Leveraging Biodiversity Net Gain to address invertebrate declines in England

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Abstract

Meeting ambitions such as the Global Biodiversity Framework 2030 targets will require multiple conservation mechanisms that benefit the widest possible range of habitats and species. Using England as a case study, here we evaluate the likely impact of a novel and ambitious ecological compensation policy, Biodiversity Net Gain (BNG), on terrestrial insects, spiders, and other arthropods ('invertebrates'), a functionally important but rapidly declining component of biodiversity. Current implementation of BNG in England sets out to provide a 10% uplift in biodiversity when infrastructure development (such as housebuilding) occurs. However, BNG is a habitat-driven approach, which risks overlooking important considerations relevant to invertebrate conservation, threatens to further reduce the size and quality of their habitats, and may increase habitat fragmentation. BNG - as currently implemented – therefore represents a missed opportunity to use a universally applied policy to benefit invertebrates and other functionally important components of biodiversity. We suggest ways forward to realign BNG with what we know to be crucial for successful invertebrate conservation, and with other policy mechanisms such as the National Pollinator Strategy. This will ensure that appropriate habitats and conditions for invertebrates are retained, enhanced, and created at a landscape scale, and that BNG is optimised to contribute to broader national conservation targets. As biodiversity accounting and offsetting schemes such as BNG are increasingly adopted around the world, the experience of BNG in England provides valuable insights into how ecological compensation programmes could be better designed, implemented, and monitored to ensure that benefits for a wide variety of taxa are achieved.

Introduction

Insects, spiders, and other terrestrial arthropods (here collectively referred to as 'invertebrates') comprise the majority of known species on Earth (May 1986) and play a pivotal functional role in ecosystems. Invertebrate-mediated ecosystem functions include pollination, nutrient cycling, and decomposition, which are essential to ecosystem health, human society, and supporting land-uses including agriculture (Nichols et al. 2008; Aizen et al. 2009; Dangles & Casas 2019; Seibold et al. 2019). There is growing evidence of declines in invertebrate populations (Wagner 2020). For example in the United Kingdom, population declines of concern have been reported for some species of carabid beetles (Coleoptera; Carabidae) (Brooks et al. 2012), moths (Lepidoptera) (Bell et al. 2020), butterflies (Lepidoptera) (Brereton et al. 2011), bees (Hymenoptera) and hoverflies (Diptera: Syrphidae) (Powney et al. 2019). These declines have been driven by a suite of pressures including agricultural intensification (Ollerton et al. 2014; Habel et al. 2019; Raven & Wagner 2021), light pollution (Boyes et al. 2021), and pesticide use (Sánchez-Bayo 2014), as well as land-use change causing habitat loss and fragmentation (Maxwell et al. 2016; Rossetti et al. 2017; Warren et al. 2021).

Such serious reductions in invertebrate biodiversity have led to calls for, and implementation of, a range of conservation targets and associated policies (Dicks et al. 2016; Forister et al. 2019; Cardoso et al. 2020; Samways et al. 2020). These include global targets such as the Global Biodiversity Framework 2030 targets

(Convention on Biological Diversity 2023) and various national targets. For example, in England, the Environment Improvement Plan (EIP) sets out an overarching target to halt the decline in species abundance by 2030, and to exceed 2022 abundance levels by 10% by 2042 (Department for Environment, Food & Rural Affairs 2023a). The indicator toward this target includes 24 species of butterfly and 88 species of moth (Joint Nature Conservation Commitee 2023). This overarching target sits within a wider body of conservation policies which are expected to contribute to its achievement, including species-focused legal protection under the Wildlife and Countryside Act 1981, and prioritisation of 'Species of Principal Importance' under the Natural Environment and Rural Communities Act 2006 (National Archives 2023b, 2023c). However, these policies do not represent the full suite of invertebrates and are better suited to the conservation of larger, more conspicuous species, such as vertebrates (Duffus & Morimoto 2022; Morris & Welch 2023). More recently, the England Pollinator Action Plan (2021-2024) has been published under the National Pollinator Strategy (NPS) (Department for Environment, Food & Rural Affairs 2022). The NPS is a 10-year strategy setting out a suite of actions aimed at improving the status of pollinating insects by 2024. Although some of the actions are unique to the conservation of pollinators, others are broader, including the aim to provide "more, better, connected habitat" (Department for Environment, Food & Rural Affairs 2022). This type of conservation action is exemplified by the Buglife B-Lines project which aims to deliver 150,000ha of connected wildlife rich habitat (Buglife 2023). These actions will benefit a wide range of taxa beyond insect pollinators, and are in line with the principles of "bigger, better, and more joined up" habitat networks as outlined in the Lawton Review (Lawton et al. 2010).

A key environmental initiative relevant to biodiversity recovery in England is Biodiversity Net Gain (BNG). From 2024, almost all developments of the built environment, including housing, road or rail construction, and renewable energy development, that require planning permission will need to provide a mandatory minimum of 10% BNG, secured for a period of at least 30 years (National Archives 2023a). BNG is to be demonstrated using the Statutory Biodiversity Metric, which is intended as a proxy for biodiversity (Natural England 2023). To calculate a biodiversity value, the metric takes the size, distinctiveness, condition, and strategic location of a site, and converts these factors into numerical values that are multiplied together to give biodiversity units for area habitats such as grasslands or woodlands, and linear landscape features such as hedgerows and watercourses. A pre-development baseline calculation of biodiversity units is made and compared to the future unit value of the site that is forecast using the same formula but with spatial, temporal, and (to account for uncertainty) difficulty multipliers. Higher values are thus assigned to future habitats which are a) more likely to be achievable; b) with little time delay after the initial impacts of development, and c) that are on or close to the development site. The projected post-development value of habitats must exceed the pre-development value by at least 10%. To achieve this net gain, a hierarchy is followed, where environmental harm is avoided, minimised, restored, and finally unavoidable harms are offset on-site (within the development footprint), then off-site (Department for Levelling Up, Housing and Communities 2023). As a last resort, offsetting under BNG can be achieved by purchasing statutory credits from the government.

