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The German insect monitoring scheme: Establishment of a nationwide long-term recording of arthropods

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ABSTRACT

A standardised monitoring is indispensable to identify trends of insect populations. However, until recently, a systematic monitoring of insects in Germany was missing. Therefore, the German federal ministry for the environment funded the conceptualisation of an insect monitoring scheme.

Here, we inform about the general concept and structure of the German insect monitoring scheme (GIMS) and the steps taken and still to be taken for the implementation of the scheme. A first step was the development of the objectives, general concept und structure of the GIMS in close collaboration with the nature conservation authorities at the national and federal state levels, as the latter are responsible for the implementation of nature conservation-related monitoring schemes. The GIMS is structured into two sections: section 1 ‘Monitoring of common insects’ and section 2 ‘Monitoring of rare insects’. Both sections contain modules that focus on selected aspects of insect diversity. In section 1, insect communities of the wider countryside will be monitored. Section 2 focuses on insect communities in rare habitats and species of high conservation value (e.g. threatened species). The next step was to develop standardised sampling methods for the modules in collaboration with experts and the nature conservation authorities. Wherever appropriate, synergies with other monitoring schemes were created, e.g. for combined analyses with environmental variables.

Parallel to the development of the concept, several federal states have already implemented selected modules of the GIMS. Furthermore, the module ‘Grasshoppers in grasslands’ was tested during a pilot phase. By using the data from the pilot phase and the High Nature Value Farmland Monitoring scheme the relationship between high nature value farmland and grasshopper diversity was evaluated. This indicated the great potential of using synergies among monitoring schemes for joint data analyses and showed that it is worth exploring such approaches in greater depth.

Introduction

The decline of insects has reached an alarming extent (Cardoso et al., 2020) and recent studies highlighting the loss of insect diversity and biomass during the last decades have raised public awareness for this issue (e.g. Hallmann et al., 2017). However, insect decline is not a novel phenomenon. First observations on the decrease of insect diversity date back to the 19th century (Samways et al., 2020; Fartmann et al., 2021). The extensive decrease in insect diversity that has occurred since then was especially caused by land-use change, which provoked the loss and degradation of habitats (e.g. Cardoso et al., 2020; Fartmann et al., 2021; Fumy et al., 2023; Zimmermann et al., 2023). Besides land-use change, the ongoing decline of insects is exacerbated by several other factors such as climate change (e.g. Weiss et al., 2024).

Insects are of vital importance for overall ecosystem functioning (e.g. as pollinators and important parts in food webs; IPBES, 2019). In addition to that, there are many other reasons for protecting the insect fauna (e.g. the responsibility to maintain healthy ecosystems for future

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generations). To detect future changes in insect populations at a sufficiently early stage and to enhance the implementation of suitable countermeasures, a broad monitoring scheme that regularly documents the status of the insect fauna is an appropriate tool and urgently needed.

In Europe, monitoring of biodiversity has a long tradition in Great Britain, where a national biodiversity monitoring centre was already established in the 1960s (Biological Records Centre; Roy et al., 2014). Here, long-term insect monitoring data are available for selected species groups such as butterflies and moths (Conrad et al., 2007; Fox et al., 2011). Also in other European countries, monitoring activities have been carried out for a long time with respect to specific insect groups such as moths (e.g. Valtonen et al., 2017; Maes et al., 2023), carabid beetles (e.g. Homburg et al., 2019) and freshwater insects (Haase et al., 2023). However, many of these activities are restricted to a low number of study sites and/or specific regions. Nationwide monitoring schemes that include a high number of study sites distributed widely across a country are still rare in Continental Europe. One well-known exception are butterflies which represent the most intensively monitored species group in Europe. In numerous European countries, nationwide butterfly monitoring schemes were implemented during the last decades (van Swaay et al., 2008).

Also in Germany, extensive and nationwide recording of insect populations was limited, until recently. Examples are the voluntary butterfly monitoring scheme that was established at the beginning of this century (Kühn et al., 2014), the monitoring of flying insects with malaise traps as part of the Long-Term-Ecological Research (LTER) network that was initiated in 2019 (Welti et al., 2022) and the monitoring of selected insect species in the framework of the EU Habitats Directive. However, a comprehensive scheme that includes a broad spectrum of insect groups and is implemented on a large number of sampling sites representative for Germany was missing so far. Therefore, and in consequence of a resolution of the federal states' environment ministers, two consecutive research and development projects were supported by the federal agency for nature conservation with funds from the federal ministry for the environment to develop a nationwide insect monitoring scheme for obtaining long-term data on the insect fauna in Germany. To date, the objectives of the German insect monitoring scheme (GIMS) and its conceptional design with a modular structure as well as standardised monitoring methods for numerous modules have been defined and several federal states have started with the implementation of selected modules.

The aim of this paper is to introduce the GIMS (e.g. as a reference of the methodology for scientific activities and publications and a guide for the development of other monitoring schemes). For this purpose, we outline the following aspects:

- workflow of the conceptualisation and implementation of the scheme,
- conceptual design and general study design of the scheme, including the exemplary description of the sampling methods of selected modules,
- conformity of the GIMS with European insect monitoring schemes,
- selected results of a test run of a selected monitoring module,
- and conclusions including a critical view on the conceptual design of the scheme.

Workflow of the conceptualisation and implementation of the German insect monitoring scheme

In Germany, the federal agency for nature conservation mainly has a coordinative function with respect to monitoring programmes, whereas the federal states are responsible for their implementation. Therefore, and in consequence of a resolution of the federal states' environment ministers, the federal agency for nature conservation took on the responsibility for designing the German insect monitoring scheme (GIMS). To promote a standardised and nationwide realisation of the scheme, a close cooperation between the national and federal states' nature conservation authorities has been of great importance from the development of the scheme onwards. For the design of the GIMS, which has a modular structure (see section 'Conceptual design of the scheme'), two consecutive research and development projects were supported by the federal agency for nature conservation with funds from the German federal ministry for the environment. The aims of the two projects were:

- the design of the conceptual structure of the scheme,
- the development of the study design including the definition of standardised monitoring methods,
- evaluation and optimisation of design and methods on the basis of a nationwide test run of a selected monitoring module and further practical experiences (e.g. by the federal states).

A first step of the design of the monitoring scheme was the definition of the objectives of the scheme in collaboration with the national and federal state nature conservation authorities. Based on the objectives, the conceptual structure and general study design of the scheme were developed. This work has led to a modular approach with various specific monitoring modules.

