Department of

BIOLOGY

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Assessing the performance of DEFRA's Biodiversity Metric.

Contents

Table of abbreviations:

BNG	Biodiversity Net Gain
NNL	No Net Loss
LERC	Local Environmental Records Centre
DEFRA	Department for Environment, Food and Rural Affairs
NBN	National Biodiversity Network

Frequently used abbreviations, defined in text.

Abstract:

Biodiversity is a multi-layered concept, necessitating the use of proxy metrics, with no single measure able to capture its full extent. Consequently, uncomplicated metrics which provide standardised ways to measure change, are valuable. Reviewing metrics of biodiversity is important in investigating the extent to which they provide reliable proxies, and reflect real progress towards conservation goals. I use England as a case study, empirically evaluating DEFRA's Biodiversity Metric, a calculation tool which uses habitat features as a proxy for biodiversity. This was developed to provide a quantitative, standardised way to measure Biodiversity Net Gain: a legal requirement under the 2021 Environment Act for development to leave biodiversity in a measurably better state. There is, however, limited academic review into the performance of the Metric. I aimed to fill this research gap, comparing empirical Metric data to observations of protected species, across 110 sites. I evaluate whether the Metric provides a reliable proxy for the richness of protected species a site supports, with a particular focus on Metric condition assessments. Significant factors in explaining variation in the richness of protected species are habitat type ($p=0.041$), and area ($p=0.039$), with preliminary evidence to indicate significant differences between Metric condition categories ($p=0.076$). However, I failed to consistently detect significantly more protected species within higher condition categories, emphasising the necessity of further research to determine if Metric condition categories can go beyond the original intention of the Metric and be a good proxy of the richness of protected species a site can support.

Introduction:

Biodiversity Net Gain and the need for a Metric:

One of the most pressing challenges facing England is the need to reconcile ambitious land development and environmental objectives. The 25 year Environment Plan has aspirational goals for nature, such as creation of 500,000ha of wildlife habitat outside protected areas (HM Government, 2018). However, policies are needed to reconcile this with the government's aims for infrastructure development, such as building 300,000 new homes annually (UK Government, 2020), with land development contributing to unprecedented declines in biodiversity in the UK (Hayhow, et al., 2019). The 2021 Environment Act addresses this, introducing a legal requirement for "Biodiversity net gain" (BNG) to be achieved and demonstrated for certain types of development in England (UK Government, 2021). From November 2023, all terrestrial developments requiring planning permission will have to achieve and demonstrate a minimum 10% gain in "biodiversity units", as measured by the DEFRA Biodiversity Metric, compared with its baseline state. This will also apply to Nationally Significant Infrastructure Developments (NSIPs) from 2025 (UK Government, 2021). England is the first country in Europe to implement a mandatory biodiversity net gain policy, as opposed to 'no net loss' (NNL) policies, which aim to have no net detrimental effect on biodiversity, and are used to protect various habitats and species in a number of countries (zu Ermgassen, et al., 2019).

To calculate the level of biodiversity enhancement required to compensate for losses, and to achieve a 10% net gain, use of a comparative method or metric is needed to quantify gains. Following DEFRA's work on scope to introduce a biodiversity offsetting scheme in the UK (DEFRA, 2009), Treweek et al. proposed a method for measuring biodiversity losses and gains, comprising a metric framework in which the area, intrinsic distinctiveness and condition of UK habitat types act as a proxy for overall biodiversity (Treweek, et al., 2010). This metric framework was used by DEFRA in biodiversity offsetting pilots from 2012-2014 (DEFRA, 2012). This work culminated in the DEFRA Biodiversity Metric, the tool used to measure net gain from development, using habitat features as a proxy for biodiversity. This Metric has undergone multiple iterations; current Metric 3.1 is a recent update (Panks, et al., 2022) to Metric 3.0, released in 2021 (Panks, et al., 2021), following version 2.0, released in 2019 (Crosher, et al., 2019).

The Metric will become an important tool in the goal of achieving BNG, by providing a standardised way to establish baseline condition of sites and measure changes in habitat relative to this baseline. This will provide the quantitative measurement of the change in biodiversity for all developments in England requiring planning permission under the Town and Country Planning Act (UK Government, 1990), and Nationally Significant Infrastructure projects (DEFRA, 2022).

