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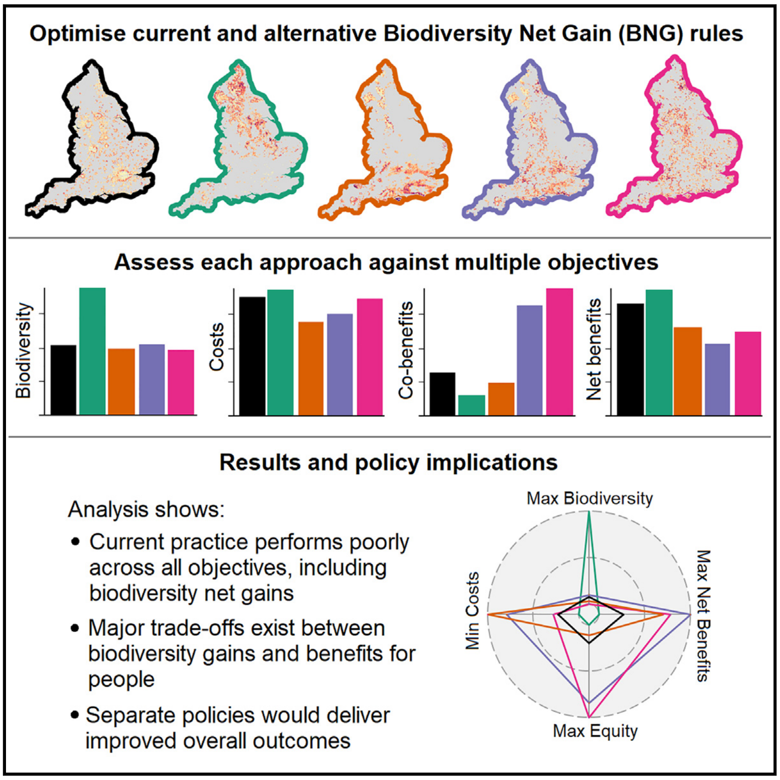
Biodiversity offsets perform poorly for both people and nature, but better approaches are available

Graphical abstract



Highlights

- Local planning constraints deliver poor biodiversity net gain (BNG) offsets
- Removing those constraints results in significant BNG improvements
- Alternatively, offsets can deliver gains in environmental access

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In brief

Biodiversity net gain (BNG) legislation requires developers in England to offset their impacts on wild species. We show that current guidelines generally capture offsets within local planning zones, resulting in relatively poor outcomes for biodiversity. Removing this planning capture would substantially enhance BNG. Alternatively, offsets could benefit communities with poor access to high-quality environments. Future strategies should consider combining these latter approaches.

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Article

Biodiversity offsets perform poorly for both people and nature, but better approaches are available

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SCIENCE FOR SOCIETY The ongoing biodiversity loss crisis has prompted worldwide interest in ensuring that new developments offset impacts upon nature through biodiversity net gain (BNG) projects, creating habitats for wild species. However, implementation of BNG projects in England favors offsets being located near new developments, in part to provide recreational benefits to local communities. We show that this approach ignores the wildlife benefits of areas where biodiversity gains could be much greater. Furthermore, we reveal that those disadvantaged communities that suffer the most degraded environments are also overlooked by current practices. A variety of alternative approaches to implementing BNG offsets are identified and assessed, including options for producing better biodiversity or improved access outcomes at no greater cost.

SUMMARY

Sustainability requires that we restore biodiversity and wider ecosystem services, yet developments such as new housing inevitably cause environmental impacts. Accordingly, developers are increasingly required to resource offset projects, delivering biodiversity or wider environmental net gains. However, analyses of offsets in England show that the large majority are conducted within development sites rather than targeted toward better opportunities for net gains elsewhere. Here, we compare current and alternative approaches to offsetting considering the biodiversity gains, ecosystem service co-benefits, and economic costs they generate. The results confirm that the current practice performs relatively poorly across all criteria. Analysis shows that by incorporating ecological and economic information into the targeting of offsets, they can provide a significant contribution to addressing the challenge of biodiversity loss or deliver substantial ecosystem service co-benefits to disadvantaged communities. The analytical methods and results presented here could support a substantial improvement in the operation and outcomes of biodiversity offsetting globally.

INTRODUCTION

Alongside conservation concerns,[1,2] adequate housing is a basic human right,[3,4] and under the Sustainable Development Goals (SDGs), there is an international commitment to expand built infrastructure (SDG 9).[3] However, this sets up a potential conflict with the simultaneous commitment to end biodiversity loss (SDG 15).[3] The recent UN Convention on Biological Diversity (CBD) Post-2020 Global Biodiversity Framework[5] requires signatory countries to halt and reverse the loss of biodiversity by 2030. Given the need for both new infrastructure and conservation enhancement, "net" biodiversity gain policies have gained attention.[6] These aim to limit the negative environmental impacts of development on a site while allowing some loss of biodiversity that is compensated for by offsets (biodiversity enhancements) elsewhere. One such policy is "biodiversity net gain" (BNG),[7] which has gained attention as a way to limit the net-negative environmental impacts of development.[1] Under BNG principles, biodiversity losses from development need to be more than offset by improvements elsewhere.[7–10] BNG policies have become widely embedded in both national and international policy discourse, as well as in business and finance.[1,8,11–13] For example, England's 2021 Environment Act mandates that for planning permission to be granted, all developments are required to deliver BNGs with a minimum uplift in biodiversity of 10%.[14] This policy has few exceptions, is considered an important contribution toward halting further biodiversity loss,[15] and has been internationally acclaimed by some as "the most ambitious biodiversity policy in the world."[16]