During the two projects, standardised monitoring methods were developed for nine monitoring modules in close cooperation between the national and federal states' nature conservation authorities (Fig. 1). One of these modules ('grasshoppers in grasslands') was tested in the second project ('pilot phase') to evaluate the developed study design and methods and optimise them, if necessary (see section 'Test run'). Additionally, numerous federal states have started with the implementation of selected modules, which are carried out by professionals on behalf of the federal state nature conservation authorities (see e.g. Kőrösi et al., 2022; Löffler et al., 2023).

The goal is the timely and nationwide implementation of at least all modules of the minimum viable scheme (which includes the modules of highest priority, see section 'Conceptual design of the German insect monitoring scheme') to enable nationwide data analyses and, in the long run, the calculation of trends of the insect fauna. To achieve this goal, the German Federal Ministry for the Environment will co-finance the implementation of selected modules by the federal states. Recently, a third research and development project, supported by the federal agency for nature conservation with funds from the German federal ministry for the environment, has started, which aims, for example, at completing further conceptual work of the GIMS in close cooperation among the nature conservation authorities.

Conceptual design of the German insect monitoring scheme

Objectives

The main aim of the GIMS is to derive long-term trends of the insect fauna by the standardised and periodic documentation of insects in Germany on sampling sites that are representative for the respective habitat types in Germany. Thereby, the GIMS contributes to the obligation of the federal nature conservation law to monitor nature and landscape for the detection and evaluation of their state and development including the reasons of their changes. Besides this, the national and federal state nature conservation authorities agreed upon more specific objectives of the GIMS. Amongst others, these include the following objectives (BfN, 2023):

- the illustration of the effects of landscape, land-use and climate change and, if applicable, of further drivers on the insect fauna,
- the evaluation of the large-scale efficacy of programmes and other instruments implemented for the conservation of insects,
- the improvement of knowledge on the causes of insect decline.

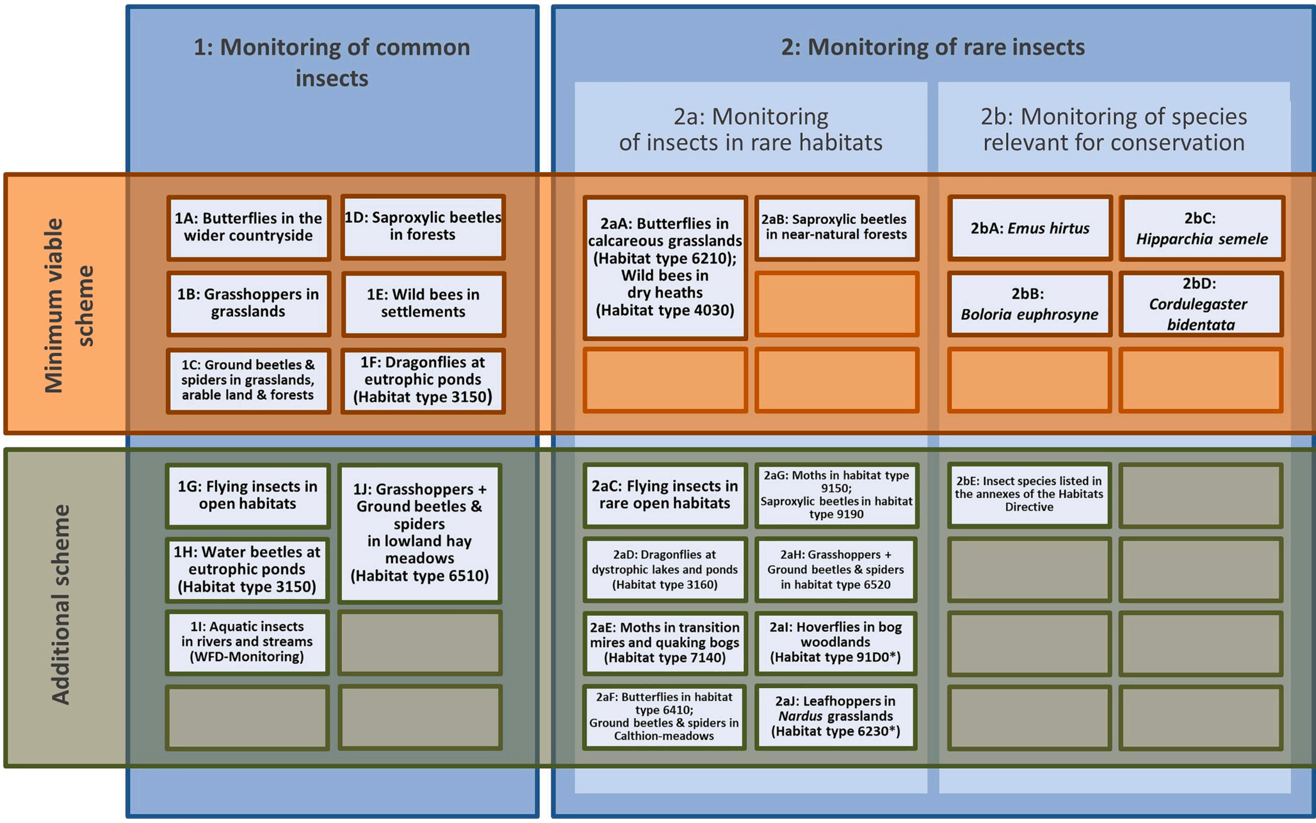

Fig. 1. Current status of the structure and modules of the German insect monitoring scheme. WFD = EU Water Framework Directive. Meaning of the abbreviations of species group names: 'butterflies': butterflies + burnet moths, 'grasshoppers': Orthoptera + Mantodea, 'dragonflies': Odonata (dragonflies + damselflies), 'spiders': ground-dwelling spiders. Detailed sampling methods were elaborated for the following modules: 1A—G, 2aA, 2aB. The other modules are being checked and, where applicable, methods are being defined in the follow-up project to the German insect monitoring scheme (2023—2026).

- To meet the targets of the GIMS, the following requirements with respect to the study design were considered during the conceptualisation of the scheme:
- a broad coverage of insect species groups, guilds and habitats,
- the inclusion of sampling sites that are representative for Germany,
- the definition of standardised methods with respect to the sampling of insects and environmental variables,
- feasibility of the scheme.

The species-rich class of insects comprises a great variety of species with different biological traits and ecological demands. Therefore, a broad spectrum of insect groups representing the different biological and ecological characteristics of the insect fauna should be included in the GIMS to allow comprehensive conclusions on the status and development of insects in Germany. Additionally, a great variety of (frequent and rare) habitats should be considered in the GIMS to represent the insect fauna as extensively as possible.

