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POLICY BRIEF

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Recommendations for effective insect conservation in nature protected areas based on a transdisciplinary project in Germany

Sebastian Köthe[1*], Nikita Bakanov[2], Carsten A. Brühl[2], Lisa Eichler[3], Thomas Fickel[4,5], Birgit Gemeinholzer[6], Thomas Hörren[7], Aleksandra Jurewicz[4], Alexandra Lux[4,5], Gotthard Meinel[3], Roland Mühlethaler[1], Livia Schäffler[8], Christoph Scherber[8,9], Florian D. Schneider[4,5], Martin Sorg[7], Stephanie J. Swenson[6], Wiltrud Terlau[10], Angela Turck[10] and Gerlind U. C. Lehmann[1,11]

Abstract

The decline of insect abundance and richness has been documented for decades and has received increased attention in recent years. In 2017, a study by Hallmann and colleagues on insect biomasses in German nature protected areas received a great deal of attention and provided the impetus for the creation of the project Diversity of Insects in Nature protected Areas (DINA). The aim of DINA was to investigate possible causes for the decline of insects in nature protected areas throughout Germany and to develop strategies for managing the problem.

A major issue for the protection of insects is the lack of insect-specific regulations for nature protected areas and the lack of a risk assessment and verification of the measures applied. Most nature protected areas border on or enclose agricultural land and are structured in a mosaic, resulting in an abundance of small and narrow areas. This leads to fragmentation or even loss of endangered habitats and thus threaten biodiversity. In addition, the impact of agricultural practices, especially pesticides and fertilisers, leads to the degradation of biodiversity at the boundaries of nature protected areas, reducing their effective size. All affected stakeholders need to be involved in solving these threats by working on joint solutions. Furthermore, agriculture in and around nature protected areas must act to promote biodiversity and utilise and develop methods that reverse the current trend. This also requires subsidies from the state to ensure economic sustainability and promote biodiversity-promoting practices.

Keywords Insect decline, Monitoring, Pesticides, Societal dialogues, Conservation practice

*Correspondence:
Sebastian Köthe
sebastian.koethe@nabu.de
[1] NABU (The Nature And Biodiversity Conservation Union), Charitéstrasse 3, 10117 Berlin, Germany
[2] iES Landau, Institute for Environmental Sciences, University of Kaiserslautern-Landau, Fortstrasse 7, 76829 Landau, Germany
[3] Leibniz Institute of Ecological Urban and Regional Development (IOER), Weberplatz 1, 01217 Dresden, Germany
[4] Institute for Social-Ecological Research (ISOE), Hamburger Allee 45, 60486 Frankfurt Am Main, Germany
[5] Senckenberg Biodiversity and Climate Research Centre, Senckenberganlage 32, 60325 Frankfurt Am Main, Germany
[6] University Kassel, Heinrich-Plett-Strasse 40, 34132 Kassel, Germany
[7] Entomological Society Krefeld (EVK), Magdeburger Straße 38-40, 47800 Krefeld, Germany
[8] Leibniz Institute for the Analysis of Biodiversity Change, Museum Koenig Bonn, Adenauerallee 127, 53113 Bonn, Germany
[9] Institute of Evolutionary Biology and Ecology, University of Bonn, 53113 Bonn, Germany
[10] International Centre for Sustainable Development (IZNE), Hochschule Bonn-Rhein-Sieg University of Applied Sciences, Grantham-Allee 20, 53757 Sankt Augustin, Germany
[11] Evolutionary Ecology, Humboldt University Berlin, Unter den Linden 6, 10099 Berlin, Germany