While the BNG principle has been well received, it is its mode of implementation that will determine the practical effectiveness of the policy. Spatial targeting of offsets is particularly important, as the effectiveness of management interventions to improve biodiversity and natural capital landscapes is context dependent.[17] However, many land use policies (for example, agricultural subsidies[18,19]) are applied at uniform rates across all areas irrespective of the fact that the natural and human environment and corresponding benefits of change vary vastly between locations. This means that, at best, the limited funds available for environmental improvement are allocated inefficiently, delivering poorer outcomes, while at worst, this approach encourages the wrong activities in the wrong places (for example, planting trees in high-carbon soils, leading to a net increase in greenhouse gas emissions[20]). Quite obviously, the spatial targeting of BNGs to places that are poor for biodiversity will do little to bend the curve on biodiversity loss.[21] Similarly, if we are interested in enhancing access to high-quality environments for disadvantaged groups, then an implementation mechanism that targets BNG offsets in order to minimize their cost or ties them to the sites of infrastructure development is unlikely to provide high value for money in terms of addressing inequality. As such, land use policy and its implementation should not implicitly treat the natural environment as homogeneous but rather should incorporate environmental and social variability into both the formulation and implementation of policy.

While net gain for biodiversity is the stated motivator for BNG in England, official guidance also adds a second policy objective requiring that offsets should also be "of clear benefit to people and local communities."[22] Indeed, the BNG "spatial hierarchy" adopted does not target either biodiversity or disadvantaged groups, instead simply preferring on-site or near-site offsets to more distant off-site compensation.[23–25] Given this, a key research need is to understand the degree to which the adopted spatial hierarchy delivers against biodiversity and social equity goals, a need that has relevance well beyond the use of BNG in England.[17,26]

The current BNG spatial hierarchy is further incorporated into a "mitigation hierarchy"[9,27] where, once opportunities for avoiding damage are exhausted,[15] on-site or near-site offsets are given precedence over more distant options. The explicit bias toward on-site and near-site offsets is incorporated as a "spatial risk multiplier" within England's biodiversity metric,[28] a habitat-based assessment tool developed to estimate pre- and post-development biodiversity. The inclusion of the spatial risk multiplier systematically reduces the "biodiversity value" of offset sites located outside the development's local planning authority[28] so that a more substantial improvement occurring at distance from the development site can be accorded a lower value than a smaller improvement near that development. Higher weighting of local offsets is further supported within the National Planning Policy Framework.[25] Unsurprisingly, analyses of early adopters of BNG show that the majority of offsetting sites are typically located within or near development sites.[2]

While local offsetting is administratively straightforward, it gives local planners additional incentives to permit more development as BNG benefits are captured locally, which may in itself have undesirable impacts if biodiversity offsets are inadequate. This aside, from an ecological perspective, the current approach to BNG is difficult to defend. Proximity in itself does not ensure fungibility, as offsets are, by definition, substitutes for the original habitat. The "ecological equivalence" of offsets is evaluated according to a metric that reflects a hierarchy of values set by institutional perceptions of stakeholder preferences regarding the aspects of nature to be prioritized[12,29] rather than solely conservation priorities. An emphasis on proximity may result in inefficient outcomes for conservation at a national scale, thus wasting resources that could be targeted to generate far greater biodiversity improvements. Perhaps most importantly, the bias toward local offsetting ignores the well-established need to restore coherent national networks of conservation habitats[30] and address the central problem of biodiversity loss.[31,32]

From a social perspective, the local focus also disregards national concerns over recreational access to nature. The UK's National Planning Policy Framework[25] specifies that "opportunities to improve biodiversity in and around developments should be integrated as part of their design, especially where this can secure measurable net gains for biodiversity or enhance public access to nature where this is appropriate" (p. 52, para. 180). However, this specification limits considerations of access to the development site and does not consider wider socio-economic inequalities associated with greenspace access in England.[33] Consequently, the local approach may be unfair to disadvantaged groups currently suffering the most degraded environments,[34] doing nothing for problems of poor well-being, health care needs, and lower overall life expectancy.[35–37] Such neighborhoods are typically unattractive for developers and therefore unlikely to benefit from BNG policies biased toward offsets near developments.