Moreover, a set of sampling sites that represents Germany with respect to the country's geographical and land-use characteristics is essential for the GIMS to allow representative statements on the insect fauna. In addition to that, a high number of sampling sites should be used in the GIMS to enable manifold statistical analyses of the data.

To obtain temporally and spatially comparable and reliable data, standardised monitoring methods are essential. With respect to insect sampling, quantitative sampling methods, which gather information on the abundance of species, should be prioritised over qualitative methods, which solely document the presence or absence of a species within a sampling site. With the help of abundance data, population changes can be revealed much earlier and more precisely compared to qualitative data (Conrad et al., 2007; van Dyck et al., 2009). Also, quantitative sampling enables more diverse analyses, e.g. by the calculation of diversity indices that include abundance data and, therefore, provide information on the frequency distribution of species within the sampling sites (Magurran, 2004).

The need for standardisation not only holds true for the insect data, but also for environmental data which should be included in the GIMS to analyse the effects of landscape, land-use and climate change on the insect fauna. For this purpose, the study design should enable the analysis of the effects of environmental variables on the insect fauna on different spatial scales (habitat and landscape level). Habitat quality, which is defined, amongst other factors, by land-use intensity, vegetation structure and/or the availability of specific food plants, is crucial for determining insect species assemblages at the habitat level (e.g. Krämer et al., 2012). Besides habitat quality, landscape-structure characteristics such as habitat diversity and connectivity are key factors for determining insect diversity and abundance (Brückmann et al, 2010; Poniatowski et al., 2016). Therefore, selected parameters on different spatial scales should be considered in the GIMS and specified for the different modules. If essential parameters are not available from external data sources (e.g. from habitat mapping data of the specific sites), they should be recorded on site as part of the GIMS according to a defined standardised method.

Moreover, the feasibility of the GIMS should be taken into account to promote the implementation of the GIMS by the federal states. Therefore, monitoring approaches (regarding species groups, sampling design and methods) that require low financial and personnel resources, or for which the appropriate resources are available, should be prioritised for the GIMS.

Structure

To cover a broad spectrum of insect species groups, guilds and habitats, the GIMS has a modular structure and comprises several modules, which highlight selected aspects of insect diversity and habitats, respectively. The modules complement each other and are assigned to one of two sections.

Section 1 ('Monitoring of common insects') focuses on the insect fauna of the wider countryside in Germany, which mainly consists of intensively used and unprotected habitats. In contrast, section 2 is dedicated to rather rare or semi-frequent insects with a clustered distribution and is divided into section 2a, which addresses insect communities of rare habitats (e.g. dry grassland), and section 2b, which focuses on species that are particularly relevant for conservation and monitored by species-specific surveys (Fig. 1). Examples of such species are rare or endangered species or species of national responsibility (i.e. species for which Germany has a particular conservation responsibility from a global perspective). Each section comprises numerous modules which were either assigned to the minimum viable or additional scheme. The minimum viable scheme comprises those modules that have highest priority and are meant to be implemented by all federal states. Modules of the additional scheme are optional for all states and supplement the minimum viable scheme with additional species groups, guilds and habitats.

In section 1 'Monitoring of common insects', the most widespread land-use types are represented by specific modules (Fig. 1). These include agricultural land (arable land, grassland), forests and settlements, which cover more than 90% of the terrestrial surface in Germany (Statistisches Bundesamt, 2022). In addition, other common habitats (e.g. waterbodies) were included in section 1 to expand the range of habitats and achieve a comprehensive coverage of the overall landscape in Germany. The aim was to select a diverse set of species groups of different ecological guilds for the module set to allow extensive conclusions on the insect fauna of the wider countryside. For the selection of species groups, manifold technical, methodical and practical criteria were developed, which had to be fulfilled by the selected species groups, either obligatorily (e.g. availability of a standardised sampling method) or optionally (e.g. availability of experts). After the selection of species groups, the specific modules were developed by assigning at least one species group to the selected land-use and habitat types.

Ecological guilds/taxa included in the minimum viable scheme are butterfly and burnet moths (hereinafter referred to as 'butterflies'), grasshoppers (Orthoptera and Mantodea), ground beetles (Carabidae) and ground-dwelling spiders (hereinafter referred to as 'spiders'), wild bees, dragonflies and damselflies (hereinafter referred to as 'dragonflies') and saproxylic beetles. Examples of modules of the minimum viable scheme of section 1 are the monitoring of grasshoppers in grasslands or wild bees in settlements (Fig. 1). In addition to habitat-specific surveys, butterflies will be monitored along transects crossing the wider countryside to draw conclusions on the effects of landscape changes on an insect group. In modules of the additional scheme of section 1, further insect groups, guilds and habitats are included (e.g. water beetles, flying insects across all species groups and lowland hay meadows).

Analogous to section 1, the module set of section 2a comprises a wide variety of species groups, which will be monitored in selected rare habitats. The minimum viable scheme of section 2a 'Monitoring of insects in rare habitats' addresses open habitats and forests (Fig. 1). In module 2aA, the focus is on calcareous grasslands and dry heaths (habitat types 6210 and 4030 of the EU Habitats Directive) as two examples of rare open habitats. Calcareous grasslands and dry heaths have a complementary distribution in Germany. Thus, they were included in one module so that the overall set of sampling sites of the module is approximately evenly distributed across the German federal states. Butterflies were selected for monitoring in calcareous grasslands. This allows comparisons between the current status and development of butterfly communities in the wider countryside (module 1A, Fig. 1) and those in calcareous grasslands as one of the most important habitats for insects in general and butterflies in particular (van Swaay, 2002; Löffler et al., 2020). To increase the variety of sampled species groups in section 2a, especially within the minimum viable scheme, wild bees will be monitored in dry heaths. In addition, the minimum viable scheme of section 2a includes the module 2aB, which focuses on saproxylic beetles in near-natural forests. This type of forest is characterised by a natural development and near-natural tree species composition due to a lack of silvicultural intervention and is therefore rare in today's German landscapes. This module can be compared with module 1D, which comprises the survey of saproxylic beetles in forests of the wider countryside, where most forests are managed.

Modules of the additional scheme in section 2a consider further species groups, such as hoverflies, leafhoppers, moths and groups that are also part of section 1 for enabling comparisons between the insect fauna of common and rare (often protected) habitats (Fig. 1). Besides that, these modules cover a wide variety of rare habitats (e.g. dystrophic lakes and ponds or transition mires and quaking bogs).

