations available to investigate the underlying mechanisms more closely. In this study, we used a 12.2 m high suction trap comparable to those used by the Rothamstedt insect survey to monitor aphids, other invertebrate herbivores and antagonists in an agriculture-dominated landscape (mid Germany) since 1985. The research project uses samples and data that were collected over a period of 35 years to compile indices of total aerial invertebrate biomass or species data across recent decades and then investigates temporal trends to analyse the complex interrelationships between environmental or climate change and shifts in species assemblages of a range of insect taxa. Here, we present first results of this exceptional large dataset.

Key Words: Insect declines, Biodiversity, Farmland, Environmental change, Nationwide monitoring, Phenology

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Introduction

Insect decline is a highly topical issue in modern societies and the rate of change in insect abundance is commonly associated with e. g., habitat losses, land-use intensification, stress-factors such as pollution or insecticides, and seasonal weather changes or extrem climatic events (BECKMANN & al. 2019, SÁNCHEZ-BAYO & WYCKHUYS 2019). Despite widespread concern about declines in insect assemblages, little is known about the underlying patterns of change during the last decades to fully understand the causes and consequences of this phenomenon. Very few standardised, long-term datasets on insect populations are available to investigate the underlying mechanisms more closely and it is thus difficult to establish direct causal relationships. In such an environment, there is a high need to gain timely and reliable information on existing long-term data sets while an ongoing systematic and technically comparable monitoring is gaining in significance. To determine how current conservation strategies in agricultural landscapes can be improved and to formulate specific requirements, it is crucial that a sufficient quantity of specific insect groups is monitored.

Generally, the importance of insect diversity for the stability of natural systems in combination with the provision of fundamental ecosystem services in agriculture has been widely acknowledged in theoretical (Petchey & al. 2008) and empirical studies (Altieri 1999). Natural systems provide ecosystem services on which humans depend (Losey & Vaughan 2006) and also the sustainable management of modern agriculture is partly related to insect abundance and diversity. Several services which are currently in the focus of attention are provided by foraging strategies of insects including pollination, pest control, and the decomposition of organic substances in soils. Besides, insects are an essential part of ecosystems as they represent the nutritional basis for higher trophic levels and the role of biodiversity in the functioning of ecosystems is far from being resolved (Gaston 2000).

However, changes in agricultural practices or other factors may take several years or decades to have any measurable effects (McDonalds & al. 2018). Consequently, there is a strong need for continuous biodiversity monitoring in agricultural landscapes that uses specific groups of species at a sufficient spatial coverage, applies similar collection methodologies, and allows for analysing data at different spatio-temporal scales (Pereira & Cooper 2006). Available data and already existing monitoring programmes should be implemented in the decision for the sampling methods and the target insect groups. Indicators should be used based on existing data, the monitoring design with a focus on regional and national scales, and a sampling method that has proved its reliability in the past. Moreover, the biodiversity monitoring programmes from the past should be implemented in a nationwide monitoring of insects.

In this study we use long-term data from an Insect Survey suction trap for a retrospective analysis of aphids, other invertebrate herbivores and antagonists in an agriculture-dominated landscape since 1985. Based upon these long-term data we investigate temporal trends of a change of total aerial invertebrate biomass and different taxonomic levels such as family and order level across the last decades to analyse the complex interrelationships between agricultural practice, environmental or climate change and shifts in species assemblages of a range of insect taxa.

Material and Methods

The suction trap continuously measures the aerial density of flying insects. The trap has an air intake rate of 3000 m^3/hr and samples between mid April and mid November. The current trap location is situated within a larger field trial area (N 51.771937, E 11.146757) surrounded by agricultural landscapes (Fig. 1b).

Part of an International insect survey: The suction-trap network began operation on the 29th April 1964 and continues to this day to monitor small to medium-sized insects migrating at height of 12.2 m (https://www.rothamsted.ac.uk/insect-survey). Currently, 16 traps are in operation in the UK although over the last 50 years a total of 37 traps with at least two years‘ worth of data have been in service (Bell & al. 2015) and about 128 traps worldwide.