Introduction

In recent decades, declines in insect richness and abundance have been observed worldwide [42, 50, 51, 64]. Insects are an extremely diverse group but knowledge of their diversity and impact on ecosystem function is still limited [14]. However, it is known that ecological services by insects such as pollination, decomposition, food supply, and biological pest control are essential to ecosystems [40]. The diversity and abundance of insects have declined in a wide range of habitats and even in nature protected areas (NPA—one of the strictest German categories: "Naturschutzgebiet" and category IV according to IUCN) [13, 36, 42, 53, 64]. A multitude of drivers are associated with insect declines, climate change related factors such as droughts, fire, storm intensity, global warming, and interaction disruption or human related effects based on agricultural intensification, deforestation, insecticides, nitrification, pollution, introduced species, and urbanization [50, 65]. In Germany, a study reported the loss of more than 75% of the flying insect biomass in NPA over the course of 27 years [35]. This study triggered extensive media coverage and a renewed focus on insects in society and in environmental policy. In the course of this widespread attention, cautionary voices were also raised, stating that not all insects are affected by this decline, some species have been able to thrive due to various influencing factors such as climate change or habitat transformation but also natural fluctuations in population sizes can lead to different outcomes along a timeline [5, 16, 19, 20]. However, due to a lack of long-term data on a broad geographical scale, these trends are usually difficult to determine for entire insect populations. Primary data, collected according to standardised methods, are necessary to accurately assess the situation and to detect and counteract threats [13, 15, 18, 55].

The DINA project was initiated to detect causes of insect decline as well as to develop measures to mitigate the decline of flying insects in NPA in Germany (Diversity of Insects in Nature protected Areas, [45]). Previous studies provide support for the assumption that agricultural practices are related to the decline in flying insect biomass [13, 53]. Therefore, only NPA with neighbouring or integrated agricultural areas were included in the experimental design to determine if agricultural impact could be verified. All sites consisted of grassland-dominated habitat types to ensure comparability and avoid biases while representing a wide range of German natural regions [45]. After a thorough assessment of the terrain, followed by consultations with the responsible nature conservation authorities and local farmers, 21 sites were selected, which are also Natura 2000 sites and designated as special areas of conservation (SAC, habitat management areas protected under Council Directive 92/43/EEC of 21 May 1992) [45].

The aim of this study is to summarise the collected interdisciplinary results of DINA, including data on insect diversity, plant richness, pesticide residues, spatial data, and societal input, to identify potential risks for insects and to formulate recommendations to improve conditions for insects in NPA with direct contact to arable land.

Results of the DINA project

Insect biomass, an indication of insect richness, remains at low levels

Malaise traps identical to the study of Hallmann et al. [35] were used to collect insects in this study. A total of five traps were set up per area along a transect, with the first 25 m inside arable land, the second on the border between the studied fields and the NPA, and the other three at a distance of 25 m from each other reaching into the NPA [45]. This approach allows a detailed analysis of covarying factors, such as the condition of vegetation, exposure to pesticides or spatial changes along the edge-interior gradient. Due to the comparability in methodology, previous data [35–37] can be related and compared. Further, DINA also provides a comprehensive assessment of the situation throughout Germany and small-scale evaluations of the impact of agricultural practices on insect diversity in NPA.

DINA used three main methods to assess insect diversity: (i) wet insect biomass, (ii) insect metabarcoding to produce qualitative species lists, and (iii) species identification by experts [44, [49] preprint). The study by Hallmann et al. [35] had already introduced insect wet biomass as a proxy for insect presence. Since then, insect wet biomass has also been used in a range of other studies such as the Long Term Ecological Research (LTER-D) [66]. The insect biomass was weighed wet as an approximation to fresh biomass and to ensure appropriate conservation of the samples for later species identification as described in the study by Hallmann et al. [35]. In DINA, the same standardised Malaise trap protocol was applied as in the original study. Malaise traps are one of the most commonly used and very efficient passive insect traps for monitoring flight-active insect diversity, which includes more than 90% of the more than 33 000 insect species native to Germany [45, 57, 58]. However, for forest habitats other insect traps may be more suitable [12]. Comparing biomasses from DINA for the years 2020 and 2021 with the long-term data by Hallmann et al. [35] spanning 27 years from 1989 to 2016, the insect biomass remains at a low-level all-over Germany (Fig. 1, [49] preprint). Statistical analysis identified agricultural land use in a radius of