While BNG is not the sole instrument for nature recovery, it will have a large role to play in England given anticipated high levels of infrastructural development, in particular increased housebuilding (Levelling Up, Housing and Communities Committee 2023). Consequently, BNG has huge potential to influence the creation and management of many habitats in England and through this to contribute to broader aims such as the species abundance target from the EIP. However, the conservation potential of BNG has been widely criticised. There is concern about the extent to which the biodiversity metric accurately captures and represents important dimensions of biodiversity (Wilson 2021; Weston 2021), and there is no evidence of a consistent relationship between biodiversity units generated by the metric calculation and records of species of conservation concern (Hawkins et al. 2022).

Done properly, given the fine spatial scale and the ubiquity of its adoption in England, BNG has the potential to be a powerful tool for invertebrate conservation. However, to be successful BNG must generate habitats that support diverse invertebrate communities, including at the large spatial extent envisaged under policies such as the National Pollinator Strategy. Here, we detail some of the specific habitat requirements of invertebrates and discuss how the current implementation of BNG is not optimised to provide those habitat requirements. Then, we discuss the potential to realign BNG with wider invertebrate conservation activities to create a more joined up policy landscape.

Biodiversity accounting and offsetting policies such as BNG are increasingly proposed and established around the world in order to reconcile biodiversity conservation with development (zu Ermgassen et al. 2019). This is accompanied by the use of area and condition based biodiversity metrics including in Sweden (Ecogain 2023), Singapore (AECOM 2023), Australia (Parkes et al. 2003), and Scotland (Scottish Government 2023). Therefore, a critical evaluation of the situation in England provides an opportunity to reflect on the likely consequences of such policies for invertebrates more generally, and to highlight a range of considerations that could greatly increase the biodiversity benefits when designing biodiversity accounting and offsetting schemes and associated metrics.

Tensions between invertebrate conservation requirements and BNG

Habitat condition and heterogeneity

BNG takes a very simplified approach to habitat quality, assessing it as ‘poor’, ‘moderate’ or ‘good’ using a checklist of habitat features. Since different invertebrate species and guilds often have specific and variable resource requirements, scoring habitat components in isolation risks failing to recognise the importance of habitat complexity, topography, and heterogeneity. The complex life histories of many invertebrates, with distinct larval and adult requirements, will inevitably increase the necessity for heterogeneous habitats. For example, while pollinators require a diversity of suitable floral and nectar resources as adults, their immature stages often depend on very different resources, such as the nutrient-enriched water sources favoured by the larvae of *Eristalis* spp. hoverflies Latreille, 1804 (Falk & Castle 2019), or the dry rot holes in dead wood required by bees such as the Fringe-horned Mason Bee (*Osmia pilicornis* Smith, 1846) (Falk 2015). For such species, the proximity of features needed by adult and immature stages may be crucial, making heterogeneous habitat mosaics especially important. Ecotones (transitions between habitat types) also constitute important invertebrate habitats in their own right (Schirmel et al. 2011). For example, the transition from grassland to tall grass sward and scrub habitats is known to support at least 2653 invertebrate species in the UK (Webb et al. 2018).

As an example of over-simplification under the current scheme, for most grasslands to be in 'good' condition, they should have no more than 5% cover of bare ground or scrub (Natural England 2023). This low threshold fails to recognise the value of mosaics of bare ground, grassland, scrub, and woodland. 'Good' condition grasslands must also have 20% of vegetation taller than 7cm and 20% shorter than 7cm (Natural England 2023). The metric fails to recognise that satisfying this criterion is dependent on sampling season and the grazing or mowing regime, with that regime being equally if not more important to invertebrates such as spiders than sward height (Lyons et al. 2018). A further stipulation for 'good' condition grassland is that a set of plant species 'indicative of sub-optimal condition' cannot cover more than 5% of the grassland. Such species include White Clover (*Trifolium repens* L.), Creeping Buttercup (*Ranunculus repens* L.), Creeping Thistle (*Cirsium arvense* L.), and Common Nettle (*Urtica diocia* L.) (Natural England 2023). Scrub, including Bramble (*R. fruticosus* agg. L), must also account for less than 5% of grassland area (Natural England 2023). *Cirsium arvense, R. fruticosus* agg. and *T. repens* are among the most nectar productive plants on pasture, supporting pollinators throughout the season (Timberlake et al. 2019). Also of importance is *U. dioica* which is associated with 123 invertebrate species in the UK (Biological Records Centre 2023); shaded nettle beds maintain higher humidity and are an important resource which invertebrates use to over-winter or shelter during periods of high temperatures (Davis 1983).

A further issue is that the metric is applied by subdividing sites into relatively homogeneous parcels. For example, for an ecotone of grassland transitioning into woodland, the grassland and woodland might be delineated separately with a line positioned within the transition zone; or the transitional zone may be recorded as a separate parcel of scrub habitat. These categorisations are potentially confusing for the field surveyor, will depend heavily on skill and experience, and provide no mechanism to recognise ecotones, within-patch heterogeneity, and habitat mosaics.

In summary, the reliance on condition-based assessments as currently designed, has the potential to be detrimental to invertebrate biodiversity because it fails to account for attributes that may be valuable for invertebrates. As a result, important invertebrate habitat could be undervalued pre-development, and during development the removal of features important to invertebrates could actually be incentivised

Habitat Connectivity

At a larger spatial scale, connectivity of sites across the landscape is an important consideration that is not fully accounted for by the current implementation of BNG. The level and type of connectivity required for colonisation varies greatly among invertebrate guilds and depends on their dispersal capabilities, with less mobile species likely to require higher connectivity to maintain viable populations and to facilitate range shifts under climate change (e.g. Mason et al., 2015). To avoid sites becoming too isolated from areas with similar habitat, connectivity can be improved by creating corridors or stepping stones of the same or similar habitat types, or linear features such as hedgerows, which can facilitate the movement of more mobile groups such as many pollinators (Cranmer et al. 2012).