More generally, any offsetting strategy needs to explicitly acknowledge that tradeoffs are an inherent feature of land management, involving not only conservation objectives but also human livelihoods and well-being.[38–45] Further, evidence shows that localized mitigation activities often result in highly dispersed conservation projects that generate limited ecological benefits but impose substantial oversight burden on the regulatory community.[46] In contrast, landscape- and national-scale planning with a habitat network perspective (e.g., providing effective linkage between existing, fragmented conservation habitats) is both more cost effective and more ecologically effective for promoting biodiversity gains.[30,46]

Table 1. BNG offset scenarios and corresponding rules for the selection of offset sites

Offset scenario	Rules for selecting offset site
(1) Local offset (status quo)	offset within or adjacent to construction/infrastructure site (current practice)
(2) Maximize conservation benefits	offset where the highest improvements for a set of species of conservation priority can be achieved
(3) Minimize costs	offset where the major costs of offsetting (compensation to landowners) are minimized
(4) Maximize access co- benefits minus costs	offset where the sum of the monetized co-benefits of offsetting (access for recreation) minus the offsetting cost is maximized
(5) Maximize equity-weighted access co-benefits	using HM government allowances,[49] giving higher weights to the co-benefits received by those with lower incomes

As a local approach is no guarantee of win-win outcomes from BNG offsetting, here we show the potential for improvements arising from removing the current bias in favor of local offsets. To do so, we use existing models of biodiversity and ecosystem services[47,48] to quantify species richness for a set of species of conservation priority[48] (details in assessing the biodiversity response to land use change and supplemental information SI-3), assess recreational access co-benefits[47] (assessing the recreational access co-benefits of land use change and co-benefits minus costs; supplemental information SI-5), and calculate the costs of offsetting (the major element of which is the compensation farmers and landowners require for land use change; assessing the costs of land use change; supplemental information SI-4).[47] These models are applied across England to five scenarios, each examining a different rule for BNG offsetting (applying the offsetting rules; supplemental information SI-7): (1) local offsetting (the status quo), (2) maximize conservation benefits, (3) minimize costs, (4) maximize co-benefits (access) minus costs, and (5) maximize equity-weighted co-benefits. Table 1 details the rules used in each scenario.

To clearly demonstrate the different consequences of these approaches to offsetting, each of the rules given in Table 1 was applied to estimates of housing developments across England over a 25 year period[50] (modeling urban expansion and the demand for offset land; supplemental information SI-2). We assessed the expected change in species richness[51] for a set of 100 species of conservation priority, the value of recreational access co-benefits (assessed using standard economic techniques), and the expected costs of the scheme (compensation to landowners). Following the common practices of offsetting to date,[52] we assume that offset areas are the same size as development areas. Offsets were modeled as the conversion of agricultural farmland to semi-natural grassland, both the most common habitat type delivered through BNG so far[53] and an outcome land use applicable throughout the study area. This ensured that assessments were determined by biodiversity, co-benefit, and cost outcomes alone and not influenced by variation in the offset habitat type. Optimization according to each of the offset rules used in each scenario was achieved using the natural environmental valuation (NEV) decision support system[47,54] (which underpinned the UK National Ecosystem Assessment[55,56]; further details, along with additional information on each scenario, are provided in the experimental procedures and supplemental information). Using these scenarios, we show that removing the current bias toward local offsetting and instead targeting offsets according to expected outcomes can provide superior improvements in biodiversity, cost effectiveness, and equity.

RESULTS

Just over 300,000 ha of farmland are expected to be lost to development across England over the 25 year analysis period. This area was allocated via each of the five scenarios shown in Table 1, and the differing rules for each were applied to generate the offset locations shown in Figure 1A. As can immediately be seen, changing the offset rules radically alters the offsetting locations. While the (1) current bias toward development sites skews offsets to the environs of major cities (the ring of offsets around London is particularly prominent), (2) maximizing conservation priority radically alters this by favoring locations where species of conservation concern would benefit most from offsetting. Minimizing costs (3) moves offsets away from prime-value farmland in the east of the country, a pattern echoed in the maximization of access co-benefits minus those costs (4). In comparison to the latter, the weighting of access co-benefits toward disadvantaged communities (5) shifts offset locations away from the generally affluent south-east of England.

The radar chart in Figure 1B compares all five offset scenarios. Here, the closer it is to the edge of the chart, the more a scenario delivers against the goals set at each compass point. Perhaps most noticeable is the poor performance of the current implementation of BNG (scenario 1, shown in black) across all criteria. This approach is outperformed on all criteria by other rules (e.g., scenario 4, the maximization of co-benefits minus costs dominates current implementation on all counts). Removing the bias toward local implementation and allowing offsets in locations that are best for biodiversity (scenario 2) produces much better outcomes for species of conservation concern (i.e., BNG focused on biodiversity rather than largely human preferences) than current implementation, although at the cost of poor performance across other criteria.

