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Chapter 21: Insect Conservation in Grasslands

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Abstract

Temperate, semi-natural grasslands are among the most species-rich ecosystems across the globe. However, due to land use intensification, abandonment, and afforestation, their extent has greatly decreased, and the remaining patches have become fragmented. Additionally, grassland remnants often suffer from habitat deterioration due to: i) inappropriate management; ii) eutrophication because of airborne nitrogen deposition; and iii) climate change. Habitat quality, size, and connectivity are considered the main drivers of patch occupancy of grassland insects in our fragmented landscapes. Additionally, global warming is rapidly proceeding and already seriously threatens grassland insects. It is assumed that habitat availability and global warming will determine the distribution of insects in temperate, semi-natural grasslands in the future. Conservation management should aim to: i) enhance the habitat quality of the remaining grassland patches; ii) enlarge their sizes; and iii) improve functional connectivity between grassland patches. When conducting such measures, focus should be on increasing heterogeneity at all spatial scales, due to its buffering effect against extreme weather events, such as drought periods. The stabilization of the water level or even the restoration of the natural water table are also invaluable measures for mitigating the effects of climate change. Low-intensity land use without fertilisation, or at least with low levels of fertilisation, is of vital importance for high habitat quality in temperate, semi-natural grasslands. In most cases, grazing with low stocking rates should be preferred over mowing. Low-intensity grazing systems are highly effective in shaping heterogeneous grasslands with species-rich insect assemblages. This is true for rough grazing by sheep (and goats in shrub-rich grasslands), summer grazing by cattle and year-round grazing by horses, cattle, or indigenous grazers such as Red deer (*Cervus elaphus*) or European bison (*Bison bonasus*).

Keywords: bare soil, functional connectivity, fragmented landscapes, grazing management, habitat quality, heterogeneity, metapopulation, phytodiversity.

Grasslands – definition, extent, and importance for insect conservation

Overall, grasslands cover 31%–43% of the earth's surface and occur on every continent (except Antarctica) (Gibson and Newman 2019). The range of estimates results from differences in grassland definitions by the different authorities. In the simplest case, grasslands are defined as a habitat dominated by grasses and an upper limit of tree cover in the overstorey (Squires et al. 2018). Among natural grasslands, three types can be differentiated: i) savannas are restricted to the frost-free tropics (they are covered by Chapter 20); ii) steppes occur in extra-tropical regions where conditions are too dry for woodland establishment; and iii) arctic-alpine grasslands are found in those regions that are too cold for woodlands. By contrast, secondary grasslands have evolved at the expense of natural shrublands and woodlands due to human land use. Today, they occupy substantial areas, in particular across Europe.

Despite the wide distribution of grasslands around the globe, by far the most studies on insect conservation in grasslands are from Europe, followed by North America, and address temperate, semi-natural grasslands (literature search: Web of Science, 10/06/2022, search terms 'grassland' AND 'insect conservation'). Of the 704 detected studies, 65% were conducted in Europe and 17% in North America. In total, 57% examined temperate, semi-natural European grasslands. Since measures for insect conservation have been most extensively investigated for such grasslands, focus is on these in this chapter. However, it is highly likely that the findings presented here also apply for natural grasslands and grasslands on other continents.

Temperate, semi-natural grasslands are among the most species-rich ecosystems across the globe (Bonari et al. 2017; Feurdean et al. 2018; Fartmann et al. 2021a). They hold the world record in fine-scale species richness of vascular plants and are hotspots of insect diversity. For example, for three fifths of the 436 native European butterfly species, dry calcareous grasslands and steppes are the main habitat (Van Swaay et al. 2006).

Habitat loss, fragmentation, and deterioration threaten insects in temperate, semi-natural grasslands

Throughout Europe, traditional land use has created and maintained temperate, semi-natural grasslands, with their outstanding biodiversity, for centuries (Bonari et al. 2017; Feurdean et al. 2018; Fartmann et al. 2021a). However, due to the transition from pre-industrial land use to modern-day agriculture, particularly after World War II, the extent of such grasslands has greatly decreased, and the remaining patches have become fragmented. Two contrasting, large-scale processes have been responsible for habitat loss and fragmentation of grasslands, namely: i) land use intensification on the one hand and ii) abandonment and afforestation on the other hand (Squires et al. 2018; Fartmann et al. 2021a). The former includes the conversion of nutrient-poor, semi-natural grasslands to improved grasslands or arable fields. Just recently the increasing cultivation of bioenergy crops, in particular maize, has accelerated the transformation of semi-natural grasslands to arable land (Fartmann et al. 2021a, b). Land use intensification has mainly occurred on productive soils in the lowlands (Fartmann et al. 2021a; Löffler et al. 2023). However, in recent times, grassland management has been intensified in low-mountain ranges as well (Fumy et al. 2021). By contrast, abandonment and afforestation have taken place on marginal land, which is particularly true for wet soils where drainage is difficult and for mountain areas exhibiting a varied relief (Fartmann et al. 2021a; Fumy et al. 2021).