The metric currently attempts to reflect landscape connectivity via a 'strategic significance' multiplier (Natural England 2023) which assigns a higher value to sites within priority strategic areas such as recovery zones in Nature Recovery Networks (NRN) (Department for Environment, Food & Rural Affairs 2023b). However, this scoring approach does not consider the habitat types of sites being connected, or indeed any actual permeability or functional connection, and thus the extent to which invertebrates will be able to disperse across the landscape and colonise new sites. Furthermore, sites within the NRN will not inherently have higher value for invertebrates than those outside it; their relative value will depend on the habitat on the site and the goals and implementation of the Local Nature Recovery Strategy (LNRS) underpinning the NRN (Department for Environment, Food & Rural Affairs 2023b).

Habitat Size

Biodiversity Net Gain allows for large areas of either or both low distinctiveness or 'poor' condition habitat to be traded for smaller areas with higher distinctiveness and/or 'good' condition. Trading habitats in this way has been associated with a 38% reduction in green space post-development (Rampling et al., 2023). The tendency to create small and relatively isolated sites, even if their individual biodiversity value is higher, is likely to compromise biodiversity outcomes, for two main reasons.

First, smaller habitats can support smaller populations which are less resilient to stochastic events and environmental changes which can drive local extinction (Hodgson et al. 2011; Oliver et al. 2013). Small sites also have increased edge effects and encompass less environmental heterogeneity, further eroding population resilience (Stein et al. 2014; Kuli-Révész et al. 2021). Collectively, this means that landscapes of smaller habitats will tend to support less biodiversity in the long term than those with larger ones (Connor & McCoy 1979; Rukke 2000).

Second, as discussed above, the transition from a 'poor' to a 'good' condition habitat might in fact reduce the quality and extent of habitat suitable for invertebrates. Populations in these smaller habitats will be even less resilient without measures to improve connectivity and thereby facilitate colonisation (Steffan-Dewenter & Tscharntke 2002; Rösch et al. 2013). In England, two of the most threatened bumblebee species, the Shrill Carder Bumblebee *Bombus sylvarum* Linnaeus, 1761, and the Moss Carder Bee *Bombus muscorum* Linnaeus, 1758 exist only in small, isolated habitat fragments. As a consequence, these species have low effective population sizes and reduced genetic diversity, with evidence of inbreeding, reducing population resilience (Darvill et al. 2006; Ellis et al. 2006). Invertebrates that depend on highly patchy resources that occupy only a small fraction of any site may be especially vulnerable to isolation effects. One such resource required by many invertebrates of conservation concern is dead wood; for saproxylic invertebrates such as long-horn beetles (Coleoptera: Cerambycidae), sites will need to be either large enough or connected enough to provide spatial and temporal continuity in the provision of this resource (Schiegg 2000).

Habitat Pressures

To date, sites delivered under early adopter BNG councils have primarily occurred "on site", i.e., within the footprint of the development (Rampling et al., 2023). Smaller areas of post-development green space, such as those within housing developments, will face high levels of anthropogenic disturbance including erosion by footfall, littering, over-management, colonisation by Invasive Non-native Species (INNS), nutrient enrichment from domestic animal waste, pesticide use, and high densities of managed beehives in urban environments (Coleman 1981; De Frenne et al. 2022; MacKell et al. 2023). Nutrient enrichment and pesticide use are of particular concern for invertebrates, and can have effects beyond the development site, with sealed surfaces creating run-off into sensitive water-dependent habitats, such as floodplain meadows or alkaline fens (Cook 2007; Manninen et al. 2010; Bart 2022). BNG guidelines currently make no mention of restricting use of pesticides, despite their detrimental impacts on invertebrate biodiversity (Alkassab & Kirchner 2017; Cavallaro et al. 2019). Most gains made under BNG are likely to be within the built environment (Rampling et al., 2023) where pesticide use is commonplace. Grounds managers regularly use dicamba and glyphosate for the control of ‘weeds’ in gardens and on hard surfaces and gravel paths (Garthwaite et al. 2020). Both herbicides are directly harmful to invertebrates (Freydier & Lundgren 2016; Smith et al. 2021), and the plant species targeted such as Dandelion (*Taraxacum officinale* L.) are important resources for pollinators (Sirohi et al. 2022). An additional route of pesticide input comes from domestic pets. There are the flea treatments imidacloprid and fipronil, commonly used on domestic pets, which are concerning pollutants of aquatic habitats in England, particularly in urban areas (Perkins et al. 2021).The NPS sets out plans to develop guidance for managers of amenity spaces, urging them to ‘think carefully’ about their use (Department for Environment, Food & Rural Affairs 2022), but as it stands, there is nothing to prevent sites retained, created, or enhanced under BNG receiving substantial pesticide inputs, compromising their suitability for invertebrates.

How to reconcile BNG with invertebrate conservation goals

At present, BNG misses the opportunity to provide habitats which serve the needs of invertebrates, making it inconsistent with policies for the conservation of invertebrates such as the Pollinator Action Plan. Important components of ecological resilience such as habitat size and connectivity risk being compromised, and resources and habitat features necessary for maintaining favourable conservation status of invertebrate assemblages are not recognised. These technical risks within BNG are likely exacerbated by (and may further exacerbate) the lack of invertebrate awareness within the planning system more broadly. Here, we set out possible pathways to optimise invertebrate conservation within BNG, and within the planning system.

Redefining Habitat Condition

Condition scoring used for BNG requires a careful balance between ease-of-use and ecological resolution. Over-simplification is sometimes problematic, for example in the case of medium, high, and very high distinctiveness grasslands, where a single set of condition scoring criteria is applied to ten distinct grassland types (Natural England 2023). In the literature from which these condition scoring criteria were adapted (Joint Nature Conservation Commitee 2019), each grassland type has its own set of criteria for assessing quality. Under BNG, having the same criteria for all streamlines the assessment process but risks neglecting the significance of features in different grassland types. For instance, what is considered an acceptable amount of bare ground will vary depending on the grassland type and soil substrate. While less than 5% bare ground could be considered favourable on lowland meadow, this could be considered too little on acid grasslands, where bare ground of 25-50% can be a favourable feature (Joint Nature Conservation Commitee 2019).