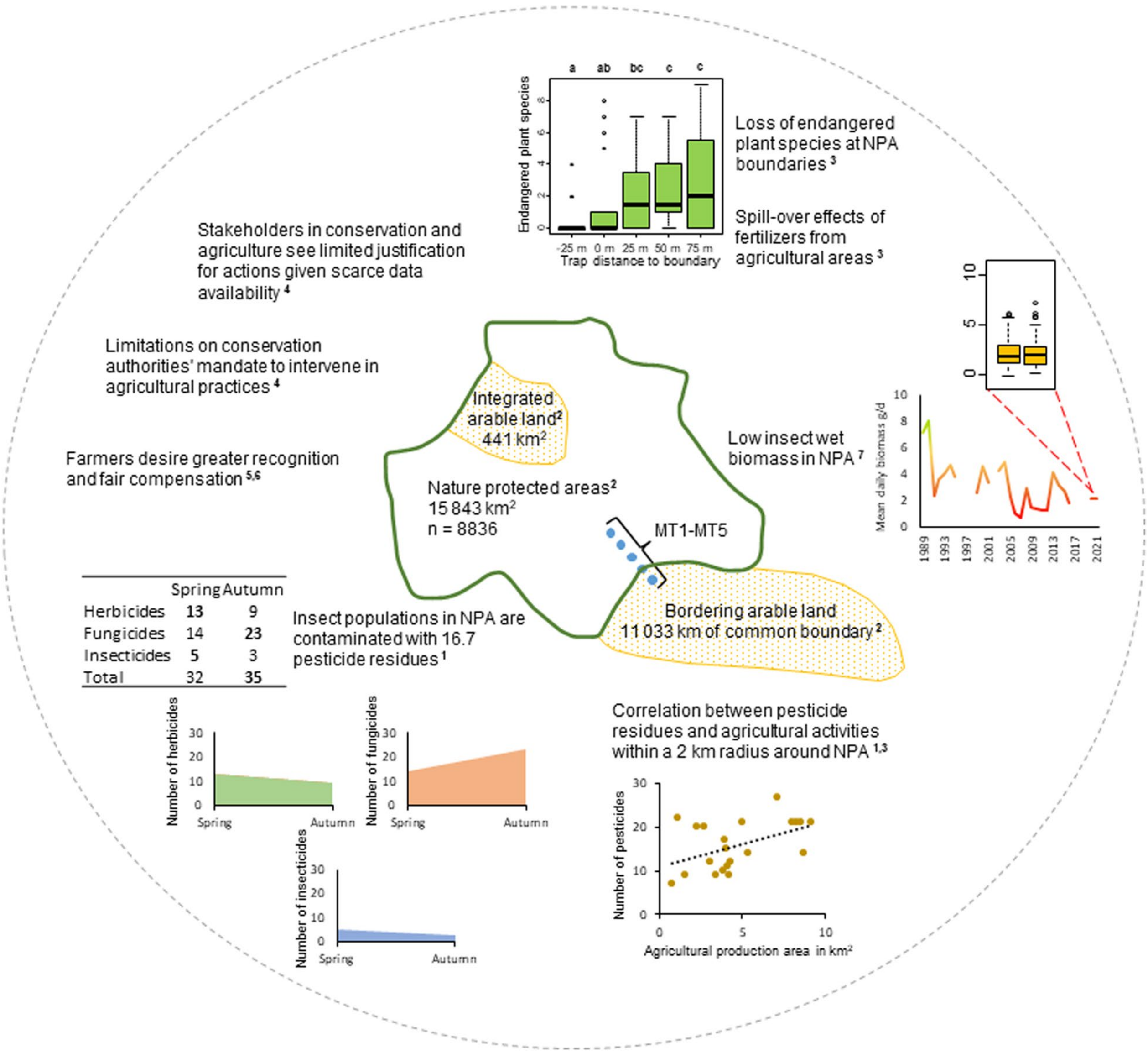

Fig. 1 Key results of the DINA project; *MT1-5* Malaise traps. (The numbers refer to the following references: (1) [10]; (2) [22]; (3) [43]; (4) [44]; (5) [62]; (6) [61], (7) [49] preprint)

two km around NPA, as a predictive variable explaining the number of common current-use pesticide residues found in the ethanol of the Malaise traps [10]. Based on the correlational evidence the decline in insect species richness is linked to this amount of pesticides found in the ethanol [44]. Using metabarcoding also allowed us to arrive at species lists at an unprecedented taxonomic resolution. To guarantee the best possible results for insect identification in DINA, several methodological advances like fractionization of mass bulk samples and size sorting of insects were applied [23, 38, 67]. Our results also show a reasonable correlation between wet biomass and insect species richness (r = 0.72, [44]). With the complete data coverage for insect biomass we concentrate currently on these data. However, despite the strong interdependence both insect biomass and insect species richness should be evaluated in parallel for the future.