Today, the remaining patches of semi-natural grasslands are embedded in a hostile matrix, which is mainly used for intensive agriculture (e.g., arable fields) (Poniatowski et al. 2018a; Fartmann et al. 2021a, b). Additionally, grassland remnants often suffer from habitat deterioration due to: i) inappropriate management (Poniatowski et al. 2018a; Fartmann et al. 2021a; Fumy et al. 2021); ii) eutrophication because of airborne nitrogen deposition (WallisDeVries and Bobbink 2017); and iii) climate change (IPBES 2019; Fartmann et al. 2021a).

Drivers of insect persistence in fragmented grasslands

Habitat quality, size, and connectivity are considered the main drivers of patch occupancy of grassland insects in our fragmented landscapes (Poniatowski et al. 2018a; Figure 21.1). However, the relative importance of each of the three parameters varies depending on the population structure of the species, which is related to its mobility, and the landscape composition (Fartmann et al. 2021a). Insect species with low mobility, e.g., many flightless Orthoptera (hereinafter termed 'grasshoppers'), often form closed populations (Poniatowski et al. 2018a; Cardoso et al. 2020). They can survive for longer periods of time, even in isolated grasslands, if the patches are characterised by a permanently high habitat quality and are large enough to contain a viable population. By contrast, insect species capable of flight, and therefore with higher mobility, such as many butterflies, often build metapopulations (Hanski 1999). Besides habitat quality and habitat size, the connectivity of the patches is also crucial for the long-term survival of such species (Poniatowski et al. 2018a; Cardoso et al. 2020). Metapopulation species vitally depend on a network of well-connected, high-quality grassland patches of sufficient size. However, not all insect species can clearly be assigned to one of the two population types. Often, there are fluent transitions between the two ends of the continuum (Fartmann et al. 2021a).

In less fragmented landscapes, habitat connectivity usually plays a minor role for patch occupancy, even among metapopulation species. Here, habitat quality is the main driver of persistence (Krämer et al. 2012; Löffler and Fartmann 2017; Poniatowski et al. 2018a). However, with an increasing degree of habitat fragmentation, connectivity becomes more important. Overall, habitat quality is the most important predictor of patch occupancy of grassland insects. All species depend on habitats that exhibit suitable habitat quality, irrespective of differences in their population structure and the composition of the landscape surrounding the patches. High habitat connectivity is of crucial importance for metapopulation species, particularly in highly fragmented landscapes. For range shifts, however, all insect species need a certain degree of connectivity between the habitat patches.

Habitat quality

Habitat quality for grassland insects is particularly defined by i) vegetation structure, which is interrelated with microclimate and ii) the availability of vital resources, in particular the occurrence of patches of bare ground and high plant species richness (Fartmann et al. 2021a). Insects are ectothermic organisms that vitally depend on high ambient temperatures for activity and reproduction. Accordingly, many and in particular threatened insect species prefer warm micro-habitats, which are characteristic for early- and mid-successional stages of temperate grasslands with short and heterogeneous swards (Fartmann et al. 2021a; Fumy et al. 2021; Schwarz and Fartmann 2022).