A revised set of habitat condition scoring criteria could usefully draw on existing work evaluating sites for invertebrates using habitat features. One example is the Invertebrate Habitat Potential (IHP) Assessment (v3.07a Dobson and Fairclough, 2021). Much like the metric, IHP takes a habitat-led approach, assessing 11 site features, but bases the valuation on their potential to support invertebrates on a grading scale of A-E. Some habitat features such as bare ground are shared between the IHP and the metric but are treated differently. Whereas the metric uses a simple 1-5% threshold of acceptable bare ground, the IHP seeks to identify if the site has examples of un-shaded and well-drained bare ground which could be used for nesting or basking by invertebrates. The IHP also adds components lacking from the current metric condition score sheets, by assessing ecotones, decaying wood, still air (areas sheltered by wind breaks are often used for displaying and mating behaviours by flying insects), and structural patchworks.

In addition to changing the way individual habitat features are scored, the present way that each habitat type is treated in isolation within the metric should also be addressed.

For instance, by signposting ecotones and enabling them to be recorded as their own habitat type. This would make the retention of ecotones simpler than when they are delineated in multiple small parcels of differing habitat types.

Recognising Connectivity

There are many different approaches to quantify connectivity based on, for example, inter-site distances (Mancini et al. 2022), and the capacity of species to colonise new sites (Hodgson et al. 2012). A previous version of the metric (Metric 2.0 - Natural England, 2019) did in fact use a specific connectivity multiplier value of low, medium, or high. Connectivity was determined by the number of 1km squares adjacent to a focal site with the same or related habitat types, accounting for the permeability of the wider landscape to species on the focal site (Hodgson et al. 2011; Oliver et al. 2013). Ultimately, this multiplier was removed from the metric, as it was only feasible for 'high' and 'very high' distinctiveness habitats and was challenging for users to implement (Natural England 2019). From the perspective of resources and features supporting invertebrate assemblages within a site, this method of valuing connectivity appears more robust than the current strategic significance multiplier, as it accounts for the habitat types being connected. To make the strategic significance mechanism a more meaningful connectivity tool, one approach could be to use systematic conservation planning to set the spatial priorities of a Nature Recovery Network to explicitly consider functional connectivity and include species distribution data from biodiversity record centres or distribution modelling in network design (Smith et al. 2022).

Limiting Losses in Habitat Area

The overall reduction in post-development green space incentivised by the current implementation of BNG (Rampling et al., 2023) is a significant challenge that will not be solved by improved condition scoring alone. It is driven by the trading of existing large, low distinctiveness, 'poor' condition habitats for future small higher distinctiveness, 'good' condition habitats under the assumption that newly created habitats will have increased biodiversity value. In reality, the timescales for restoring biodiversity on high distinctiveness grassland sites can be longer than the 30-year minimum requirement for BNG. In some cases, complete restoration of plant biodiversity can take 70-150 years depending on management (Woodcock et al. 2011), and colonisation of the complete invertebrate assemblage could lag further behind that, depending partly on the degree of isolation from existing populations (Woodcock & McDonald 2010).

One potential solution would be to impose a size threshold for BNG, for example by requiring no net loss in overall habitat area, particularly for high and very high distinctiveness habitats. This would likely increase the need for developers to feed into the biodiversity offset market, generating greater financial investment into large offsite nature recovery projects (Hawkins et al. 2023).

Standardised Guidance on Surveys

Currently, there is no consistent approach for including invertebrates as part of Ecological Impact Assessments (EcIA), an existing suite of ecological surveys that are undertaken during the planning application process. Within the context of EcIA, faunal surveys have historically shown a strong tendency to focus on a small set of protected vertebrate species. However, in the last 5-10 years, a wider focus has been normalised, which has included invertebrate surveys.

Sixteen invertebrate species have some legal protection as European Protected Species and 50 invertebrate taxa are protected under the Wildlife and Countryside Act 1981 (as amended) (Natural England 2022). In England, Section 40 of the Natural Environment and Rural Communities Act 2006 (as amended by the Environment Act 2021) (National Archives 2023c), requires decision makers such as local planning authorities to conserve and enhance biodiversity based on a 'Species of Principal Importance' list published by the Secretary of State. Commissioning a standardised invertebrate survey before development allows for a better-informed, tailored BNG approach which retains, creates, and enhances habitats, features and resources recognised as significant for maintaining the conservation status of a site's invertebrate assemblage.

Not all application sites will require an invertebrate survey. Justification for when one is needed may draw on existing biological records and the ranking and scoring of important habitat features, as for the IHP (Dobson & Fairclough 2021). Standardised approaches to surveying a range of taxonomic groups such as Arachnida, Coleoptera, Diptera, Lepidoptera, Hemiptera, and aculeate Hymenoptera can then be applied at sites where an invertebrate survey is deemed necessary (Drake et al. 2007). Species from these taxa are included in the Pantheon database (Webb et al. 2018), which allows users to identify which key features, habitats, or resources are needed by the species recorded, ensuring that habitat features on which invertebrates depend are not overlooked or penalised within the BNG process. The Pantheon database can also identify whether ‘Specific Assemblage Types’ have favourable status based on the number of species present (Webb et al. 2018), making it a useful tool for decision-making.

New technologies also have the potential to streamline the invertebrate identification process within such surveys. These include automated monitoring approaches such as camera traps for moths (UKCEH 2023) and DNA-based technologies, which are becoming increasingly cost-effective. While work is still needed to overcome primer biases and increase taxonomic coverage in DNA barcode libraries (Rees et al. 2022), approaches such as DNA metabarcoding and environmental DNA have the potential to generate extensive data on species composition and richness rapidly, extending the range of taxa included within survey work (Ritter et al. 2019; Mata et al. 2021). Using these approaches for pre-development surveys would be another way to generate data to inform the habitat design and development under BNG in a way that benefits invertebrates.

Conclusion

Biodiversity Net Gain in England seeks to mediate the conflict between infrastructure development and biodiversity, by seeking to leave biodiversity in a better state post-development. Flaws in the design of BNG mean that, as it currently stands, it may not have the intended positive outcomes for biodiversity. Here, we have detailed ways in which this is particularly true for invertebrates, which have specific habitat requirements not recognised in the metric, and require heterogeneous, connected habitats which project proponents are not incentivised to provide under BNG. By failing to create habitats with high invertebrate conservation value, BNG risks missing opportunities to support larger overarching targets to halt and reverse declines in invertebrate biodiversity, including the species abundance target in the EIP. Given that BNG and similar schemes elsewhere will drive large amounts of nature provision within developments and contribute financially to nature recovery through an offset market, it is vital that the mechanisms for habitat assessment and creation are ecologically sound.