Details of these measures for all scenarios are given in the histograms of Figure 1C. While the current practice of scenario 1 performs relatively poorly against the central stated aim of the BNG policy, scenario 2 doubles the conservation gains achieved by local offsetting, although it performs poorly against other criteria. Similarly, scenario 3, which locates offsets so as to minimize costs, also performs poorly against other criteria, although it still outperforms the status quo in terms of its net

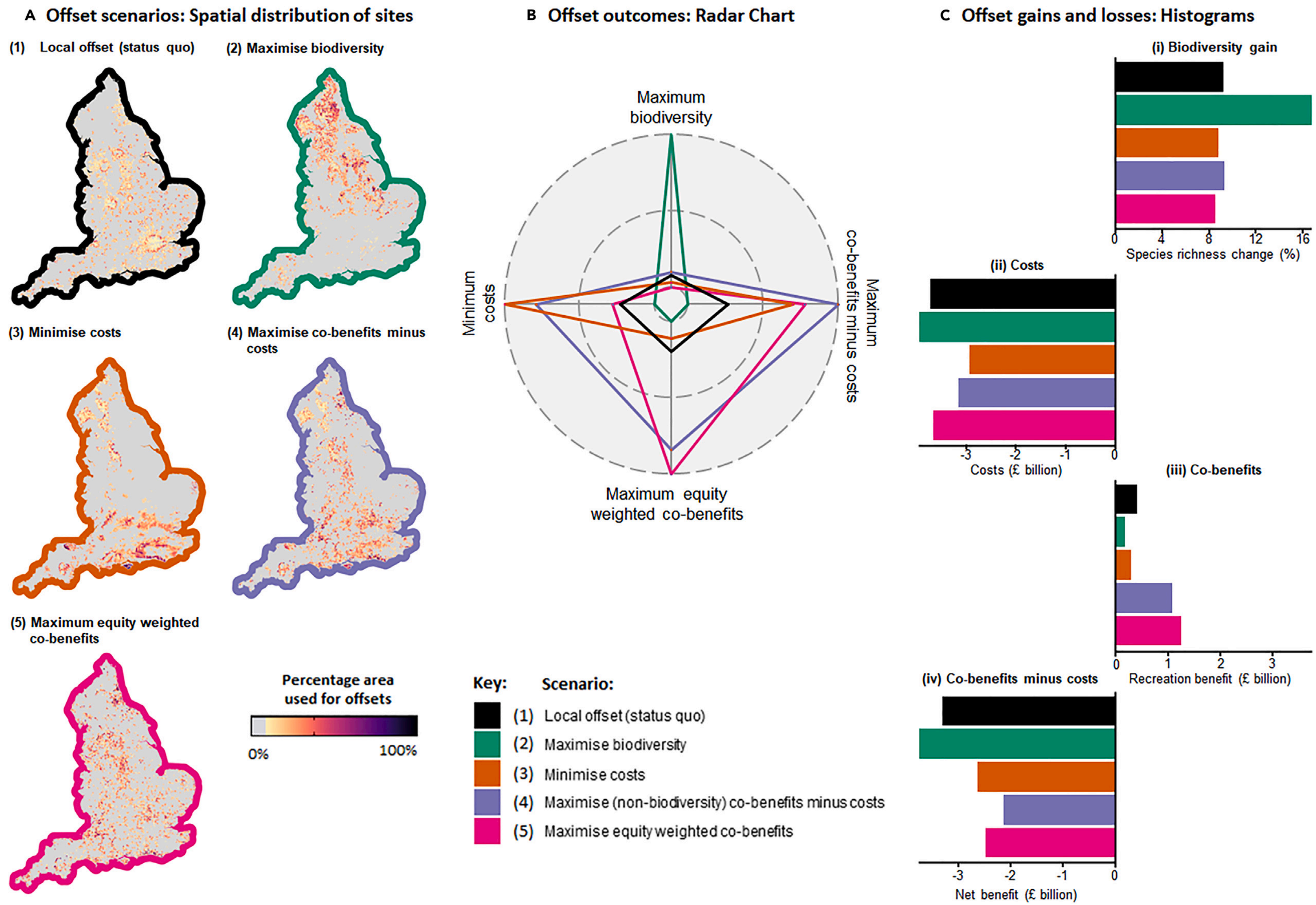

Figure 1. Alternative scenarios for BNG offset rules

(A) The location and area of offsets under each scenario: (1) local offset (status quo), (2) maximize conservation priority, (3) minimize costs (market allocation of offset locations), (4) maximize co-benefits (access for recreation) minus costs, and (5) maximize equity-weighted co-benefits.

(B) Radar chart comparing the relative performance of the biodiversity net gain (BNG) scenarios across four criteria: maximum biodiversity, minimum costs, maximum co-benefits minus costs, and maximum equity-weighted co-benefits.

(C). Scenario-specific values for four measures: (i) gains in species richness for species of conservation priority, (ii) costs, (iii) co-benefits, and (iv) co-benefits minus costs.

co-benefits minus costs. The latter measure is maximized by scenario 4, which also performs well against all other criteria except conservation improvements (although even here it marginally outperforms the status quo). In comparison to this, scenario 5 trades off to varying degrees across criteria while delivering the best outcomes in terms of equity-weighted co-benefits for disadvantaged communities. It is worth noting that while Scenario 2 maximizes conservation gains, it performs the worst when it comes to equity-weighted benefits from accessing nature. Equally, while scenario 5 maximizes equity-weighted benefits from accessing nature, it yields the lowest levels of biodiversity improvements for species of conservation priority, illustrating the existing tradeoffs between improving biodiversity and making nature accessible even before the influence of human disturbance on biodiversity is accounted for.