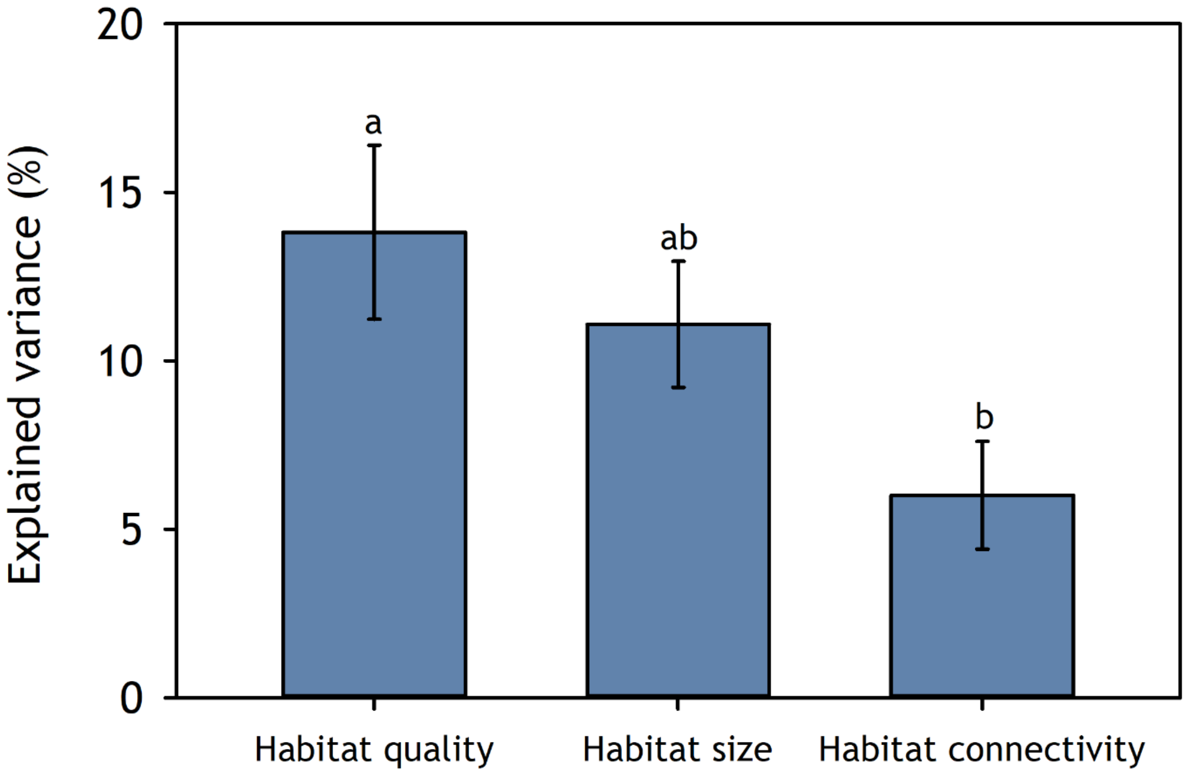

Figure 21.1. *Explanatory power of habitat quality, area and connectivity with respect to the patch occupancy of 13 habitat specialists (butterflies, grasshoppers, leafhoppers) in calcareous grasslands of the Diemel Valley (central Europe), expressed as the mean (± SE) proportion of variance explained exclusively by the respective parameter. Different letters indicate significant differences between the parameters ($P < 0.05$) (From Poniatowski et al. 2018a).*

Habitat heterogeneity particularly affects species richness in three ways, namely by: i) being a mandatory prerequisite for many species; ii) generally favouring species richness; and iii) being a suitable buffer against extreme weather events. Many grassland insects are decisively dependent on heterogeneous swards since they undergo microhabitat shifts during their life cycle (Fartmann et al. 2021a). Species like the Wartbiter (*Decticus verrucivorus*), for instance, use bare soil for oviposition, and the tiny young nymphs also prefer these warm microhabitats. By contrast, the larger older nymphs, and in particular the huge adults, favour taller and more dense vegetation that provides shelter against predators or can also be used as a song post by the adult males. In general, heterogeneous habitats offer more niches, which support coexistence of species with different habitat requirements and, therefore, have high overall species richness (Löffler and Fartmann 2017; Fartmann et al. 2021a). Moreover, heterogeneous grasslands, are generally more resistant and resilient against climate change than homogeneous ones (Fartmann et al. 2022). In the former, insects can adapt to global warming by microhabitat shifts, at least to some degree (Stuhldreher and Fartmann 2018; Fartmann et al. 2022).

Within heterogeneous grasslands, patches of bare ground play a special role (Fartmann et al. 2021a). Bare soil favours warming during sunny days and is an important breeding habitat for many insects. For example, in central Europe, more than 70% of the grasshoppers and almost 60% of the bee species use bare soil for nesting. Among phytophagous insects, many exhibit high host-plant specificity. Hence, species richness of taxa such as Auchenorrhyncha (hereinafter termed 'leafhoppers'), bees, and butterflies increase with phytodiversity (Krämer et al. 2012; Helbing et al. 2017; Fartmann et al. 2021a). In turn, a high diversity of phytophagous insects fosters species richness of insectivorous insects and parasitoids (Fartmann et al. 2021a).