In 1985, a 12.2 m high suction trap of identical design (Fig. 1a) was placed near experimental field studies of the Institute for Resistance Research and Stress Tolerance and its predecessors (1985 – 2006 Aschersleben; 2007 – 2019 Quedlinburg) to monitor migrating aphids. However, other insect guilds (spiders, psyllids, leafhoppers) are counted on a daily basis, as well, many of which are determined to the species level, using the identification keys of Müller (1975), Taylor & Robert (1984) and Basky (1993). Insect biomass: We determined total biomass of flying insects from daily samples (24 h) and subsequently began with the selection of insect orders meant to be determined to the species level (e.g., Hemiptera – especially aphids or psyllids; Araneae). The measure of the weight of insects followed a similar pattern: daily insect-samples (plastic bottle; 250 ml) were directly poured into a plastic sieve, were separated from the fluid, dried (approximately ten seconds) and weighed. We initially compared two single years of sampling (1997 and 2017).

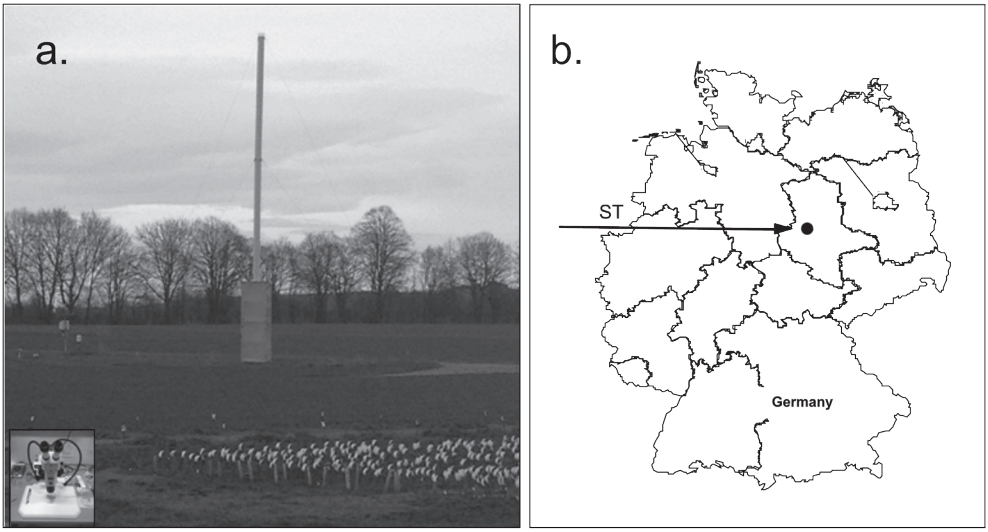

Fig. 1: a. The suction trap samples flying insects between April and November. The traps, coordinated by the European Union-funded thematic network EXAMINE, vary little from a standardized design which draws in air at a rate of approximately 3000 m^3/h through an aperture 12.2 m above ground level. **b.** Location of the suction trap (Quedlinburg, Saxony-Anhalt).

Results

Overall, more than 621.451 aphids were captured (1985–2018) by the suction trap (ST). Between 1985 and 2000 approximately 183.072 aphids were determined to the species level with 87 species from 41 genera. During the early period between 1985 and 1996, the majority of the aphids belonged to the family of the Aphididae (91.3 %). The remaining individuals had been assigned to the families of the Drepanosiphidae (2.2 %), Lachnidae (0.50 %) Pemphigidae (3.62 %), Anoeciidae (1.02 %), Thelaxidae (0.04 %), Adelgidae (1.22 %) and Phylloxeridae (0.11 %).