Finally, Figure 1Civ reveals that, in purely monetary terms, all scenarios generate net costs. This shows that protecting biodiversity is not a cost-free undertaking, with the current approach delivering the second-highest net costs.

DISCUSSION

Our findings prompt a number of conclusions, the first being that in our modeling framework, the current practice of encouraging local offsetting delivers relatively poor biodiversity gains at high costs and with low co-benefits. If the commonly adopted practice of local offsetting continues,[2] then it may result in highly inefficient use of resources to deliver suboptimal biodiversity gains.

Addressing biodiversity loss requires a coordinated approach, and constraining offsets to the proximity of development sites does not support the widely recognized need to embed biodiversity policies within a coherent conservation network.[30] While some defend local offsets as more likely to deliver like-for-like ecological equivalence,[57] the very concept of offsetting embodies the idea of some form of trade between surrogates. "In-kind" considerations assume substitutability of ecological communities, and the outcomes depend on the specific metric adopted[12,27] (note that the CBD definition of biodiversity excludes the notion of an ecologically equivalent offset).

BNG offsets are (at least in name) supposed to benefit species of conservation concern, but one anthropocentric argument for local offsetting might be that it compensates those who have lost out from development via reduced opportunities for recreation and associated health benefits.[10,58] However, one case study assessment demonstrates the risk that, instead of being designed to benefit those who have suffered losses from the development (i.e., those who lived in the area previously and used that site for access to nature), offsets are located to the best advantage of those living in the new homes created by the developer, with houses nearest to such offsets being sold at a premium.[34] By building on greenspace, we necessarily see access worsen for those who already lived in the surrounding area previously, and research clearly shows a strong distance decay (particularly for poorer communities) in the value of recreational space as its distance from households increases.[59–61] In other words, local offsetting as currently implemented has the potential to reward the "winners" from developments with ready access to high-quality environments rather than compensating the "losers" for their reduced access to nature.[34] More importantly though, local offsets ignore the potential for BNG regulation to benefit those who suffer the worst environments, in areas where developers build fewer houses and local offsetting will rarely apply.

As Figure 1B shows, while there is no single, unambiguously dominant, win-win approach to offsetting, by combining natural science and economic insights, we can identify alternatives to the status quo that, if taken together, can provide far superior outcomes than the current practice of local offsetting. Scenario 2 shows that readily available information on the consequences of alternative offsetting sites for species of conservation importance means that a redesigned BNG policy could significantly contribute to policy goals of reversing biodiversity decline. Similarly, scenarios 4 and 5 show that offsets can significantly enhance access to nature both generally and for disadvantaged communities. Both biodiversity restoration and access enhancements are identified as targets in the UK National Planning Policy Framework.[25] Therefore, a reformed BNG strategy should consider an efficient mix of dedicated pro-biodiversity, pro-access, and pro-equity offsets, each with its targeted and specifically designed policy tools. Our analysis of scenario 3 provides a warning: a simplistic, accountancy-driven policy of minimizing the costs of offsetting produces very poor value outcomes in both biodiversity and access terms. The beguiling attractions of schemes to cut costs must be resisted in favor of principles that boost the net value of outcomes.

Our results provide an illustration of the Tinbergen Rule[62,63] that if there are two (or more) policy objectives that are not perfectly correlated, then a single policy instrument cannot optimize both. Either one accepts this and finds the most preferred tradeoff between objectives or the budget associated with the regulation is divided according to socially optimally outcomes, and each objective maximized in line with those allocated resources. Here, the objectives of biodiversity gain and access improvement seem most pertinent. Dividing the resources raised by the BNG between scenarios 2 and 5 would provide a useful alternative to any single strategy.

In a diverse natural and human environment, exceptions can occur. While our analysis highlights the inefficiencies of setting up rules that bias outcomes in favor of local offsetting, areas local to a development could, of course, be chosen if they are indeed the best locations for biodiversity offsetting or the provision of access to nature. Similarly, common species should not be ignored, especially if they are becoming a conservation concern or contribute to recreational benefits.[64] However, rules should not be constructed to bias offset decision-making into consideration of anything but their intended outcomes. Another consideration concerns ecological fungibility. If offsetting occurs near to the location of ecological loss, then problems regarding the comparability or substitutability of species may be less likely to arise. However, such an approach fails to prioritize those species at greatest risk and is therefore less likely to contribute to the wider need to bend the curve on biodiversity loss. Similar arguments can be constructed with regard to recreational access; while local constraints may benefit local communities, they are unlikely to help those disadvantaged groups facing the most degraded environments and in the greatest need.