Complementary to the sections 1 and 2a, section 2b comprises species-specific surveys of rare or endangered species or species of national responsibility. From the viewpoint of the federal states in Germany, special interest lies on species that are highly susceptible to specific threats such as the desiccation of habitats caused by climate change. So far, four species were suggested for section 2b (Fig. 1). One example is the Sombre Goldenring (*Cordulegaster bidentata*), an endangered dragonfly species dependent on springs and upper reaches of streams (Mey et al., 2015) and threatened by climate change (Behrens et al., 2009; Ott et al., 2021). In addition to that, a module that focuses on the insect species of the annexes of the EU Habitats Directive was included in section 2b. The objective of this module are species-specific analyses by using data derived from the monitoring of the EU Habitat Directive.

General study design

Sampling sites

To enable representative statements on the insect fauna in Germany, the sampling of sites that represent the country with respect to its geographical and land-use characteristics is essential. In Germany, a network of nationwide representative sampling sites is established. These sampling sites represent the wider countryside and are used for monitoring programmes with focus on nature conservation. Amongst them are monitoring programmes with respect to birds (Sudfeldt et al., 2012) and 'High Nature Value (HNV) Farmland' (Benzler et al., 2015), which have been carried out on these sites for more than ten years. Additionally, a habitat monitoring scheme (Ecosystem Monitoring), which aims at detecting landscape changes by the regular mapping of habitats, is currently under development and will be implemented on these sampling sites (Ackermann et al., 2023). The basic programme of this network includes a high number of 1 km^2 sampling sites ($n = 1{,}000$; Fig. 2). To generate statistically reliable, nationwide statements for the wider countryside, the sampling sites were randomly selected by using a double-stratified procedure (stratification criteria: land-use types and ecoregions based on e.g. geological and climatic characteristics) (Schröder & Schmidt, 2001; Sudfeldt et al., 2012). Each site was assigned to one of six broad land-use types (according to the land-use type in the centre of the site): arable land, grassland, forest, special crops (e.g. orchards, vineyards), further habitats (e.g. bogs/mires, heaths) and settlement (Fig. 2). Due to the representative distribution and high number of sampling sites, the network of the nationwide representative sampling sites is applicable to different modules of the GIMS. Numerous modules of section 1 that address the wider countryside in general or frequent land-use types in particular are implemented on these sites (such as transect counts of butterflies in module 1A,

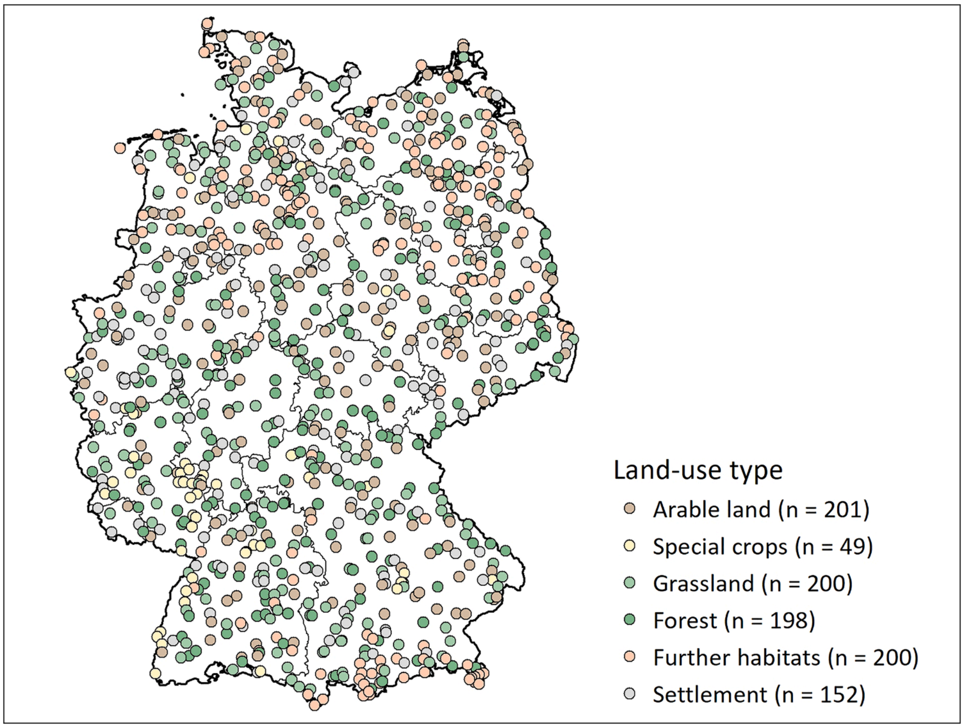

Fig. 2. Distribution of the nationwide representative sampling sites (basic programme with n = 1,000) in Germany.

grasshoppers in grasslands [module 1B] or saproxylic beetles in forests [module 1D]). Here, insect monitoring activities are carried out either on the landscape level to reveal effects of landscape changes on insects (e.g. transect counts of butterflies in module 1A) or include surveys of insects on single patches of a specific land-use type to document their changes in the respective land-use type (e.g. grasshoppers in grasslands [module 1B]). The joint use of sampling sites enables combined analyses of the data derived from the different programmes, for example by using data from the Ecosystem and HNV Farmland Monitoring as explanatory variables for the analysis of trends of insect diversity and abundance. These two monitoring programmes provide valuable data on habitat diversity and the availability of HNV farmland within the 1 km^2 sampling sites, which are useful, for example, for the analysis of the effects of habitat diversity and land-use intensity at landscape level on insect diversity and abundance. Additionally, data from the two monitoring programmes can be used for analysis on the habitat (patch) level, e.g. with respect to the question how changes in the environmental condition and land-use intensity of the analysed patches affect insect diversity and abundance (see section 'Test run').

However, since the nationwide representative sampling sites focus on the wider countryside, they are not representative of more specific habitats such as the habitats of the EU Habitats Directive. Therefore, the habitat-specific monitoring sites of the monitoring under the Habitats Directive in Germany will be used for modules that focus on these habitat types (e.g. module 1F 'Dragonflies at eutrophic ponds [Habitat type 3150]'). One advantage of the joint use of these monitoring sites is that the insect data generated by the GIMS can be used to improve the knowledge of the conservation status of the analysed habitats. The monitoring sites of the Habitats Directive are distributed representatively across Germany according to the geographic distribution of the respective habitat type and cover a high number of sampling sites (usually n = 63 per continental and atlantic biogeographic region, respectively).