As approaches to biodiversity accounting and offsetting proliferate globally, such insights should be widely relevant to informing the design of area and condition metrics for measuring biodiversity. This is of particular significance for invertebrates which thrive in complex heterogeneous habitats.

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Author Contribution Statement

O.T.L. and N.E.D. conceived the idea for the paper. N.E.D. collated ideas and information from all co-authors and synthesised the first draft. All authors contributed to subsequent iterations of the paper and approved it for final submission.

Conflicts of Interest

The authors have no conflicts of interest to declare.

References

AECOM, 2023. SG Bio Accounting Metric - Singapore Biodiversity Accounting Metric [WWW Document]. URL https://anz.planengage.com/singapore-bio-metric/page/SG-Bio-Accounting-Metric-10 (accessed 12.19.23).

Aizen, M.A., Garibaldi, L.A., Cunningham, S.A., Klein, A.M., 2009. How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. Annals of Botany 103, 1579–1588. https://doi.org/10.1093/aob/mcp076

Alkassab, A.T., Kirchner, W.H., 2017. Sublethal exposure to neonicotinoids and related side effects on insect pollinators: honeybees, bumblebees, and solitary bees. J Plant Dis Prot 124, 1–30. https://doi.org/10.1007/s41348-016-0041-0

Bart, D., 2022. Predictors of Calcareous Fen Floristic Quality in a Rapidly Urbanizing County. Wetlands 42. https://doi.org/10.1007/s13157-022-01595-x

Bell, J.R., Blumgart, D., Shortall, C.R., 2020. Are insects declining and at what rate? An analysis of standardised, systematic catches of aphid and moth abundances across Great Britain. Insect Conservation and Diversity 13, 115–126. https://doi.org/10.1111/icad.12412

Biological Records Centre, 2023. Urtica dioica. Biological Records Centre - Database of Insects and their Food Plants [WWW Document]. URL https://dbif.brc.ac.uk/hostsresults.aspx?hostid=6094 (accessed 11.17.23).

Boyes, D.H., Evans, D.M., Fox, R., Parsons, M.S., Pocock, M.J.O., 2021. Street lighting has detrimental impacts on local insect populations. Science Advances 7, eabi8322. https://doi.org/10.1126/sciadv.abi8322

Brereton, T., Roy, D.B., Middlebrook, I., Botham, M., Warren, M., 2011. The development of butterfly indicators in the United Kingdom and assessments in 2010. Journal of Insect Conservation 15, 139–151. https://doi.org/10.1007/s10841-010-9333-z

Brooks, D.R., Bater, J.E., Clark, S.J., Monteith, D.T., Andrews, C., Corbett, S.J., Beaumont, D.A., Chapman, J.W., 2012. Large carabid beetle declines in a United Kingdom monitoring network increases evidence for a widespread loss in insect biodiversity. Journal of Applied Ecology 49, 1009–1019. https://doi.org/10.1111/j.1365-2664.2012.02194.x

Buglife, 2023. B-Lines [WWW Document]. Buglife. URL https://www.buglife.org.uk/our-work/b-lines/ (accessed 11.16.23).

Cardoso, P., Barton, P.S., Birkhofer, K., Chichorro, F., Deacon, C., Fartmann, T., Fukushima, C.S., Gaigher, R., Habel, J.C., Hallmann, C.A., Hill, M.J., Hochkirch, A., Kwak, M.L., Mammola, S., Noriega, J.A., Orfinger, A.B., Pedraza, F., Pryke, J.S., Roque, F.O., Settele, J., Simaika, J.P., Stork, N.E., Suhling, F., Vorster, C., Samways, M.J., 2020. Scientists' warning to humanity on insect extinctions. Biological Conservation 242, 108427. https://doi.org/10.1016/j.biocon.2020.108426

Cavallaro, M.C., Main, A.R., Liber, K., Phillips, I.D., Headley, J.V., Peru, K.M., Morrissey, C.A., 2019. Neonicotinoids and other agricultural stressors collectively modify aquatic insect communities. Chemosphere 226, 945–955. https://doi.org/10.1016/j.chemosphere.2019.03.176

Coleman, R., 1981. Footpath erosion in the English Lake District. Applied Geography 1, 121–131. https://doi.org/10.1016/0143-6228(81)90029-1

Connor, E.F., McCoy, E.D., 1979. The Statistics and Biology of the Species-Area Relationship. The American Naturalist 113, 791–833. https://doi.org/10.1086/283438

Convention on Biological Diversity, 2023. 2030 Targets (with Guidance Notes) [WWW Document]. URL https://www.cbd.int/gbf/targets/ (accessed 1.16.24).

Cook, H.F., 2007. Floodplain nutrient and sediment dynamics on the Kent Stour. Water and Environment Journal 21, 173–181. https://doi.org/10.1111/j.1747-6593.2006.00061.x

Cranmer, L., McCollin, D., Ollerton, J., 2012. Landscape structure influences pollinator movements and directly affects plant reproductive success. Oikos 121, 562–568.

Dangles, O., Casas, J., 2019. Ecosystem services provided by insects for achieving sustainable development goals. Ecosystem Services 35, 109–115. https://doi.org/10.1016/j.ecoser.2018.12.002

Darvill, B., Ellis, J.S., Lye, G.C., Goulson, D., 2006. Population structure and inbreeding in a rare and declining bumblebee, Bombus muscorum (Hymenoptera: Apidae). Molecular Ecology 15, 601–611. https://doi.org/10.1111/j.1365-294X.2006.02797.x

Davis, B.N.K., 1983. Insects on nettles. Cambridge University Press, Cambridge.

De Frenne, P., Cougnon, M., Janssens, G.P.J., Vangansbeke, P., 2022. Nutrient fertilization by dogs in peri-urban ecosystems. Ecological Solutions and Evidence 3, e12128. https://doi.org/10.1002/2688-8319.12128

Department for Environment, Food & Rural Affairs, 2023a. Environment Improvement Plan 2023. HM Government.