Overall, nutrient-poor conditions and low-intensity management secure the occurrence of early- and mid-successional stages of grasslands characterised by a warm microclimate and heterogeneous swards exhibiting some bare ground and high phytodiversity (Grime et al. 2007; Fartmann et al. 2021a). By contrast, intensive land use (i.e., more than two mowing events per year or grazing with high stocking rates over long time periods) and land abandonment result in homogeneous swards comprising low species richness of both plants and insects (Fartmann et al. 2021a; Fumy et al. 2021; Schwarz and Fartmann 2022).

Habitat size

Habitat size of grassland patches is directly related to three parameters that are of vital importance for species-rich insect communities, namely: i) habitat heterogeneity (see above); ii) edge effects due to the adjoining matrix; and iii) the minimum area requirements of the species (Fartmann et al. 2021a). The larger a grassland patch, the higher the likelihood that different microhabitats occur within the patch and, hence, that it has high habitat heterogeneity (Löffler and Fartmann 2017), which is generally known to foster high species richness (see above). Additionally, larger patches are less prone to negative edge effects of the adjacent matrix, for example, due to the input of pesticides and nutrients from arable fields (Helbing et al. 2017; Fartmann et al. 2021a). The assumption behind this is that with increasing size the share of the patch that is influenced by edge effects should decrease. Large vertebrates are well known for their large area requirements (Fartmann et al. 2021a). However, even insects may depend on large habitats for long-term viability. This is particularly true for some butterfly species that form metapopulations. For example, the Niobe fritillary (*Fabriciana niobe*) requires at least 100 ha of well-connected grassland with the occurrence of its host plants (violets (*Viola* spp.)) (Salz and Fartmann 2009).

Habitat connectivity

For insects, the connectivity between grassland patches depends on: i) the composition of the landscape; ii) mobility of the species; and iii) its habitat specificity. Habitat connectivity is not only defined as the edge-to-edge distance between habitat patches (Euclidean distance) but rather by considering both the inter-patch distances and the resistance of the matrix biotopes between the patches for dispersal (functional connectivity) (Poniatowski et al. 2016). In general, short-growing grassland-like biotopes facilitate dispersal of grassland insects, whereas tall-growing land cover types usually hamper their movements. Modern-day arable fields play a special role as matrix habitats since they represent a very hostile environment for grasslands insects (Helbing et al. 2017; Fartmann et al. 2021a). They provide neither nectar resources nor host plants, and additionally, the applied pesticides are harmful to them. Accordingly, arable fields surrounding grassland patches have repeatedly been shown to decrease patch occupancy of mobile but not of sedentary insects, which rarely immigrate from the patches. Usually, flightless insects and habitat specialists depend on high functional connectivity for dispersal between patches. By contrast, species capable of flight or small insects that are light in weight and might be passively dispersed by wind, and habitat generalists can colonise even more remote and isolated grassland patches.

Climate change meets habitat fragmentation – another challenge for grassland insects

As a result of climate change, particularly since the late 1980s, temperatures are rising and extreme weather events, such as drought periods, have become more frequent (IPCC 2021, see also Chapters 8 and 9). Although annual precipitation has only slightly changed in temperate European grasslands, summer droughts have increased because of precipitation shifts from summer to winter and higher evapotranspiration due to increased summer temperatures (Poniatowski et al. 2020; IPCC 2021). Global warming already seriously threatens grassland insects, and this is expected to worsen over time (IPBES 2019; Stuhldreher and Fartmann 2018; Fartmann et al. 2021a, 2022). This is true for the effects of slow climatic alterations and in particular for those of extreme weather events. However, often the responses to climate change are rather complex and differ among related species. As described for the general drivers of patch occupancy of grassland insects, landscape composition and species traits also strongly determine how global warming affects species. In the following section, the different responses of two congeneric bush-cricket species and a butterfly species to climate change are discussed.