For habitats that are not represented by nationwide established sampling sites, specific criteria for the selection of sampling sites are fundamental for gaining standardised data. With the help of these criteria, sampling site selection must be carried out by the federal states prior to the implementation of the respective module. For example, in the case of module 2aB 'Saproxylic beetles in near-natural forests', only forests where forestal intervention is banned and near-natural forest stands are present should be selected for monitoring by the federal states. The nationwide network of near-natural forests (Meyer et al. 2007) represents an important basis for the selection of sampling sites for module 2aB. For this module, a minimum of 100 sampling sites should be distributed across Germany.

Sampling methods of selected modules

To promote a nationwide and standardised implementation of the insect monitoring scheme by the federal states, the methods for sampling both insects and environmental parameters were designed in close cooperation between the national and federal state nature conservation authorities. To specify the most practical and robust sampling methods, several experts of the selected species groups and methods were involved. In general, sampling methods that generate quantitative data were prioritised over qualitative methods (see section 'Conceptual design of the German insect monitoring scheme').

The module 1A 'Butterflies in the wider countryside' focuses on butterflies at the landscape level to exemplarily draw conclusions on the effects of landscape change on an insect group, since butterflies are known to respond rapidly to environmental changes at the landscape and habitat level (Thomas, 2005; Löffler et al., 2023). Monitoring of butterflies (module 1A) is carried out in all nationwide representative sampling sites (basic programme with n = 1,000) by using 1.5 km long transects that are mainly placed along road verges and paths to ensure full and long-term access to the transects (Fig. 3). Moreover, road verges and field margins represent relevant habitats for butterflies within intensively used landscapes (Sybertz et al., 2017). Due to differences in the phenology of the species, transect walks should be carried out five times per year from May until August (Lang et al., 2016).

Complementary, in module 1B 'Grasshoppers in grasslands' (module 1B), grasshoppers are monitored in grassland patches in the nationwide representative sampling sites that are assigned to the land-use type 'grassland' (basic programme with n = 200). Most grasshopper species

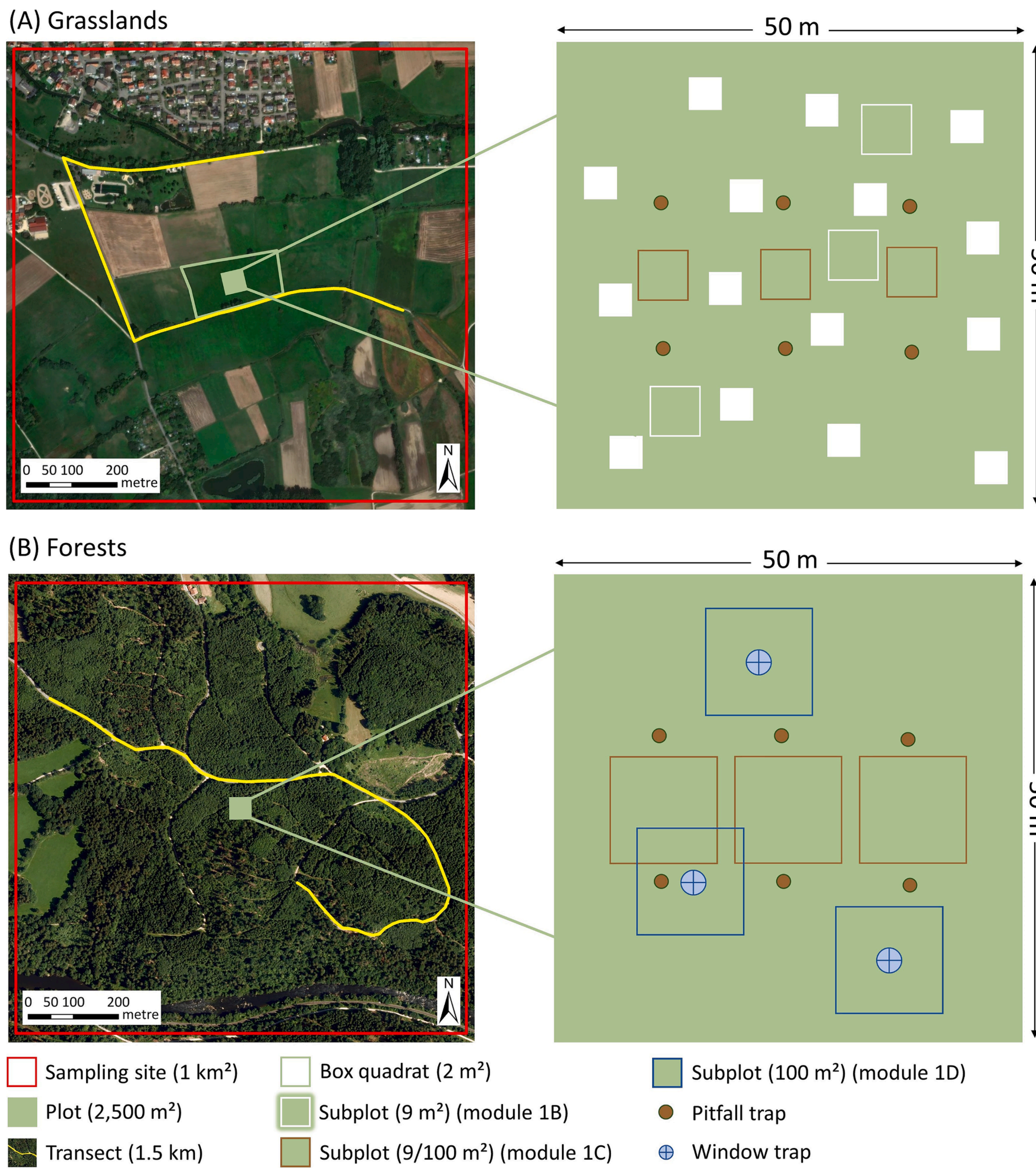

Fig. 3. Study design of modules 1A, B, C and D. Butterflies are sampled within the nationwide representative sampling sites along 1.5 km long transects. In those sampling sites assigned to grasslands (A), grasshoppers are sampled within a 2,500 m^2 plot in the central grassland patch by placing a box quadrat 15 times on the ground. In the same plot, ground beetles and ground-dwelling spiders are sampled by using six pitfall traps placed along two transects. Vegetation structure characteristics are sampled in three subplots in both modules. In the forest sites (B), a 2,500 m^2 plot is placed in the centre of the site. Here, ground beetles and ground-dwelling spiders are sampled using the same approach as in the grassland (and arable land) sites. Saproxylic beetles are surveyed with three window traps within the plot. Vegetation structure characteristics are documented within three subplots placed between the pitfall transects (module 1C) and around the window traps (1D), respectively.