Department for Environment, Food & Rural Affairs, 2023b. Local nature recovery strategies [WWW Document]. GOV.UK. URL https://www.gov.uk/government/publications/local-nature-recovery-strategies/local-nature-recovery-strategies (accessed 8.17.23).

Department for Environment, Food & Rural Affairs, 2022. National Pollinator Strategy: Pollinator Action Plan, 2021 to 2024.

Department for Levelling Up, Housing and Communities, 2023. National Planning Policy Framework.

Dicks, L.V., Viana, B., Bommarco, R., Brosi, B., Arizmendi, M. del C., Cunningham, S.A., Galetto, L., Hill, R., Lopes, A.V., Pires, C., Taki, H., Potts, S.G., 2016. Ten policies for pollinators. Science 354, 975–976. https://doi.org/10.1126/science.aai9226

Dobson, J., Fairclough, J., 2021. A Methodology for Assessing the Invertebrate Habitat Potential (IHP) of Terrestrial and Aquatic Habitats.

Drake, C.M., Lott, D.A., Alexander, K.N.A., Webb, J., 2007. Surveying terrestrial and freshwater invertebrates for conservation evaluation (No. NERR005). Natural England.

Duffus, N.E., Morimoto, J., 2022. Current conservation policies in the UK and Ireland overlook endangered insects and are taxonomically biased towards Lepidoptera. Biological Conservation 266, 109464. https://doi.org/10.1016/j.biocon.2022.109464

Ecogain, 2023. CLIMB - Changing land use impact on biodiversity [WWW Document]. URL http://climb.ecogain.se (accessed 12.19.23).

Ellis, J.S., Knight, M.E., Darvill, B., Goulson, D., 2006. Extremely low effective population sizes, genetic structuring and reduced genetic diversity in a threatened bumblebee species, Bombus sylvarum (Hymenoptera: Apidae). Molecular Ecology 15, 4375–4386. https://doi.org/10.1111/j.1365-294X.2006.03121.x

Falk, S., 2015. Field Guide to the Bees of Great Britain and Ireland. Bloomsbury, London.

Falk, S., Castle, T., 2019. Status and Conservation of the Bog hoverfly Eristalis cryptarum on Dartmoor. Buglife.

Forister, M.L., Pelton, E.M., Black, S.H., 2019. Declines in insect abundance and diversity: we know enough to act now. Conservation Science and Practice 1, e80. https://doi.org/10.1111/csp2.80

Freydier, L., Lundgren, J.G., 2016. Unintended effects of the herbicides 2,4-D and dicamba on lady beetles. Ecotoxicology 25, 1270–1277. https://doi.org/10.1007/s10646-016-1680-4

Garthwaite, D., Parrish, G., Ridley, L., 2020. Amenity Pesticide Usage in the United Kingdom 2020. Land Use and Sustainability Team, FERA.

Habel, J.C., Ulrich, W., Biburger, N., Seibold, S., Schmitt, T., 2019. Agricultural intensification drives butterfly decline. Insect Conservation and Diversity 12, 289–295. https://doi.org/10.1111/icad.12343

Hawkins, I., Smith, A., Addison, P., Malhi, Y., Whitney, M., zu Ermgassen, S.O.S.E., 2023. The potential contribution of revenue from Biodiversity Net Gain offsets towards nature recovery ambitions in Oxfordshire. Report by the University of Oxford and the Oxfordshire Local Nature Partnership.

Hawkins, I., zu Ermgassen, S.O.S.E., Grub, H., Treweek, Milner-Gulland, E.J., 2022. No Consistent Relationship Found Between Biodiversity Metric Habitat Scores and the Presence of Species of Conservation Priority. Inpractice 16–20.

Hodgson, J.A., Moilanen, A., Wintle, B.A., Thomas, C.D., 2011. Habitat area, quality and connectivity: Striking the balance for efficient conservation. Journal of Applied Ecology 48, 148–152. https://doi.org/10.1111/j.1365-2664.2010.01919.x

Hodgson, J.A., Thomas, C.D., Dytham, C., Travis, J.M.J., Cornell, S.J., 2012. The Speed of Range Shifts in Fragmented Landscapes. PLOS ONE 7, e47141. https://doi.org/10.1371/journal.pone.0047141

Joint Nature Conservation Commitee, 2023. C4a. Status of UK Priority Species - Relative Abundance.

Joint Nature Conservation Commitee, 2019. Common Standards Monitoring guidance | JNCC - Adviser to Government on Nature Conservation [WWW Document]. JNCC. URL https://jncc.gov.uk/our-work/common-standards-monitoring-guidance/ (accessed 8.18.23).

Kuli-Révész, K., Korányi, D., Lakatos, T., Szabó, Á.R., Batáry, P., Gallé, R., 2021. Smaller and isolated grassland fragments are exposed to stronger seed and insect predation in habitat edges. Forests 12, 1–12. https://doi.org/10.3390/f12010054

Lawton, J.H., Brotherton, P.N.M., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J., Wynne, G.R., 2010. Making Space for Nature: a review of England’s wildlife sites and ecological network. Report to Defra.

Levelling Up, Housing and Communities Committee, 2023. Reforms to national planning policy: Seventh Report of Session 2022-23. House of Commons.

Lyons, A., Ashton, P.A., Powell, I., Oxbrough, A., 2018. Epigeal spider assemblage responses to vegetation structure under contrasting grazing management in upland calcareous grasslands. Insect Conservation and Diversity 11, 383–395. https://doi.org/10.1111/icad.12287

MacKell, S., Elsayed, H., Colla, S., 2023. Assessing the impacts of urban beehives on wild bees using individual, community, and population-level metrics. Urban Ecosyst 26, 1209–1223. https://doi.org/10.1007/s11252-023-01374-4

Mancini, F., Hodgson, J.A., Isaac, N.J.B., 2022. Co-designing an Indicator of Habitat Connectivity for England. Frontiers in Ecology and Evolution 10.