Both the Bog bush-cricket (*Metrioptera brachyptera*) and Roesel's bush-cricket (*Roeseliana roeselii*) are usually short-winged and flightless (Poniatowski and Fartmann 2011; Poniatowski et al. 2012). However, the habitats of the two species are quite different: *M. brachyptera* is a habitat specialist that occurs in calcareous grasslands and mires in low population densities. By contrast, *R. roeselii* is a habitat generalist that inhabits different types of open grassy habitats, and its abundance is usually higher than those of the sibling species. In both species, density stress in the early nymphal period results in the release of a stress hormone that triggers the development of long-winged (macropterous) morphs that are capable of flight (Poniatowski and Fartmann 2011; Poniatowski et al. 2012). In recent years, due to global warming, springs were often disproportionally dry, reducing nymphal mortality and favouring high abundance. Since densities in *M. brachyptera* are usually low, even a lowered nymphal mortality due to very favourable climatic conditions is mostly insufficient to cause density stress and produce macropters. Even in the rare case that long-winged individuals emerge, the likelihood that they are able to track climate change is low since their preferred habitats are usually highly fragmented, which hinders dispersal (Poniatowski and Fartmann 2011b, see also above). Moreover, the eggs of the species are drought sensitive. Therefore, *M. brachyptera* suffers from the more frequent drought occurrences due to global warming (Fartmann et al. 2021a). For the habitat generalist *R. roeselii,* the situation is different. Due to its naturally higher abundance, in recent times, dry springs have regularly led to density stress during the nymphal period. Nowadays, macropters of *R. roeselii* can regularly be observed and proportions of 20% long-winged individuals within populations is common (Fartmann et al. 2021a). These morphs exhibit a higher mobility than the short-winged morphs since they are capable of flying (Poniatowski et al. 2012). Due to the high availability of suitable habitats, this species can track global warming, and it has recently expanded its range in western, central, and northern Europe (Poniatowski et al. 2012; Fartmann et al. 2021a).

The Duke of Burgundy butterfly (*Hamearis lucina*) is a habitat specialist that—within the calcareous grasslands of the Diemel Valley (central Europe)—prefers west-facing slopes with the occurrence of its host plant, Cowslip (*Primula veris*) (Fartmann 2006). South- and south-west-facing slopes are avoided since the abundance of *P. veris* is generally lower there and the risk of desiccation in spring, when the caterpillars hatch, is already high. Due to an increase in spring droughts as a result of climate warming, such a mismatch is also assumed to become more likely on west-facing slopes. A study across different habitats in central Europe showed that females of *H. lucina* adapt batch size to the desiccation risk of the *Primula* plants (Anthes et al. 2008). In the calcareous grasslands of the Diemel Valley, due to the generally high probability of host-plant desiccation, the species had by far the smallest batches and already pursued a risk-spreading strategy. Batches usually only contain two eggs or are even deposited singly. Therefore, a further reduction in batch size is hardly possible. Shifts to moister north- or east-facing slopes are often not feasible because they were abandoned often decades ago and are now mostly covered by dense shrubland or woodland (Fartmann 2006). Since the dispersal ability of *H. lucina* is generally poor and the calcareous grasslands are fragmented, the likelihood to track climate warming by inter-patch movements is low. In line with this, patch occupancy of the species decreased in the Diemel Valley by a quarter from the end of the 1990s to 2014 (Fartmann et al. 2021a).

Overall, particularly hygrophilous and cold-adapted habitat specialists with low mobility have suffered from global warming (Stuhldreher and Fartmann 2018; Poniatowski et al. 2020; Fartmann et al. 2021a). However, during recent drought periods, even in mesic and dry grasslands, the abundance of complete insect assemblages collapsed due to large-scale desiccation of above-ground vegetation (Fartmann et al. 2022). By contrast, many thermophilous and mobile habitat generalists were able to expand their ranges in response to climate change (Poniatowski et al. 2020; Fartmann et al. 2021a, b; Engelhardt et al. 2022). However, even for these species, the range shifts lag behind the increase in temperature since their dispersal is also constrained by insufficient habitat connectivity (Cardoso et al. 2020). In general, climate change has led to biotic homogenisation of grassland insects favouring some habitat generalists at the expense of many habitat specialists (Fartmann et al. 2021a).

Restoration of calcareous grasslands – a case study on how to foster species-rich insect assemblages

Calcareous grasslands are hotspots of insect diversity in temperate regions (Van Swaay et al. 2006; Fartmann et al. 2021a). The Diemel Valley (central Europe) contains—with about 750 ha—the largest area of such grasslands in the northern part of Germany (Fartmann 2006). However, during the past 150 years, the extent of these traditionally grazed grasslands strongly declined due to abandonment and afforestation. In the early 2000s, almost half of all calcareous grasslands were abandoned (340 ha, 45%). Long-term abandonment of calcareous grasslands results in litter accumulation, closed swards, and shrub encroachment, favouring a few competitive plant species at the expense of many light-demanding ones (Fartmann et al. 2021a). Due to the unfavourable microclimatic conditions (cooler and moister) as well as the loss of bare soil and phytodiversity, the richness of insect species also decreased.