have specific requirements in terms of microclimate and vegetation structure (Wünsch et al., 2012; van Eupen et al., 2024). Therefore, this species group is a valuable indicator for structural changes in grassland ecosystems (Fartmann et al., 2012). Moreover, in grasslands, grasshopper diversity is correlated with the species richness of other species groups (Sauberer et al, 2004). For grasshopper monitoring, a 50 × 50 m plot is arranged in the grassland patch located in the centre of a sampling site (Fig. 3). In this plot, grasshopper sampling is carried out by using a box quadrat with an area of 2 m^2 to obtain accurate data on the abundance of grasshoppers (Fartmann et al., 2024). The box quadrat is placed 15 times on the ground at randomly selected locations within the plot. The sex and species of all grasshopper individuals within the box quadrat are identified. To record the presence of species that occur in low density, an additional qualitative search is carried out within the plot for a duration of ten minutes. Monitoring of grasshoppers takes place once a year during the phenology peak of most species in July/August. To enable conclusions on the effects of habitat change on grasshoppers, selected habitat-related environmental parameters are ascertained. For example, vegetation structure characteristics which are essential drivers of grasshopper community composition (Fartmann et al., 2022; Schwarz & Fartmann, 2022) are sampled within three 3 × 3 m subplots placed randomly within the plot (Fig. 3). Furthermore, landscape characteristics of the 1 km^2 sampling sites such as habitat diversity derived from the ecosystem monitoring will be included in the analysis to detect the effects of landscape changes on grasshopper diversity and abundance.

Module 1C 'Ground beetles and spiders in grasslands, arable land & forests' comprises the monitoring of ground beetles and spiders in grassland, arable land and forest patches in the nationwide representative sampling sites that are assigned to these land-use types (basic programme with n = 200 [grassland], 201 [arable land] and 198 [forest]). Due to the high number of species with different ecological demands, ground beetle and spider assemblages react sensitively to environmental changes and are therefore suitable indicators for them (e.g. Schirmel & Buchholz, 2011; Weiss et al., 2024). Furthermore, ground beetles are a broad indicator of invertebrate abundance and order diversity (Cameron & Leather 2012). Sampling of ground beetles and spiders takes place by using pitfall traps within a 50 × 50 m plot which is placed in the central (grassland, arable land or forest) patch of a sampling site (Jahnová et al., 2016; Fartmann et al., 2022). Within each plot, six pitfall traps are placed with a minimum distance of 10 m to each other along two transects (Fig. 3). Sampling is carried out for six weeks in spring and six weeks in autumn. In addition to the identification of the sampled individuals, total biomass is weighed separately for ground beetles and spiders as well as for rove beetles and further arthropods according to the method of Ssymank et al. (2018). Additionally, habitat parameters are recorded within three 3 × 3 m (arable land, grassland) or 10 × 10 m (forest) subplots located between the pitfall transects. Like in module 1B, landscape characteristics of the 1 km^2 sampling sites such as habitat diversity will be derived from the ecosystem monitoring and included in data analysis to reveal the effects of landscape changes on ground beetle and spider assemblages.

Module 1 D 'Saproxylic beetles in forests' contains the monitoring of saproxylic beetles in forest patches in the nationwide representative sampling sites that are assigned to forest (basic programme with n = 198). Saproxylic beetles are a sensitive indicator for the intensity of forestry (Stenbacka et al., 2010; Lachat et al., 2012). Typically, window traps are used for standardised sampling of saproxylic beetles (Knuff et al., 2019; Seibold et al., 2019). In the GIMS, three window traps are placed in the 50 × 50 m plot in the centre of a sampling site, where ground beetles and spiders are also monitored (module 1C). Sampling of saproxylic beetles is carried out for 16 continuous weeks between March and August. In addition to the identification of beetle species (for economic reasons, the time-consuming identification of species of Staphylinidae and Scolytinae is optional), total biomass of all sampled beetles, further insects and additional arthropods is determined by weighing (Ssymank et al., 2018). In each site, habitat characteristics are documented on two spatial scales: on the one hand, in three 100 m^2 subplots around the window traps to characterise tree composition and vegetation structure of the close vicinity of the traps and, on the other hand, in the entire 2,500 m^2 plot where a diverse set of habitat structure characteristics is sampled (e.g. dead wood quantity and quality). Furthermore, landscape variables derived from available data sets will be considered in the analysis. To enable comparisons between forests of the wider countryside and near-natural forests, the same sampling methods will be applied in module 2aB for the monitoring of saproxylic beetles in near-natural forests.

In addition, several other sampling methods are employed in the GIMS. For example, in module 1E 'Wild bees in settlements', wild bees are monitored along five 50-m-long transects placed randomly in areas of the 1 km^2 sampling sites (assigned to the land-use type 'settlement') that are favourable for bees (e.g. flower-rich parks) to gain abundance data. Additionally, further species are sampled by controlling all potential bee resources (flowers, nesting structures) in the sites during a standardised time. In the calcareous grassland and heath monitoring sites of the EU Habitats Directive, butterflies and wild bees are also sampled with the help of transect counts (module 2aA).

Module 1G, 'flying insects in open habitats' (e.g. Diptera, Hymenoptera), includes the use of Malaise traps in open habitats to sample flying insects (Hallmann et al., 2017; Ssymank et al., 2018) on randomly selected nationwide representative sampling sites that are assigned to arable land, grassland, special crops (e.g. orchards, vineyards) and further habitats (e.g. bogs/mires, heaths). The morphological identification of wild bees, the determination of biomass as well as the identification of sampled species by metabarcoding are options for analysing the samples.

Conformity with European insect monitoring schemes

In order to generate comparable data that can be used for pan-European analyses, standards established in other European countries for the monitoring of insects were integrated whenever possible in the GIMS. Module 1A 'Butterflies in the wider countryside' is consistent with the standards of the European Butterfly Monitoring Scheme (van Swaay et al., 2018). More precisely, the monitoring methods of this module follow the standards of the voluntary butterfly monitoring scheme in Germany (Kühn et al., 2014), which uses 500 to 1,500 m long transects (subdivided into 50 m sections) for recording butterflies and is comparable to the European monitoring standards established in other European countries (e.g. Netherlands, UK; van Swaay et al., 2018; Middlebrook et al., 2022). Due to the use of five 50-m-long transects placed randomly across the selected habitat patches, habitat-specific monitoring of butterflies (e.g. in calcareous grasslands, module 2aA) also generates data comparable to the standards of the voluntary butterfly monitoring scheme in Germany.