Manninen, S., Forss, S., Venn, S., 2010. Management mitigates the impact of urbanization on meadow vegetation. Urban Ecosystems 13, 461–481. https://doi.org/10.1007/s11252-010-0129-4

Mason, S.C., Palmer, G., Fox, R., Gillings, S., Hill, J.K., Thomas, C.D., Oliver, T.H., 2015. Geographical range margins of many taxonomic groups continue to shift polewards. Biological Journal of the Linnean Society 115, 586–597. https://doi.org/10.1111/bij.12574

Mata, V.A., Ferreira, S., Campos, R.M., da Silva, L.P., Veríssimo, J., Corley, M.F.V., Beja, P., 2021. Efficient assessment of nocturnal flying insect communities by

combining automatic light traps and DNA metabarcoding. Environmental DNA 3, 398–408. https://doi.org/10.1002/edn3.125
Maxwell, S.L., Fuller, R.A., Brooks, T.M., Watson, J.E.M., 2016. Biodiversity: the ravages of guns, nets and bulldozers. Nature 536, 143–145. https://doi.org/10.1038/536143a
May, R.M., 1986. Biological diversity: How many species are there? Nature 324, 514–515. https://doi.org/10.1038/324514a0
Morris, R.K.A., Welch, M.D., 2023. Is invertebrate conservation in Great Britain best achieved by policies that increase species protection? J Insect Conserv 27, 527–531. https://doi.org/10.1007/s10841-023-00485-9
National Archives, 2023a. Wildlife and Countryside Act 1981 [WWW Document]. URL https://www.legislation.gov.uk/ukpga/1981/69 (accessed 8.17.23).
National Archives, 2023b. Natural Environment and Rural Communities Act 2006 [WWW Document]. URL https://www.legislation.gov.uk/ukpga/2006/16/contents (accessed 8.17.23).
National Archives, 2023c. Environment Act 2021 [WWW Document]. URL https://www.legislation.gov.uk/ukpga/2021/30/contents (accessed 12.19.23).
Natural England, 2023. The Biodiversity Metric 4.0 - JP039 [WWW Document]. Natural England - Access to Evidence. URL https://publications.naturalengland.org.uk/publication/6049804846366720 (accessed 8.17.23).
Natural England, 2022. Invertebrates: advice for making planning decisions [WWW Document]. GOV.UK. URL https://www.gov.uk/guidance/invertebrates-advice-for-making-planning-decisions (accessed 9.6.23).
Natural England, 2019. ARCHIVE SITE for the Biodiversity Metric 2.0, 3.0, 3.1 and the beta test version of the Small Sites Metric [WWW Document]. Natural England - Access to Evidence. URL https://publications.naturalengland.org.uk/publication/5850908674228224 (accessed 8.26.23).
Nichols, E., Spector, S., Louzada, J., Larsen, T., Amezquita, S., Favila, M.E., 2008. Ecological functions and ecosystem services provided by Scarabaeinae dung beetles. Biological Conservation 141, 1461–1474. https://doi.org/10.1016/j.biocon.2008.04.011

Oliver, T.H., Brereton, T., Roy, D.B., 2013. Population resilience to an extreme drought is influenced by habitat area and fragmentation in the local landscape. Ecography 36, 579–586. https://doi.org/10.1111/j.1600-0587.2012.07665.x

Ollerton, J., Erenler, H., Edwards, M., Crockett, R., 2014. Extinctions of aculeate pollinators in Britain and the role of large-scale agricultural changes. Science 346, 1360–1362. https://doi.org/10.1126/science.1257259

Parkes, D., Newell, G., Cheal, D., 2003. Assessing the quality of native vegetation: The 'habitat hectares' approach. Ecological Management & Restoration 4, S29–S38. https://doi.org/10.1046/j.1442-8903.4.s.4.x

Perkins, R., Whitehead, M., Civil, W., Goulson, D., 2021. Potential role of veterinary flea products in widespread pesticide contamination of English rivers. Science of The Total Environment 755, 143560. https://doi.org/10.1016/j.scitotenv.2020.143560

Powney, G.D., Carvell, C., Edwards, M., Morris, R.K.A., Roy, H.E., Woodcock, B.A., Isaac, N.J.B., 2019. Widespread losses of pollinating insects in Britain. Nature Communications 10. https://doi.org/10.1038/s41467-019-08974-9

Rampling, E.E., zu Ermgassen, S.O.S.E., Hawkins, I., Bull, J.W., 2023. Improving the ecological outcomes of compensatory conservation by addressing governance gaps: a case study of Biodiversity Net Gain in England. https://doi.org/10.31219/osf.io/avrhf

Raven, P.H., Wagner, D.L., 2021. Agricultural intensification and climate change are rapidly decreasing insect biodiversity. Proceedings of the National Academy of Sciences 118, e2002548117. https://doi.org/10.1073/pnas.2002548117

Rees, H.C., Maddison, B.M., Owen, J.P., Baker, C.A., Bishop, K., Gough, K.C., Webb, J.R., 2022. The Efficacy of DNA sequencing on samples of terrestrial invertebrates 2018/2019 (No. NECR388). Natural England.

Ritter, C.D., Häggqvist, S., Karlsson, D., Sääksjärvi, I.E., Muasya, A.M., Nilsson, R.H., Antonelli, A., 2019. Biodiversity assessments in the 21st century: the potential of insect traps to complement environmental samples for estimating eukaryotic and prokaryotic diversity using high-throughput DNA metabarcoding. Genome 62, 147–159. https://doi.org/10.1139/gen-2018-0096