Large-scale restoration measures have been carried out since 2009 to counteract the negative effects of abandonment on species richness (Helbing et al. 2015, 2021; Poniatowski et al. 2020). In abandoned calcareous grasslands, shrubs have been cut and processed to woodchips for energy production. In areas with intensive resprouting of shrubs after cutting (e.g., former thickets of Blackthorn (*Prunus spinosa*)), the woody plants have been additionally suppressed by mulching. To maintain open habitat structures in the long run, grazing has been reintroduced. So far, assessments of restoration success have focused on plants, leafhoppers, and a threatened butterfly species, the Blue-spot hairstreak (*Satyrium spini*). These studies have shown that the conducted measures are suitable to create species-rich calcareous grasslands. However, this requires time. Three to eight years after removal of shrubs, the restoration sites exhibited transitional stages between shrubby and open calcareous grasslands. They had heterogeneous swards with some bare soil and a mixture of different ecological groups of plants (Poniatowski et al. 2020). In addition to plants of calcareous grasslands, thermophilous fringe and ruderal species as well as species of woodlands, clear-cuts, mesic grasslands, and nitrophilous ruderal habitats have been typical of this seral stage. Many of these plant species were even restricted to the restoration sites, not occurring in calcareous grasslands characterised by continuous grazing. An example is the threatened Downy woundwort (*Stachys germanica*). The combination of bare ground—which favours a warm microclimate and serves as a potential nesting habitat for insects (e.g., bees or grasshoppers, see above)—as well as the unique composition of plant species resulted in suitable habitat conditions for some threatened insects such as the leafhopper *Eupteryx origani* and the butterfly *S. spini* (Helbing et al. 2015; 2021).

Given that the effects of restoration measures on *S. spini* have been studied in detail, I will present the main findings here (Helbing et al. 2015). Caterpillars of *S. spini* feed monophagously on Buckthorn (*Rhamnus cathartica*), a shrub characteristic of thermophilous shrubberies on base-rich soils. Both the host plant and butterfly responded rapidly to restoration efforts. They exhibited a much higher abundance on restored sites four years after shrub cutting than in shrubby calcareous grasslands or those with continuous grazing. Density of host plants was twice as high on restored sites than on grazed grasslands and 27 times higher than on abandoned ones. Batch densities of the butterfly were 15 and 80 times higher, respectively. Overall, shrub cutting promotes the rejuvenation of *R. cathartica* because the species requires bare soil for germination and vigorously produces suckers from the stump after cutting. Additionally, the large number of small buckthorn plants growing under sunlit conditions offered ideal conditions for the thermophilous butterfly species.

In conclusion, three to eight years after conducting the measures, the restoration sites still differed in habitat structure and assemblage composition from calcareous grasslands. However, with continuous grazing, species of calcareous grassland will become dominant. The transitional successional stages between shrubby and open calcareous grasslands already had high conservation value. Many threatened species were even restricted to them. Accordingly, even on patches where the reintroduction of grazing is not possible, shrub removal alone is a suitable conservation measure on shrubby grasslands. Such a measure mimics traditional coppice management known from woodlands, which is widely recognised for its beneficial effects on insect diversity in general and for threatened species in particular (Helbing et al. 2015; Fartmann et al. 2021a).

Conserving grassland insects in times of global change

It is assumed that habitat availability and global warming will determine the distribution of insects in temperate, semi-natural grasslands in the future (Fartmann et al. 2021a, b). Accordingly, and based on the aforementioned, conservation management should aim to i) enhance the habitat quality of the remaining grasslands; ii) enlarge their sizes; and iii) improve functional connectivity between patches (Samways et al. 2020; Fartmann et al. 2021a; Figure 21.2). When conducting such measures, focus should be on increasing heterogeneity at all spatial scales due to its buffering effect against extreme weather events, such as drought periods (Fartmann et al. 2021a). For centuries, most landscapes in temperate regions had been intensively drained by humans. Accordingly, the stabilisation of the water level or the restoration of the natural water table is crucial for mitigating the effects of climate change on insects.

Enhancing habitat quality of the remaining habitat patches

Low-intensity land use without fertilisation or at least low levels of fertilisation is of vital importance for high habitat quality in semi-natural grasslands (Poniatowski et al. 2018a; Stuhldreher and Fartmann 2018; Fartmann et al. 2021a; Helbing et al. 2021). Overall, habitat management should aim to maintain and create nutrient-poor grasslands with heterogeneous swards that exhibit some bare ground and a high phytodiversity. Mowing causes direct mortality of insects. Additionally, it results in short homogeneous swards directly after the management event, which leads to increased predation of insects by vertebrates (e.g., many insectivorous bird species). Consequently, in most cases, pastures with low stocking rates should be preferred over meadows. Exceptions are meadows characterised by long-term continuity of traditional mowing management and that still host species-rich insect assemblages. However, there are also strategies to reduce the loss of insects associated with mowing. This is the case when mowing is conducted before or after the phenology peak of most insects in summer. For example, the so called “litter meadows” are mown in autumn to obtain bedding for livestock and are famous for their high insect diversity (Schwarz and Fartmann 2022). Another possibility to diminish insect losses through mowing, is to establish uncut areas, which can act as a refuge (Fartmann et al. 2021a). However, their location should rotate between mowing events to avoid the negative effects of long-term abandonment (see above).