The most frequent species in the vegetation periods between 1985 and 1995 were *Rhopalosiphum padi* (L.) (32.7 %), *Brevicoryne brassicae* (L.) (21.5 %), *Metolophium dirhodum* (11.7 %), *Hyalopterus pruni* (Geoff.) (3.7 %), *Pemphigus* spp. (3.3 %), the *Aphis fabae*-group (2.4 %), *Brachycaudus helichrysi* (Kalt.) (2.3 %), *Cavariella aegopodii* (Scop.) (1.8 %), the *Myzus persicae*-group (1.6 %), *Anoecia corni* (Fabr.) (1.0 %) and *Acyrthosiphon pisum* (Harris) (1.0 %). All other species represented 14.7 % of the captured aphids (Schliephake & Karl 1995).

Daily biomass data (total catch) of two years over a period of two decades were used to estimate (i.), the rate at which seasonal changes of flying insects may occur, and (ii.), the extent of insect decline in an agricultural landscape. As expected, the data indicate a major decline of aerial insect biomass between 1997 and 2017 within the investigated agricultural region. In 1997, the insect biomass remained on a high level during the summer season (27th May – 25th of Aug), but slightly decreased towards the fall season. In 2017, a similar pattern of daily biomass occured across the season, but at a markedly lower level.

The total size of aphid populations in nature is known to vary e. g., with regard to seasonal weather conditions, which is here reflected in annual aphid abundances over a period of 35 years (Fig. 2a). However, total annual catch of aphids, displayed here as the count of aphids per day (Fig 2a) increased considerably during past three decades. At the same time, the suction trap sample analysis continuously showed longer time periods with flying aphids during the vegetation period (Fig. 2b). Over time, the flight period started earlier in spring with significantly more aphids sampled in April and May (Fig. 2c) and longer flight periods in fall (Fig. 2b). Also, the patterns in aphid flight changed in terms of a summer period without aphids between 1985 and 2018 (Fig. 2b); recently, an increasing number of aphids flew in July and August.

Phenological activity of flying aphids and winter temperatures are positively related for the winter season (November–February) and late winter (January/February) temperatures, but most obvious in a time period between 1990 and 2002. The mean late winter temperature explained almost 50 % of the variance in a regression analysis (Fig. 2d); warm winter supported earlier flights in spring ($R^2 = 0.4989$). However, this effect became less significant when using the entire time series in a regression analysis (1985–2019; $R^2 = 0.1037$) in which extrem dry and warm summer events occurred (e.g., 2003; 2006; 2015, or 2018).