Nature protected areas share long contact lines with arable land

In Germany, 15 843 km² are designated as NPA and 45 035 km² as SAC of the European Natura 2000 network (status 2018, Fig. 1). These areas serve to restore or maintain a favourable condition of natural habitats and species (Federal Nature Conservation Act of Germany § 23). Usually, in Germany these areas are surrounded by and/or have integrated arable land. Spatial analyses show that an area of 441 km^2 of NPA (2.78% of the total area of NPA of Germany) is used as arable land (Fig. 1, [22]). Within the SAC, which may overlap with the NPA, there are 1 283 km^2 arable land (2.85% of the total area of SAC of Germany). Despite these very small proportions, influences from agricultural practices are noticeable, suggesting that not only farming inside is decisive, but also in the surrounding. Every fourth NPA in Germany incorporates arable farming and only an area of 70 km^2 of the NPA is cultivated organically, which is a small fraction of 16 percent of the total arable land inside NPA [21]. Agroecological measures in the surroundings of protected areas should be designed to reduce contact lines with agricultural fields, thereby leveraging the conservation value of the measure while at the same time limiting impacts on crop yields in the region. The common contact boundary of NPA and agricultural land sum up to 11 033 km, respectively 21 102 km for SAC (Fig. 1). This is mainly due to the fact that NPA in Germany are distributed in a mosaic-like manner and there are rather many small and narrow areas, which increases the contact area.

Loss of endangered plant species at the edges of nature protected areas

In the contact zone between NPA and arable land, negative spill-over effects of fertilizers and herbicides were observed, leading to a significant loss of endangered plant species up to 25 m within the NPA, while the overall plant diversity was stable within the NPA [43]. The number of endangered plant species was low at the border of NPA and increased with distance from fertilized and herbicide-treated arable land (Fig. 1, [44]). The cause for these changes in plant communities is the continuous supply of nitrogen from arable land in the vicinity, as nitrogen is easily transported by wind and water [33]. Losses of endangered species in NPA increase the likelihood of these species disappearing completely, small-scale or narrowly shaped areas in particular may fail to fulfill their protective function. A reliable proxy for these changes was the Ellenberg indicator value for nutrients [24], which indicated a loss of nitrogen-avoiding species, many of them endangered, with increasing distance to the centre of NPA. The locations analysed in DINA showed distance influences of up to 75 m, the maximum distance measurable in the transects [43].

Insects in nature protected areas are exposed to a mixture of pesticides

There is growing concern about the impact of pesticides from agricultural practices on insects. Many flying insects are highly mobile and may encounter a variety of pesticides on arable land surrounding their habitats. Even sublethal doses have negative effects on insects [2, 17, 60]. Pesticide residues were determined from soil, vegetation, and for the first time also from ethanol samples of the Malaise traps [1, 10, 44]. A nalyses of ethanol from the Malaise traps revealed an average number of 16.7 current-use pesticide residues across the 21 study areas (Fig. 1, [10]). This figure provides an indication of the number of pesticide residues that the captured insects in the traps were exposed to in the surrounding area of the NPA [11]. The number of pesticides detected in the ethanol at the NPA correlated positively with the extend of the agricultural area in the surrounding within a two km radius [10, 44]. It has been demonstrated that insect richness within NPA decreases based on the number of pesticides in their environment, but no risk analysis or risk management has been carried out to date [10, 44].