Given the serious flaws evident in current practices, why has this approach been adopted? One likely reason appears to be that flexibility within the biodiversity metric makes it relatively cheap for developers to meet their regulatory liabilities within their own development footprint. Recognized inadequacies in mechanisms for the governance, monitoring, or enforcement of on-site biodiversity gains[53] also mean that a developer faces lower risks of being found non-compliant with BNG regulations when on-site rather than off-site offsetting is adopted. Secondly, implementing BNG on site has been perceived by regulators as helping achieve BNG's explicit policy objective to be ''of clear benefit to people and local communities.'' However, as our results show, such an assertion fails to account for the complexities of such benefits and, in particular, greatly constrains the potential for offsets to benefit disadvantaged communities. A third, political economy argument is that the local capture of offsetting benefits within planning authorities incentivizes these institutions to accept housing development proposals.[65] A fourth driver of the status quo might be institutional challenges in coordinating the implementation of BNG nationally when the main level of government responsible for the practical implementation of BNG delivery is the local authority. However, evidence on strategic planning gain[46] suggests that the intervention of a national-level authority, such as Defra, would remove significant and repeated administrative burdens across all planning authorities and, hence, almost certainly reduce overall costs and improve effectiveness.

The new UK government has made it abundantly clear that it intends to deliver on its plans to build 1.5 million new homes over the next 5 years but has also informed wildlife non-governmental organizations (NGOs) of its intentions to do this in a way that enhances nature.[66] Our results clearly show that extending the present approach would, at best, be highly inefficient and expensive and fail to seize the real opportunities available to bend the curve of biodiversity loss (and do little to address access inequalities). The core concept underpinning BNG is a sound extension of the polluter pays principle but, as Barber[67] notes, in delivering change, ''policy is 10% and implementation 90%''; regrettably, BNG has provided a further example of an excellent idea being poorly implemented.

A general conclusion, applicable across all regions and countries, is that when policies and their implementation ignore the natural variability in the environment, there is always a cost, typically both environmental and social. Within the context of BNG, while the underlying concept is sound and does indeed raise the potential for biodiversity to be incorporated into decision-making (a potential that extends well beyond the context of house building), the implementation of this policy incurs major opportunity costs. Tying offsets within the environs of the development that necessitates them ignores the potential for much greater improvements to biodiversity elsewhere. Similarly, from a human perspective, the potential for offsets to address the most needy and disadvantaged communities is negated by constraining them within development planning areas. The simple and very general principle is that ignoring the natural variability of the environment will always impair the effectiveness of the often limited funds available for environmental improvement. We already have the knowledge to make policies and their implementation sensitive to environmental and social variation—we simply need to start using that information.

EXPERIMENTAL PROCEDURES

This section outlines the modeling processes to assess the biodiversity gains, access co-benefits and costs of undertaking offsets in any location across England, and implement the offsetting rules defined by each scenario. Further information is provided in the supplemental information, and all output data are available upon request.

Baseline land cover

The baseline land cover was taken from the CEH 25 m resolution raster Land Cover Map (LCM 2000).[68] This reports land use across a detailed set of categories, a summary of which is provided in the supplemental information.

Note that the land use model described below uses agricultural data, which, to ensure the anonymity of financial records of individual farmers, are aggregated up to a 400 ha (i.e., 2 × 2 km) spatial grid. These data inform the analyst of the precise area (specified to fractions of a hectare) of each land use within the grid square but not the precise location of that area within the grid, thereby ensuring that the private records of each farmer cannot be reconstructed. For this reason, the uncertainty of costing estimates (which are driven by the profitability of land) increases below the resolution of grid square, and we report findings at a consistent 400 ha grid level throughout.

Modeling urban expansion and the demand for offset land

Expected locations of development and its extent (and hence the area required for offsetting) were determined using the model of urban expansion at constant housing densities over a 25 year period proposed by Eigenbrod et al.[50] This provided the number of hectares within each grid square converted from farm to developed land over this period. In line with existing environmental policies, areas under forest and peatlands were deemed ineligible for urban expansion. We focused on housing (rather than industry or nationally strategic infrastructure such as railways, motorways, and roads) as the primary contributor to the loss of greenspaces in Great Britain.[69]

Assessing the biodiversity response to land use change

The UK Joint Nature Conservation Committee (JNCC) biodiversity modeling framework,[48] which follows Croft et al.,[70] links biophysical land characteristics, climate-related variables, and land use to measures of species richness. As such, it provides an assessment of the biodiversity consequences of land use change taking into account all the site-specific, climate change, and other factors that impinge on such responses (see supplemental information). The JNCC model was incorporated within the NEV decision support framework[47] to assess the impact of land use change on biodiversity at a high degree of spatial resolution across all of England. Assessments were made for 100 at-risk species, representing a variety of taxonomic groups (birds, herptiles, invertebrates [including bees, beetles, butterflies, crickets, moths, and snails], lichen, mammals, and vascular plants); see supplemental information SI-4 for further details.