Furthermore, in module 1F 'Dragonflies at eutrophic ponds (Habitat type 3150)', adult dragonflies will be sampled along two transects with a length of 25 m located at the banks of eutrophic ponds. This is comparable to the Dutch dragonfly monitoring scheme, in which dragonflies are sampled along transects with a minimum length of 25 m (van Swaay et al., 2018). In the GIMS, exuviae of dragonflies will be additionally collected in standardised plots placed along the pond banks to obtain more detailed information on autochthonous species. In addition to that, the EU Pollinator Monitoring Scheme, which is currently under development and aims at monitoring pollinating insects (e.g. butterflies, wild bees and moths) (Potts et al., 2021), will be integrated in the GIMS after its finalisation.

Test run of module 1B 'grasshoppers in grasslands'

The federal agency for nature conservation implemented a nationwide test run of the module 1B 'Grasshoppers in grasslands' in the scope of the pilot phase of the GIMS in two consecutive years (2020–2021) according to the methods described above. The purpose was to test the suitability of the sampling methods under real-world conditions and to evaluate the study design from a spatio-temporal viewpoint to derive recommendations for the optimisation of the module.

All in all, the *sampling methods* developed for monitoring grasshoppers in grasslands proved to be practicable in the test run with the exception of minor details, e.g. with respect to the sampling of environmental variables which was optimised. The mean *duration* for sampling of grasshoppers, including the recording of environmental variables, was 2.25 h per site. In addition, organisational work was required for the implementation of the test run. Prior to grasshopper sampling, the landowners of the grassland patches where the monitoring was to be carried out (central patch within a sampling site, see below) were informed and asked for permission, either by us or, in most cases, by the federal state or local authorities. The support by the authorities was very helpful as it was time-consuming to successfully contact the landowners. A minimum time of two hours per site should be calculated for this purpose. With respect to the costs, this module deviates strongly from the other modules of the GIMS, which are much more laborious. For example, the volume of work of module 1C ‘Ground beetles and spiders in grasslands, arable land & forests’ was estimated to be more than 100 h per sampling site, based on the experiences of the federal states that have already implemented this module. Because of the low effort, module 1B should be implemented annually on all sampling sites by the federal states. In contrast, the other, more laborious and costly modules will be carried out every four years. Regarding *sampling sites*, the concept proved to be feasible in principle, although difficulties became apparent. The biennial test of the module was carried out according to the nationwide standard (Fig. 3), i.e. all 200 sites of the nationwide representative sampling sites that were assigned to ‘grassland’ were included in the test (Fig. 2). According to the standard, grasshopper sampling was to be carried out in the grassland patch in the centre of a sampling site. However, during the test run, it was not always possible or reasonable to sample the central grassland patch (e.g. because of access denial by the landowners or the conversion of the site to arable land). Consequently, only 174 sites were surveyed. To guarantee that the full set of sampling sites is monitored in the future, a standardised procedure was developed for the selection of alternative grassland patches in the sampling sites. This procedure comes into effect if the central patch is converted into another land-use type or cannot be monitored (e.g. due to access denial by the landowner).

Concerning the gained data, a total of 35 grasshopper species was recorded on the 174 sampling sites in 2020 (Fig. 4). Based on the German red list (Poniatowski et al., 2024), seven of them are considered threatened. The frequency of the four most common species ranged from 81 to 64%. Threatened species rarely occurred (frequency: always < 10%). On average (± SE) 5.0 ± 0.2 species were detected per sampling site, and the mean density (± SE) was 17.0 ± 1.4 adult individuals per 10 m^2. As described above, the other monitoring schemes established on the nationwide representative sampling sites provide valuable data that can be used as explanatory variables for the analysis of the insect data derived from these sites. As an example of a combined analysis, we used data of the High Nature Value (HNV) Farmland Monitoring scheme to analyse how grasshopper diversity is influenced by land-use intensity. HNV farmland is characterised by low land-use intensity and semi-natural vegetation and categorised into three quality classes (Benzler et al., 2015). Therefore, data of the HNV Farmland Monitoring scheme can be used as a proxy for land-use intensity on habitat (HNV quality class of the sampled patch) and landscape level (amount of HNV farmland within the 1 km^2 sampling site). Data generated by the pilot phase showed that grasshopper diversity peaked in grasslands of high and very high HNV farmland quality (Fig. 5). Even though this is not a novel finding, as it is well-known that biodiversity is favoured by