Stakeholder participation as a transformative pathway towards feasible solutions

To interrelate scientific data, political regulations, and societal requirements, two social science approaches were pursued in DINA. Local farmers, conservation authorities, NGOs, land owners, and residents, as well as state level authorities for agriculture and conservation participated in a series of in-depth dialogues at three of the 21 locations to identify local problem perceptions, empower the local network and to scope feasible management measures for insect conservation [44]. In addition, qualitative surveys (among farmers at the 21 study sites) and quantitative surveys with 97 farmers operating within NPA from all over Germany were conducted [61, 62]. Current legislation or funding schemes are perceived as an insufficient framework for reliable and effective actions in insect conservation, which hampers the implementation of measures. Although a general threat to insect diversity is being acknowledged, many of the stakeholders in conservation and agriculture see only limited justification for actions given scarce data availability for the local situation (Fig. 1, [44]). However, we found that dialogues between all relevant stakeholders in a local NPA context may facilitate the exchange of knowledge, create understanding for obstacles and interests, and open pathways for locally specific solutions that are mutually accepted.

A participatory national workshop was initiated to engage key-stakeholders from various relevant sectors, including farmers, nature conservation organisations, administrative authorities, policymakers, local communities, and other relevant actors. The workshop participants expressed unanimously a willingness for enhanced cooperation across sectors. Farmers in particular voiced their desire for greater recognition, fair compensation, and increased flexibility at the local level (Fig. 1, [61, 62]). Two key implementation ideas were emphasized during a plenary discussion. Firstly, the concept of "enhanced education for sustainable development" (learning program by the UNESCO) was given priority, with a focus on key concepts such as curriculum reform and integration of practical experiences. Secondly, the idea of "increased regional autonomy" was highlighted, encompassing measures aimed at strengthening regional networking and local interaction.

Considerable shortcomings in the management of nature protected areas

The planning documents available for the NPA at the 21 monitoring sites of the DINA project were analysed for measures and objectives to reduce negative impacts of agricultural practice on the protected area (for a full list of the planning documents see Additional file 1: Table S1). For a detailed description of methods see Additional file 2.

The spatial analysis identified that 18 of the 21 protected areas investigated in DINA contain arable land (Additional file 3; [21]. For 15 sites, the respective management documents include some type of regulation of the practice on arable land inside the protected area (Additional file 1: Table S2). The use of pesticides was forbidden in 12 locations and in 11 sites, fertilisers were generally prohibited.

None of the management documents made organic farming or similarly extensive practices (i.e. allowing only application of non-synthetic pesticides or fertilizer) a prerequisite for arable land inside the protected area (Additional file 3). Eight plans name specific measures to convert parts of arable land into grassland.

Arable habitats with low agricultural intensity can be habitat for a large number of rare plant [48] and insect species and are recognised as endangered habitat according to the European Red List of habitats [27]. Developing or maintaining this habitat type has been included in the conservation targets of seven protected areas (Additional file 3). However, only four of the respective management plans specify measures to implement and preserve these habitat types.

Nine management plans prescribed measures with the objective to reduce harmful impacts from the surrounding area (Additional file 3): all of these nine areas included the development of structures or buffer zones to reduce contaminations from the outside, and six introduced measures targeting at agricultural practice outside the NPA.

The last issued dates of the management plans for the 21 sites investigated varied greatly. The oldest management plan dated from 1994, the most recent from 2020 (the first management plan for this area), and one site has no management plan (Additional file 1: Table S2, according to the status for the year 2020). Regularly updating management plans and clear documentation of measures taken would be necessary to assess the success of the measures established and to make adjustments, if they fail to achieve their objective, or to identify successful measures for specific objectives.

Recommendations for effective insect conservation in nature protected areas

By combining the obtained results from the 21 DINA sites and the expertise within the DINA framework, four key areas were identified as potential risks to insects in German NPA (Fig. 2). First, insects are largely absent as targets in conservation legislation and need to be included in specific objectives and management measures of planning documents for NPA. Second, the fragmentation of NPA leads to extended contact areas with the surrounding landscape, which reduces the effectiveness of conservation efforts due to adverse spill-over effects. Thirdly, agricultural activities such as the application of pesticides and fertilizers on adjacent arable land have negative impacts and harm the biodiversity within NPA. And lastly, the lack of communication and cooperation between relevant stakeholders prevents optimal protection of insect diversity in designated areas.

Based on these four key areas, recommendations for improving insect conservation in NPA were formulated.