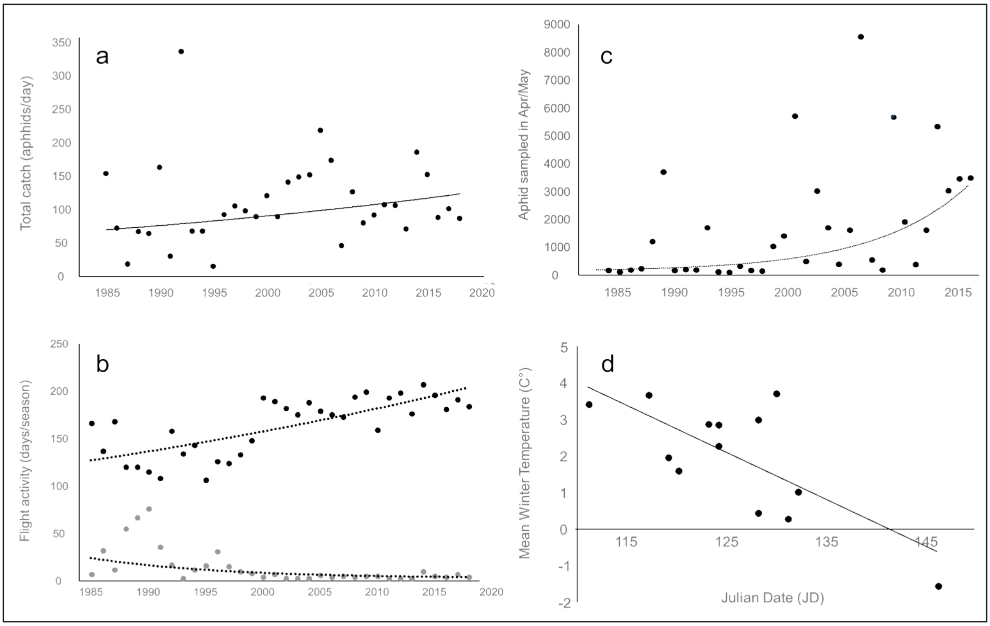

Fig. 2: a. Total amount of aphids per day sampled by the suction trap (ST) between 1985 and 2018. **b.** Period of days with sampled aphids during the vegetation period (black dots; April until December) or continuous period of days without aphid catches in summer (grey dots) **c.** Total aphids sampled in springtime (April / May) **d.** Relationship between mean late winter temperatures (January / February) and time of first record of aphids in ST (1990-2002).

Discussion

The monitoring data indicate that aphids changed phenology. As we started working within the viewing and data processing environment, several aphid species demonstrated earlier first flight records and longer flight periods in fall season and thus almost continuously flying aphids during the vegetation period more recently. Analyses of first flight trends in suction trap data were published and appear to be a good proxy for measuring the effect of winter temperatures on a population (Bell & al. 2015). An anholocyclic overwintering of the aphids in mid Germany is only possible within mild winters. Aphids respond particularly strong to environmentral changes (Harrington & al. 2007), and thus winter temperatures and first aphid records show a significant correlation before 2002. A very early flight activity in the spring of the two most essential vectors of the *Barley yellow dwarf virus* (BYDV), *R. padi* and *S. avenae*, has been observed following the exceptional mild winters of the years 1989 and 1990. However, the exceptional warm and dry summer of 2018 decreased flight activity and thus suggests markedly lower aphid densities during drought periods or at a temperature that exceeds a given threshold value.

First results on insect biomass up to now only available for two years hint to a loss of flying invertebrates during the past two decades for an agricultural dominated region in mid Germany. Insect declines have been reported from across the globe (Sánchez-Bayo & Wyckhuys 2019) and the results demonstrate the value and need for a successful monitoring programme for insects in agricultural landscapes.

Agricultural intensification has led to a widespread decline in farmland biodiversity measured across many different taxa and there is now much evidence to suggest that the decline in farmland biodiversity is related to changing farming practices (Benton & al. 2003).

In contrast, aphids generally increased in density and activity during 35 years of monitoring as evidenced by the ST daily sampling. This might also be a result of changes in agricultural practices such as crop rotation, the spatio-temporal cultivation of the most important crops and land-use intensification. Those changes may have positively contributed to the availability of resources for aphids in farmlands. Resource quality and resource heterogeneity both have the potential to enhance population densities and thus species diversity of herbivorous insects at the landscape scale, according to the ‚more individuals hypothesis‘ (Ziesche 2017). Moreover, climate change affects insect assemblages. For instance, species and taxa show differences in phenological responses and thus can desynchronise ecological interactions (Thackeray & al. 2016) between predator and prey thus supporting the development and spread of aphid populations.

Conclusions

Suction-traps are an old, but very reliable, technology. The suction-trap network began its work more than 50 years ago and its value lies in the fact that the technology has not changed over the years. Thus, it is providing data collected for a long time in a standardised manner over a large geographical area (Harrington & al. 2007).

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A report on the uses of the data (the Proceedings of an initial meeting and the presentations) can be found at http://composit.dimea.se/www/njf/site/redirect.asp?p=3898 (NJF Report Volume 9 Number 7 2013 (Seminar 468) ‘Suction traps in studying distribution and occurrence of insects and forecasting pests’). This report outlines the current status of suction-trapping throughout the world. We thank Kerstin Welzl and Evelyn Betke (all Julius-Kuehn Institute, Quedlinburg, Germany) for excellent technical assistance in the lab and for handling the daily sampling by ST.

References

Altieri, M. A. (1999): The ecological role of biodiversity in agroecosystems. – In: Invertebrate Biodiversity as Bioindicators of Sustainable Landscapes, Elsevier: 19-31.

Basky, Z. (1993): Identification Key for Alate Aphids caught in Yellow PanTraps. – Acta Phytopathol. Entomol. Hung. **28**: 71-121.