Suitable low-intensity grazing systems that shape heterogeneous grasslands with species-rich insect assemblages are rough grazing by sheep (and goats in shrub-rich grasslands), summer grazing by cattle and year-round grazing with horses, cattle or indigenous grazers such as Red deer (*Cervus elaphus*) or European bison (*Bison bonasus*) (Fartmann et al. 2021a; Fumy et al. 2021; Schwarz and

Fartmann 2022). Particularly in regions with increased nitrogen deposition rates (e.g., the Benelux countries or north-western Germany) or mild winters, grazing in winter or early spring is important (Fartmann et al. 2021a). In former times, winter and spring grazing was much more widespread than today; it is the basis for high plant and insect species richness in many grasslands. It secures open swards in spring where light-demanding plants can germinate and that provide warm microclimatic conditions for the successful development of many insects. Additionally, it weakens the competitive power of invasive species, such as the Upright brome (*Bromus erectus*). This grass species has recently been favoured in dry grasslands by climate warming and eutrophication (Poniatowski et al. 2018b). Additionally, grazing animals produce dung, the food source of coprophagous insects. Accordingly, the application of pesticides for parasite control in livestock, such as ivermectin, should be avoided (Samways et al. 2020). Besides livestock and indigenous grazers, there are other ecosystem engineers, such as the European mole (*Talpa europaea*), Wild boar (*Sus scrofa*), and Yellow-meadow ant (*Lasius flavus*) whose digging activities, create open swards with warm microclimates, fostering the occurrence of many insect species (Fartmann et al. 2021a).

Increasing habitat heterogeneity in semi-natural grasslands seems to be the most effective way to mitigate the negative effects of drought periods driven by climate change (Fartmann et al. 2021a). Overall, the recommended grazing regimes foster spatial heterogeneity. However, additionally, conservation management should especially focus on preserving and creating pastures with interspersed shrubs and some solitary trees (Fartmann et al. 2022). For regions with regular summer drought, it has been shown that wood pastures, like the 'dehesa' in Spain or the 'montado' in Portugal, sustain insect diversity. Moreover, conservation management should aim to maintain and restore grasslands on north- and east-facing slopes or moist soils (Stuhldreher and Fartmann 2018; Fartmann et al. 2021a). This would enable species to accommodate extreme weather events to some degree without moving to other habitat patches.

Enlargement of existing grassland patches

In particular, abandoned grasslands encroached by shrubs and afforested grasslands adjacent to existing grasslands should be restored (Fartmann et al. 2021a). In contrast to grasslands that have been converted to arable fields, they are usually characterised by low nutrient contents comparable to those of the original grassland. Additionally, if cessation of grassland management occurred at most two to three decades ago, the soils often contain a viable seed bank. Accordingly, after cutting and removing woody plants, grassland vegetation can establish without seed or hay transfer.

Improving functional connectivity between grassland patches

Habitat corridors and stepping-stones that resemble in habitat structure and plant species composition those grasslands they should connect, have the highest functional value for the facilitation of inter-patch movements (Poniatowski et al. 2018; Samways et al. 2020). Existing linear structures, such as roadside verges or powerline corridors, play an important role in establishing functional connectivity between grassland patches. To allow insects to adapt to extreme weather events and to track climate warming, it is also essential to include semi-natural grasslands across long environmental gradients (e.g., large differences in aspect, elevation, moisture, or shade) into the large-scale conservation corridors. Within such habitat corridors, conservation management should aim to maintain and restore semi-natural grasslands following the guidelines described above.