Stakeholder interviews and dialogues as well as an analysis of planning documents of NPA have shown that insects are currently lacking prioritisation for authorities and conservation practitioners which is also not clearly formulated in the German Federal Nature Conservation Act [44]. Conservation management plans need to be improved to include specific measures to promote insects. It is strongly advised to prioritize the protection of biodiversity in NPA by supporting those types of land use that support natural biodiversity and occurrence of species of nature conservation focus over types of land use responsible for deteriorating those targets and include insects explicitly as protection targets in the general conservation legislation at state and national level.

The fragmentation and loss of natural habitats drives the decline of insects and constitutes a second key area identified by DINA. Border lines between NPA and arable

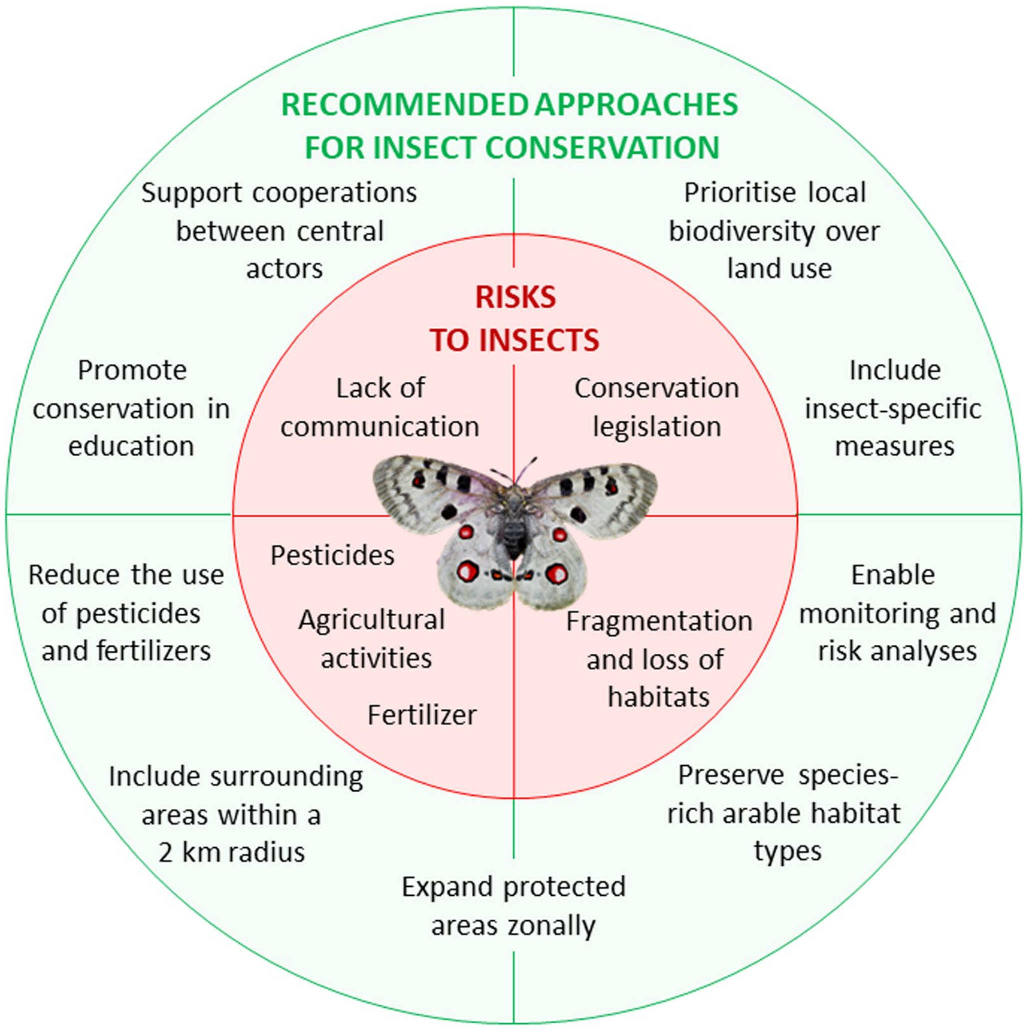

Fig. 2 Risks to insects in nature protected areas (red circle) and recommended approaches for improved insect conservation (green circle) based on the results of the DINA project