Assessing the costs of land use change

Given that the costs of converting any of the 9% of England under urban use[69] would be prohibitive and the 10% of land under forest[71] is protected (and due to rise very significantly to address net-zero commitments),[72] offsets will have to occur on the remaining land, the very large majority of which is agricultural.[73] The major cost of such land is determined by the opportunity cost of foregone agricultural output. This varies very substantially across England, being generally highest in the eastern lowlands, where productive soils and an absence of limitations on machinery use across the year result in excellent agricultural returns, and lower in upland areas or where poor soils dominate and waterlogging prevents year-round access to machinery. The simple application of average values would therefore provide highly misleading results in our offset analysis. Use is therefore made of the high-spatial-sensitivity agricultural model developed by Bateman et al., combining data provided by the UK Farm Business Survey and Agricultural Census.[55,74,75] This provides grid-referenced data stretching from the late 1960s to the present day, which, when adjusted to present-day prices, provide a rich information source capturing variation in agricultural values across locations taking into account a multitude of biophysical determinants, including climate change (see supplemental information). As per the biodiversity analysis, the agricultural model and resultant cost estimator were incorporated within the NEV decision support framework[47,54] to ensure consistent assessments.

Assessing the recreational access co-benefits of land use change and co-benefits minus costs

As noted, official guidelines emphasize co-benefits of offsets in terms of recreational access benefits. There is very substantial literature on the theory and practice of the economic valuation of access to the natural environment.[76,77] Within this, the dominant approach is to assess the preferences and values of individuals as revealed by their recreational behavior. By examining variation in the number (or absence) of recreational trips from individual's points of origin (typically their home address) to different sites and taking into account a comprehensive set of determining factors (including the socio-economic and other characteristics of the individual; the availability of other recreational and non-recreational options; the attributes of those options, including the type of recreational experience offered, landscape type, environmental quality measures, etc.; and the costs of travel and travel time between origin and visited site), the analyst can observe the recreational preferences and values revealed in the choices individuals make.

Data on visitation behavior are taken from the Monitor of Engagement with the Natural Environment (MENE),[78] which uses a nationally representative, household-level, annual sample to record the origin and destination of recreational activities. GIS software is used to convert this into travel time and cost estimates, which are then combined with census, land use, site and substitute-site attributes, linear features (e.g., rivers), and infrastructure (ranging from major roads to walking path information) data. These data are then analyzed within the Outdoor Recreation Valuation (ORVal) model,[79,80] which uses state-of-the-art revealed preference methods[76,77] to assess the number and value of visits to recreational sites by all households across the entire country. The ORVal model allows us to predict how likely it is that an individual will take a trip to a particular greenspace on a particular day. This likelihood differs according to the attributes of the person, the greenspace, and all other available greenspaces. The ORVal model also allows us to estimate a welfare function, which describes how much welfare an individual enjoys as a result of beneficial attributes of a greenspace and how much welfare is lost from each extra pound of cost incurred in traveling to a greenspace. The latter provides an exchange rate that we can use to convert estimates of changes in welfare into equivalent amounts of money, as it reveals the amount of welfare that a person considers to be equivalent to having one extra pound. Welfare values for an existing site are estimated by calculating how much each individual's welfare would fall if they were no longer able to access that site (or how much it would increase with the establishment of a new site) and then converting that welfare quantity into an equivalent monetary amount. The ORVal model and its analytical capabilities are integrated with the offset cost and biodiversity response analyses (detailed above) within the NEV decision support framework.[47,54]

Assessing equity-weighted access co-benefits of land use change

Recreational access to the environment is supported on health and equity grounds and features heavily in policy and planning guidelines. A major focus of this debate is on providing such access to those communities suffering the greatest deprivation and the poorest environmental quality. However, while BNG guidelines discuss the importance of recreation, the heavy bias toward local offsetting within policy ignores variation in access environments across the country and the much greater well-being that could be generated by locating offsets near those communities that would benefit the most from such opportunities. Instead, local offsetting is skewed to favor the winners from developments, those who live in the new houses that have been built (with access preferentially skewed toward those in the most expensive homes), rather than those who have lost the access they used to enjoy prior to this development. More importantly, both from a welfare perspective and as a policy priority, the communities who would most benefit from improved access to high-quality environments are heavily mitigated against by irrelevant criteria such as the location of recent developments. Indeed, the bias toward local offsetting is likely to entrench the inequality of access to high-quality environments. Such implementation runs directly contrary to government policy to enhance access to high-quality recreational greenspace for those who currently suffer the most degraded environments.[72] It also ignores HM Treasury guidelines that "[w]hen assessing costs and benefits of different options it may be necessary or desirable to 'weight' these costs and benefits, depending on which groups in society they fall on," such that "benefits for lower income households are given a higher social value than the equivalent benefits for higher income households."[81] The weight used in these calculations reflects the marginal utility of income (MUI), the change in utility, or satisfaction, resulting from a change in an individual's income. Drawing on empirical research,[49] Treasury guidelines recommend an MUI of 1.3, implying that "[a] n additional £1 of consumption received by someone earning £20,000 per year would be worth twice as much than to a person earning £40,000,"[81] i.e., the benefit of improving environmental access for poorer communities is weighed as being greater than delivering the same change in access for wealthier people.