Rösch, V., Tscharntke, T., Scherber, C., Batáry, P., 2013. Landscape composition, Connectivity and fragment size drive effects of grassland fragmentation on

insect communities. Journal of Applied Ecology 50, 387–394. https://doi.org/10.1111/1365-2664.12056
Rossetti, M.R., Tscharntke, T., Aguilar, R., Batáry, P., 2017. Responses of insect herbivores and herbivory to habitat fragmentation: a hierarchical meta-analysis. Ecology Letters 20, 264–272. https://doi.org/10.1111/ele.12723
Rukke, B.A., 2000. Effects of habitat fragmentation: increased isolation and reduced habitat size reduces the incidence of dead wood fungi beetles in a fragmented forest landscape. Ecography 23, 492–502. https://doi.org/10.1111/j.1600-0587.2000.tb00305.x
Samways, M.J., Barton, P.S., Birkhofer, K., Chichorro, F., Deacon, C., Fartmann, T., Fukushima, C.S., Gaigher, R., Habel, J.C., Hallmann, C.A., Hill, M.J., Hochkirch, A., Kaila, L., Kwak, M.L., Maes, D., Mammola, S., Noriega, J.A., Orfinger, A.B., Pedraza, F., Pryke, J.S., Roque, F.O., Settele, J., Simaika, J.P., Stork, N.E., Suhling, F., Vorster, C., Cardoso, P., 2020. Solutions for humanity on how to conserve insects. Biological Conservation 242, 108427. https://doi.org/10.1016/j.biocon.2020.108427
Sánchez-Bayo, F., 2014. The trouble with neonicotinoids. Science 346, 806–807. https://doi.org/10.1126/science.1259159
Schiegg, K., 2000. Effects of dead wood volume and connectivity on saproxylic insect species diversity. Ecoscience 7, 290–298. https://doi.org/10.1080/11956860.2000.11682598
Schirmel, J., Mantilla-Contreras, J., Blindow, I., Fartmann, T., 2011. Impacts of succession and grass encroachment on heathland Orthoptera. J Insect Conserv 15, 633–642. https://doi.org/10.1007/s10841-010-9362-7
Scottish Government, 2023. Measuring biodiversity: research into approaches [WWW Document]. URL http://www.gov.scot/publications/research-approaches-measuring-biodiversity-scotland/pages/2/ (accessed 12.19.23).
Seibold, S., Gossner, M.M., Simons, N.K., Blüthgen, N., Müller, J., Ambarlı, D., Ammer, C., Bauhus, J., Fischer, M., Habel, J.C., Linsenmair, K.E., Nauss, T., Penone, C., Prati, D., Schall, P., Schulze, E.D., Vogt, J., Wöllauer, S., Weisser, W.W., 2019. Arthropod decline in grasslands and forests is associated with landscape-level drivers. Nature. https://doi.org/10.1038/s41586-019-1684-3

Sirohi, M.H., Jackson, J., Ollerton, J., 2022. Plant–bee interactions and resource utilisation in an urban landscape. Urban Ecosyst 25, 1913–1924. https://doi.org/10.1007/s11252-022-01290-z

Smith, D.F.Q., Camacho, E., Thakur, R., Barron, A.J., Dong, Y., Dimopoulos, G., Broderick, N.A., Casadevall, A., 2021. Glyphosate inhibits melanization and increases susceptibility to infection in insects. PLOS Biology 19, e3001182. https://doi.org/10.1371/journal.pbio.3001182

Smith, R.J., Cartwright, S.J., Fairbairn, A.C., Lewis, D.C., Gibbon, G.E.M., Stewart, C.L., Sykes, R.E., Addison, P.F.E., 2022. Developing a nature recovery network using systematic conservation planning. Conservation Science and Practice 4, e578. https://doi.org/10.1111/csp2.578

Steffan-Dewenter, I., Tscharntke, T., 2002. Insect communities and biotic interactions on fragmented calcareous grasslands - A mini review. Biological Conservation 104, 275–284. https://doi.org/10.1016/S0006-3207(01)00192-6

Stein, A., Gerstner, K., Kreft, H., 2014. Environmental heterogeneity as a universal driver of species richness across taxa, biomes and spatial scales. Ecology Letters 17, 866–880. https://doi.org/10.1111/ele.12277

Timberlake, T.P., Vaughan, I.P., Memmott, J., 2019. Phenology of farmland floral resources reveals seasonal gaps in nectar availability for bumblebees. Journal of Applied Ecology 56, 1585–1596. https://doi.org/10.1111/1365-2664.13403

UKCEH, 2023. UKCEH AMI-trap | UK Centre for Ecology & Hydrology [WWW Document]. URL https://www.ceh.ac.uk/solutions/equipment/automated-monitoring-insects-trap (accessed 1.16.24).

Wagner, D.L., 2020. Insect declines in the Anthropocene. Annual Review of Entomology 65, 457–480. https://doi.org/10.1146/annurev-ento-011019-025151

Warren, M.S., Maes, D., Swaay, C.A.M. van, Goffart, P., Dyck, H.V., Bourn, N.A.D., Wynhoff, I., Hoare, D., Ellis, S., 2021. The decline of butterflies in Europe: Problems, significance, and possible solutions. Proceedings of the National Academy of Sciences 118, e2002551117. https://doi.org/10.1073/pnas.2002551117

Webb, J., Heaver, D., Lott, D., Dean, H.J., van Breda, J., Curson, J., Harvey, M.C., Gurney, M., Roy, D.B., van Breda, A., Drake, M., Alexander, K.N.A., Foster, G., 2018. Pantheon [WWW Document]. Pantheon - database version 3.7.6. URL https://pantheon.brc.ac.uk/about/pantheon (accessed 9.12.23).

Weston, P., 2021. New biodiversity algorithm 'will blight range of natural habitats in England.' The Guardian.

Wilson, R., 2021. Are We Delivering Biodiversity Net Gain? Do Broad Habitat Metrics Mask Biodiversity Net Loss and Can a Focus on Invertebrates Help? Inpractice 113.

Woodcock, B.A., McDonald, A.W., 2010. What goes wrong? Why the restoration of beetle assemblages lags behind plants during the restoration of a species rich flood-plain meadow. Fritillary.

Woodcock, B.A., McDonald, A.W., Pywell, R.F., 2011. Can long-term floodplain meadow recreation replicate species composition and functional characteristics of target grasslands? Journal of Applied Ecology 48, 1070–1078. https://doi.org/10.1111/j.1365-2664.2011.02029.x

zu Ermgassen, S.O.S.E., Baker, J., Griffiths, R.A., Strange, N., Struebig, M.J., Bull, J.W., 2019. The ecological outcomes of biodiversity offsets under "no net loss" policies: A global review. CONSERVATION LETTERS 12. https://doi.org/10.1111/conl.12664