land need to be taken into account in order to reduce unintended influences [22]. There is the objective of the Global Biodiversity Framework of designating 30% of all land areas as effective conservation area [39]. It would be beneficial to expand existing NPA or at least create an infrastructure of interconnected areas to best support the conservation function and population dynamics. Insects should be included in the management plans of newly designated nature conservation areas from the outset and existing plans should also be supplemented accordingly. At EU level, there is an approach to improve the situation for insects through the implementation of the revised Pollinators Initiative [26]. It goes hand in hand with the draft of the Nature Restoration Law [29] which contains a legally binding target for EU Member States to reverse the decline in pollinator populations by 2030 and maintain rising trends thereafter. The Nature Restoration Law requires EU countries to develop national restoration plans, which should enclose restoration measures, designated areas and a timetable for the realisation of these objectives and should cover the period up to 2050. Proposed measures to improve pollinator conservation include so-called 'buzz lines' to connect habitats and standardised monitoring of pollinators and highly hazardous substances such as pesticides and fertilisers across the EU. Although supporting pollinators is beneficial for many insects, the measures currently only consider wild bees, butterflies and hoverflies, but other pollinating insects such as beetles should also be incorporated.

In particular, former species-rich arable habitat types are now under severe threat of destruction [32, 48]. This is mainly caused by the extensive and preventive application of pesticides and fertilisers, the increased use of high-yielding but species-poor crop rotations, the extensive abandonment of fallow land and the expansion of cultivated land at the expense of uncultivated residual habitats in the agricultural landscape [59]. Arable habitats which are still extensively managed and provide habitat for arable species are not systematically protected or promoted in current conservation management, although they can harbour high biodiversity [25]. Close cooperation between agriculture and nature conservation is essential to improve the conservation of these biotope types [59].

To preserve habitats and biodiversity in NPA, frequent monitoring of insect populations in threatened habitats using standardised methods and risk assessment are necessary and should be implemented by the responsible authorities. Routine monitoring will validate the effectiveness of protective measures implemented and provide an opportunity for short-term corrections or indicate negative population trends in due time serving as an early warning system. To facilitate the feasibility of this process, monitoring and risk assessment should be prioritized in areas of high-risk habitats and should be extended over time. At present, research in NPA is heavily regulated and requires a great deal of bureaucracy which hinders the current possibility of monitoring and risk assessment. These processes need to be simplified and supported by nature conservation authorities across Germany.

A third key area that contributes to insect decline are agricultural activities in and next to NPA, especially the use of chemical pesticides that can lead to impairments or may have lethal effects on insects [8, 31, 63] as well as fertilizers that induce a change in vegetation composition and thereby of natural habitats [43]. Due to the frequent pesticide exposure of flying insects within a radius of 2 km, the development of extended zones with effective reduction of pesticide usage in agricultural practices are essential for the maintenance of NPA and their functions [10]. This is in line with the EU Sustainable Use Directive. The proposal sets legally binding targets at EU level to reduce the use and risk of chemical pesticides and the use of the more hazardous pesticides by 50% by 2030, in accordance with the EU Farm to Fork Strategy [28]. In addition to the sustainable use of pesticides, integrated pest management and alternative approaches or techniques, such as non-chemical alternatives to pesticides, are also to be promoted.

The results of the DINA project show negative influences from adjacent agricultural land, which are buffered inside of the NPA [43]. These buffer effects need to be shifted outside of the NPA to ensure the effectiveness of the protected area. Including such a large area in risk management would cover 30% of German arable land (or up to 51% when regarding SAC). Developing extended regulations and focussing conservation measures on this area requires participation of stakeholders to develop feasible compromises for all involved. Germany has also set itself the goal of converting 30% of German arable land from conventional to organic farming by 2030 [6, 10]. However, studies show that organic farming only contributes to a limited extent to the protection of biodiversity and that environmentally friendly measures in agriculture can also be successful in other ways, for example through diversifying cropland or reducing field size [4, 7, 34, 41, 56]. Some of these measures can cushion the slump in yields while at the same time promote biodiversity [47, 54].