To apply this weighting procedure across England, measures of disposable income after housing costs were retrieved[82] for every middle layer super output area (MSOA) across the country. This was then compared to the median income for the whole country, giving an indicator of income deprivation. This was then weighted using the HM Treasury MUI (above) to adjust for the greater value of improvements in access benefits to poorer households. This measure was then applied to the access co-benefits described in the previous section, determining the equity-weighted recreational access co-benefits of land use change for all locations across England.

Applying the offsetting rules

With the biodiversity, cost, co-benefit, and equity-weighted co-benefits models all integrated within the NEV decision support system, the various offset scenarios were implemented through two forms of algorithm. For scenario 1, local offsetting (the status quo), a simple distance-based algorithm was applied that searched for the closest location to the development site, providing an equivalent area of farmland for offsetting. For all other scenarios, 2–5, inclusive, a standard ordering algorithm was used to locate the offset area. So, for scenario 2, maximize conservation priority, the JNCC species models within NEV were run for all areas of England, hypothesizing that each area, in turn, was converted from farmland to semi-natural grassland, and the biodiversity implications were assessed. Each area was then ranked from the highest (best) to lowest (worst) biodiversity response. The required offset area was then allocated starting with that location that gave the highest gain in biodiversity and proceeding down this ranking until the required total area of offset was reached. This highest-to-lowest ranking approach was also used for scenarios 4, maximize co-benefits minus costs, and scenario 5, maximize equity-weighted co-benefits. For scenario 3, minimize costs, the ranking was ordered from lowest- to highest-cost areas, with the former being selected first and this list being worked down until, again, the required area for offsetting had been delivered.

Limitations of the modeling approach

Integrated modeling approaches at large scale rely on a series of assumptions that limit their capability of predicting the future, in particular given that they are often, as in this work, deterministic in nature; are numerically complex, limiting the possibility of exploring future ranges of outcomes; and, if estimated statistically on the basis of observed empirical data, might not be able to fully capture changes that are out of the estimation sample. While this is true of most models, we do recognize that models are useful to understand processes and dynamics and, as in this case, the relative performance of different policy-driven land use changes with the objective of offsetting nature as a result of urban development; this is because we are interested in the relative performance of different policies under same baselines rather than absolute numerical outcomes. However, a number of limitations associated with the modeling approach chosen must be acknowledged, namely, (1) the deterministic nature of the models, which do not provide a measure of the uncertainty associated with the outcomes obtained, and (2) the lack of feedback loops, which can alter the sets of conditions determining the predicted land use changes. For example, we assumed that future projections of urban land uses follow historic trends driven by projections of population increases. In addition, the costs of offsetting land are represented by the foregone agricultural income of the areas where offsets are created. However, changes in land values from previous urbanization (and offsetting) are not accounted for in our modeling setting.

Equally, other policies also affecting land use (such as planting trees to achieve net zero or promoting land-based renewable energy production) that have the potential to significantly alter land use trajectories and associated values are not included in the analysis. These issues affect all of our analyses, including those of current practices. Nevertheless, it is worth noting that all the models collated into the integrated modeling suite of this work are temporally dynamic in the sense that they respond and predict future land uses and associated provision of ecosystem services on the basis of an adaptive behavior of farmers driven by climate change. As such, the agricultural opportunity cost is an annuity of the flow of gross margins accounting for changes of farming behavior into the future driven by climate change; equally, species responses to land use change are also driven by climate. Finally, the fact that the alternative scenarios (i.e., "maximize biodiversity," "minimize costs," etc.) provide the best outcomes for the metrics they optimize is hardly surprising. These scenarios are deliberately designed to achieve their designated outcomes so as to act as counterfactual scenarios against which the current implementation of BNG can be compared.

RESOURCE AVAILABILITY

Lead contact

Requests for further information and resources should be directed to and will be fulfilled by Mattia C. Mancini (m.c.mancini@exeter.ac.uk).

Materials availability

This study did not generate new unique materials.

Data and code availability

- All original code has been deposited and is publicly available at https://doi.org/10.5281/zenodo.13857400 and https://doi.org/10.5281/zenodo.13857385 as of the date of publication.
- Due to non-disclosure agreements over some of the input data used in the analysis, those data cannot be shared; all publicly available data used in this study have been referenced in the text.

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AUTHOR CONTRIBUTIONS

The idea for the analysis was conceived by I.J.B., B.H.D., and M.C.M. and developed in collaboration with E.J.M.-G. and M.F. Analyses were undertaken by M.C.M. and R.M.C. with support from I.J.B., A.B., and F.E. Models were developed by A.B., B.H.D., F.E., C.F., N.O., M.C.M., and E.W. The paper was written in collaboration with all authors.

DECLARATION OF INTERESTS

The authors declare no competing interests.

SUPPLEMENTAL INFORMATION

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