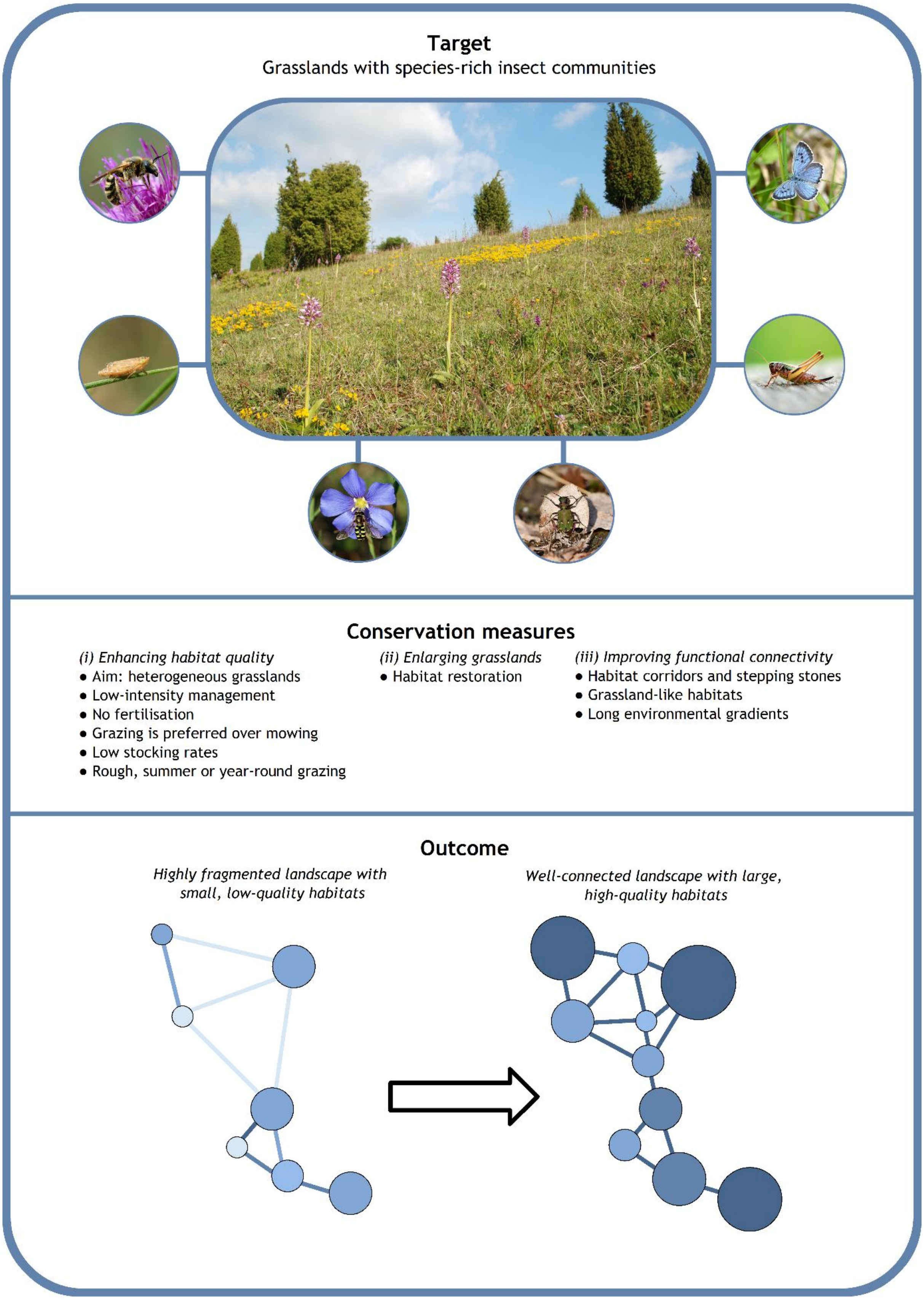

Figure 21.2. The overall target of all conservation measures is to maintain and restore grasslands with species-rich insect communities. To achieve this goal, i) enhancing habitat quality of the remaining grasslands; ii) enlarging their sizes; and iii) improving functional connectivity between the patches are necessary. These measures result in the establishment of a well-connected landscape with large, high-quality habitats. Additional information: Target – A species-rich calcareous grassland with Common juniper (*Juniperus communis*), Military orchid (*Orchis militaris*), and Horseshoe vetch (*Hippocrepis comosa*) as characteristic plant species and Large blue (*Phengaris arion*), Bog bush-cricket (*Metrioptera brachyptera*), Green tiger beetle (*Cicindela campestris*), Migrant hoverfly (*Eupeodes corollae*), the leafhopper *Adarrus multinotatus* and Great banded furrow bee (*Halictus scabiosae*) as typical insect species is shown (Photo credit: *A. multinotatus* – F. Helbing; *E. corolla* – D. Poniatowski; all others: T. Fartmann). Outcome – The darker the blue, the higher the habitat quality and the functional connectivity of the patches.

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