The aim should be to avoid negative effects of fertilizers and synthetic pesticides, and instead to promote environmental-friendly land use such as organic cultivation or other agri-environmental measures. Promising are the diversification of crop plants to increase biodiversity by crop rotation, simultaneous sewing of various crops on the same field, or intercropping [3, 9, 30, 46]. These methods are also beneficial for soil quality and could thereby reduce the need for tillage that can also lower biodiversity [52]. NPA should be interconnected to form functional connectivity between populations. This can be achieved via suitable habitat structures such as flower strips, hedge rows or uncultivated fallow land, but it should be borne in mind that insects should not be attracted to extensively utilised fields where they have increased contact with agrochemical substances. Therefore, the positioning of such measures is extremely important and further research should be conducted to establish which measure works best in which scenario. Financial subsidies are essential for such measures, which in many cases have not yet been clarified and should be done for demonstrably beneficial measures. In general, it must be clarified how yield losses that occur in connection with environmentally friendly measures can be subsidised to be attractive to farmers. But also, social aspects such as food waste and excessive consumption or political aspects such as the need for a country or region to cover the majority of its food requirements itself to reduce imports of products from other countries and thus not shift the problem to these countries should be taken into account.

The final key area that provides a potential explanation for the decline of insects is the lack of communication between societal actors, albeit they have the capacity to understand the need for biodiversity protection inside NPA and to act. Numerous actions that can initiate or enhance insect conservation have implications for a wide range of stakeholders, necessitating their active participation and engagement. Cooperative approaches provide the optimal opportunity to initiate collaborative solutions and are widely sought after [44, 61, 62]. However, this requires a large amount of time and effort for communication and moderation, which is often considered unfeasible. Therefore, suitable advisory, funding, and capacity building must be made available to implement joint dialogue processes for the development of mutually agreed solutions. Such stakeholder engagement at the local level can enable the extended conservation management and risk analyses in and around NPA, as described above. Finally, environmental education measures and agroecological training for practitioners must be implemented and supported in order to improve knowledge of stakeholders and of the (local) population regarding effective insect conservation. To facilitate a broad societal support, biodiversity and its conservation should be established as a component of Education for Sustainable Development [62].

The decline of insect diversity must be addressed quickly and effectively to prevent further unrecoverable ecological and economic losses. At present, most NPA fail to fulfill their purpose of preserving biodiversity. DINA provides confirmation and expands previous findings of shortcomings in current biodiversity conservation in and around nature protected areas. The recommended measures and actions can help to improve the protection of insects in corresponding NPA in order to create and maintain safe refuges for insects.

Abbreviations

DINA	Diversity of Insects in Nature protected Areas
NPA	Nature protected areas
SAC	Special areas of conservation

Supplementary Information

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Additional file 1: Table S1. List of the planning documents included for the 21 nature protected areas. **Table S2** Results of the planning document inspection for 21 nature conservation areas under consideration. The catalogue of questions is presented in Additional file 3.

Additional file 2. Methods for analysing planning documents.

Additional file 3. Catalogue of questions (upper table, superordinate questions in bold) to identify current measures and objectives in the relevant planning documents of the 21 nature protected areas considered in DINA regarding the reduction of arable impacts and the subsequent results of the document analysis (lower graph, superordinate questions in bold).

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Author contributions

Substantial contributions to the design of the DINA project were made by CAB, BG, AL, GM, LS, MS, WT and GUCL, while the recommendations were outlined by all co-authors. The present study was conceptualised by SK, AL, RM, FDS and GUCL. Data collection was done by LE, AJ, FDS and AT; SK, LE, AJ and FDS analysed the data; SK, AJ, RM, FDS and GUCL interpreted the data. The draft was written by SK, RM, FDS and GUCL, while all co-authors thoroughly revised the manuscript.

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Availability of data and materials

All data can be made available on request.

Declarations

Ethics approval and consent to participate

All participants consented prior to their participation.

Consent for publication

All co-authors consented to the final version of the manuscript.

Competing interests

The authors declare no competing interests.

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