Beckmann, M., Gerstner, K., Akin-Fajiye, M., Ceaușu, S., Kambach, S., Kinlock, N.L., Phillips, H.R.P., Verhagen, W., Gurevitch, J., Klotz, S., Newbold, T., Verburg, P.H., Winter, M. & Seppelt, R. (2019): Conventional land-use intensification reduces species richness and increases production: A global meta-analysis. – Global Change Biology **25**: 1941-1956.

Bell, J. R., Alderson, L., Izera, D., Kruger, T., Parker, S., Pickup, J., Shortall, C. R., Taylor, M. S., Verrier, P. & Harrington, R. (2015): Long-term phenological trends, species accumulation rates, aphid traits and climate: five decades of change in migrating aphids. – Journal of Animal Ecology **84**(1): 21-34.

Benton, T.G., Vickery, J.A., & Wilson, J.D. (2003): Farmland biodiversity: is habitat heterogeneity the key? – Trends in Ecology & Evolution **18**(4): 182-188.

Gaston, K.J. (2000): Global patterns in biodiversity. – Nature **405**(6783): 220.

Harrington, R., Clark, S.J., Welham, S.J., Verrier, P.J., Denholm, C.H., Hulle, M., Maurice, H., Maurice, D., Rounsevell, M.D., Cocu, N. & European Union Examine Consortium. (2007): Environmental change and the phenology of European aphids. – Global Change Biology **13**(8): 1550-1564.

Losey, J.E. & Vaughan, M. (2006): The economic value of ecological services provided by insects. – Bioscience **56**(4): 311-323.

Macdonald, A.J., Poulton, P.R., Clark, I.M., Scott, T., Glendining, M.J., Perryman, S.A.M., Storkey, J., Bell, J.R., Shield, I.F., Mcmillan, V.E. & Hawkins, J.M.B. (2018): Rothamsted Long-term experiments: guide to the classical and other long-term experiments, datasets and sample archive. – Rothamsted Research, Harpenden. 57 pp.

Pereira, H.M., & Cooper, H.D. (2006): Towards the global monitoring of biodiversity change. – Trends in Ecology & Evolution **21**(3): 123-129.

Petchey, O.L., Beckerman, A.P., Riede, J.O., & Warren, P.H. (2008): Size, foraging, and food web structure. – Proceedings of the National Academy of Sciences **105**(11): 4191-4196.

Sánchez-Bayo, F. & Wyckhuys, K.A. (2019): Worldwide decline of the entomofauna: A review of its drivers. – Biological Conservation **232**: 8-27.

Schliephake, E. & Karl, E. (1995): Beobachtung des Blattlausfluges mittels Saugfalle. – Mitteilungen Dtsch. Ges. f. Allg. Angew. Entomol. 10.

Thackeray, S.J., Henrys, P.A., Hemming, D., Bell J.R., Botham, M.S., Burthe, S., Helaouet, P., Johns, D.G., Jones, I.D., Leech, D.I., Mackay, E.B., Massimino, D., Atkinson, S., Bacon, Ph.J., Brereton, T.M., Carvalho L., Clutton-Brock, T.H., Duck, C., Edwards, M., Elliott, J.M., Hall, S.J.G., Harrington, R., Pearce-Higgins, J.W., Høye, T.T., Kruuk, L.E.B., Pemberton, J.M., Sparks, T.H., Thompson, P. M., White I., Winfield, I.J. & Wanless, S. (2016): Phenological sensitivity to climate across taxa and trophic levels. – Nature **535**(7611): 241.

Taylor, L.R. & Robert, Y. (1984): A Handbook for aphid identification. – Manuel d'identification des pucerons, 2nd ed.: Rothamsted Experimental Station, Harpenden, Hertfordshire, 171 pp.

Ziesche, T.M. (2017): Tree growth indicates resource quality for foliage-feeding insects: Pattern and structure of herbivore diversity in response to productivity. – Ecological Indicators **83**: 249-259.