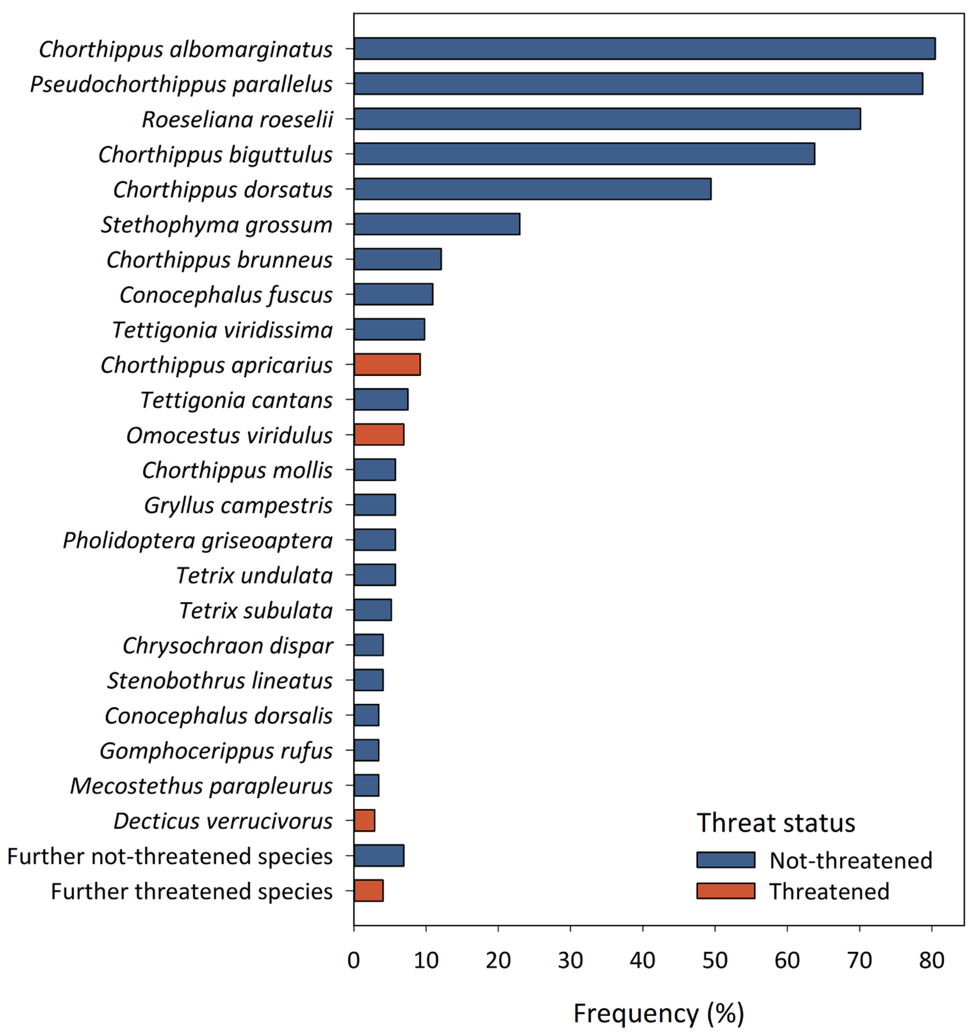

Fig. 4. Frequencies of grasshopper species in the sampled plots in 2020. Threat status: Poniatowski et al. (2024); threatened species include ‘near-threatened’ species. Species with a frequency < 2% were merged to the categories ‘further threatened species’ and ‘further not-threatened species’, respectively. Further threatened species: *Bicolorana bicolor, Pseudochorthippus montanus, Tetrix bipunctata* and *Stauroderus scalaris*; further not-threatened species: *Calliptamus italicus, Euthystira brachyptera, Leptophyes albovittata, Leptophyes punctatissima, Mantis religiosa, Oedipoda caerulescens, Phaneroptera falcata* and *Platycleis albopunctata*.

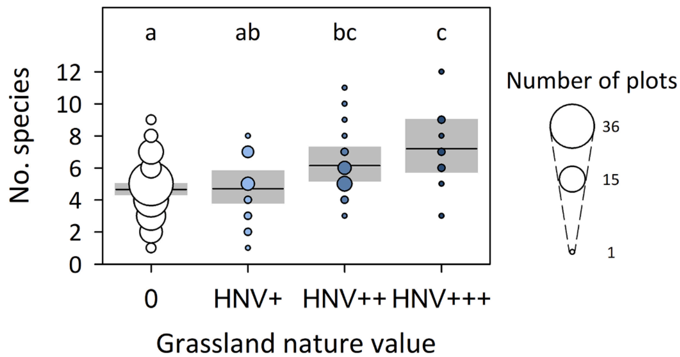

Fig. 5. Mean grasshopper species richness in grasslands of different categories of nature conservation value in 2020. The conservation value of the grasslands in which the plots were located was derived from the German High Nature Value (HNV) farmland monitoring scheme: 0 (n = 125) = no HNV farmland; HNV+ (n = 17) = moderate HNV farmland quality; HNV++ (n = 20) = high HNV farmland quality; HNV+++ (n = 10) = very high HNV farmland quality. Different letters indicate significant differences between categories ($P < 0.05$). The pairwise comparisons were performed by fitting a generalised linear model (Poisson; log link) and applying the function *glht()* (*multcomp* R package; Hothorn et al., 2023) to the model. The black horizontal bars denote the fitted values of each category, the grey bands the corresponding 95% confidence intervals.

low-intensive land use in grasslands (e.g. Gossner et al., 2016), this analysis is one of the first attempts that combines monitoring data of different nationwide monitoring schemes. The exemplary analysis of the data demonstrated that grasshoppers are suitable for reflecting environmental conditions in grasslands, although they are a species-poor group. Moreover, it underlines the great importance of promoting synergies among monitoring schemes for joint data analyses to reveal the drivers of insect population changes. However, besides HNV farmland type, detailed information on the measures that are carried out on the sampling sites, e.g. with respect to agricultural or silvicultural measures such as pesticide application or drainage, is desirable for the GIMS to gain more detailed knowledge of the effects of environmental changes on the trends of the monitored species groups and to support the fulfillment of the obligation to evaluate the state and development of nature and landscape including the reasons of their changes. Therefore, such data should be made available to the GIMS.

Conclusions on the conceptualisation of the scheme

The GIMS focuses on a wide range of different aspects of insect diversity to derive comprehensive knowledge on the status and development of the insect fauna in Germany. Besides a broad taxonomic coverage of the insect fauna, including a wide spectrum of different functional groups and feeding types such as pollinating species (e.g. bees, butterflies, hoverflies and moths), herbivorous species (e.g. many grasshoppers, leafhoppers), decomposers (e.g. saproxylic beetles) and predatory species (e.g. most ground beetles, dragonflies), the GIMS considers many different habitat types, including aquatic and terrestrial as well as rare and frequent habitats. However, despite the broad taxonomic range of the considered species groups, some functional groups are lacking in the GIMS – provided that they are not sampled as part of the non-specific catches of the Malaise or window traps. This holds true, for example, for copro- and necrophagous species such as scarab (Scarabaeidae) and carrion beetles (Silphidae), parasitic and endogeic species. Nonetheless, the GIMS achieved substantial improvement with respect to insect monitoring in Germany as, so far, monitoring activities have only included few species groups (mainly butterflies) and/or specific regions.

The design of a fully standardised insect monitoring scheme that focuses on such a wide variety of insect diversity is complex and time-consuming, especially when the methods are established in close cooperation between different authorities, like, in the case of the GIMS, the national and federal state nature conservation authorities. However, this strategy proved to be of great value as it supported the implementation of the nationwide standards by the federal states. In general, we, therefore, recommend this approach (close cooperation among experts and stakeholders involved in the implementation of the monitoring scheme) for the conceptualisation of large-scaled biodiversity monitoring schemes. Furthermore, if available and applicable, we highly recommend the usage of established monitoring sites to enable combined analyses of the data derived from the different programmes.

With respect to the GIMS, the sampling methods have already been designed in detail for the modules of the minimum viable scheme of sections 1 and 2a whereas this step is still pending for most modules of section 2b and the additional scheme. Therefore, a third research and development project (2023–2026) was recently funded by the German federal ministry for the environment not only to fill these gaps, but also to develop the concept further, e.g. by the integration of the EU Pollinator Monitoring Scheme in the GIMS. Additionally, standards for the analysis of the monitoring data regarding trend calculations, space-for-time approaches and combined analyses with data from other monitoring programs will be designed and applied e.g. to the grasshopper data. The current project also aims to create the basis for a mobile app for the digital documentation of the monitoring data to facilitate and promote the implementation of the scheme.

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CRediT authorship contribution statement

Merle Streitberger: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Gregor Stuhldreher:** Writing – review & editing, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Thomas Fartmann:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Werner Ackermann:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Hella Ludwig:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Sandro Pütz:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Wiebke Züghart:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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