Assessing biodiversity measures:

As biodiversity is a multi-layered concept, encompassing variety at genetic, species and ecosystem levels (Gaston, 2011), it cannot be captured in a single metric or measure (Burch-Brown & Archer, 2017). As such, all metrics, including DEFRA's Metric, will be proxies, measuring different elements of biodiversity (Harris, et al., 2021). It is imperative to have robust metrics to measure progress towards conservation goals (Nicholson, et al., 2012) and reliably monitor changes in the relevant biodiversity indicators underpinning these goals (Collen & Nicholson, 2014). Validating such metrics is essential to ensure changes in biodiversity are accurately reflected, and to evaluate impacts of actions taken to reverse biodiversity decline. Evaluation of DEFRA's Metric provides a valuable case study in the importance of empirically testing metrics, in addition to informing BNG policy.

Consultations by DEFRA and Natural England with professional ecologists, planning authorities, and consultancies have informed the developments of new iterations of the Metric, e.g. (DEFRA, 2019) (DEFRA, 2020). However, despite the importance of the Metric as a tool in achieving BNG, and the necessity of reviewing measures of biodiversity, there has been limited formal evaluation of its applications. The reported changes in habitat types due to implementing mandatory BNG, using the Metric, were investigated using data from developers (zu Ermgassen, et al., 2021). This study had notable landscape-level findings, including a 34% reduction in the total area of non-urban habitats in the sample, comprising 6% of England's annual housing development, for developments recorded to achieve BNG or NNL using the Metric. This loss of habitat may lead to a reduction in the species and ecological functions supported, although may be counteracted by improvements to the quality of remaining habitats, providing more resources (zu Ermgassen, et al., 2021). This is to date, the only published empirical evaluation of the ecological impacts of any version of the Metric, indicating the necessity of further academic research to assess the strengths and limitations of this important tool. Therefore, there is a crucial research gap: whether the Metric is a good representation of the biodiversity on-site. Deducing how far the Metric provides a good proxy of differences in biodiversity is vital in ensuring BNG policy does succeed in leaving biodiversity in an improved state, rather than implementing legislation which does not lead to biodiversity improvement.

Evaluating Metric condition assessments:

In this study, I aim to evaluate the Biodiversity Metric using empirical data, focussing primarily on habitat condition assessments, used as one score within the Metric to underpin the calculation of "biodiversity units". In addition I will investigate any additional effects of other Metric variables, including 'Distinctiveness', habitat type and patch area.

The condition assessment allows distinctions to be made between patches of the same habitat type, and is defined in the Metric User Guide as 'the biological working order of a habitat compared to the perceived ecological optimum' (Crosher, et al., 2019). Due to the multi-layered nature of biodiversity, no single measure can capture the full extent of biodiversity condition (Santini, et al., 2017) (Morris, et al., 2014) (Niemi, 2004). However, condition can effectively be considered as the species and functions a habitat can support (Maes, et al., 2018), compared to the perceived optimum (Crosher, et al., 2019).

However, there are potential limitations in the use of categories for understanding and detecting variation in biodiversity on site. By using broad categorisation, underlying variation between items placed in the same category can be obscured, limiting the ability to detect variability which may be important for conservation. For example, one implication of broad condition categories is that patches meeting different combinations of criteria can be placed within the same condition category. These patches may differ in the specific species and functions they are able to support, yet are categorised as the same Metric condition category, and are given the same condition multiplier.

Additionally, using the Metric requires a number of judgements to be made by ecologists. Whilst both necessary and important, Metric inputs may be influenced to an extent by this subjectivity. Which UKHab type is assigned to a habitat patch determines the distinctiveness multiplier a patch receives: inconsistencies in this judgement have significant effects. For example, classification as 'Modified' rather than 'Other neutral' grassland would halve the distinctiveness score, hence requiring only half the biodiversity units to be created post-development, all else being equal (zu Ermgassen, et al., 2021) Beyond habitat classification, the element with the most potential to be subject to inconsistencies due to subjectivity, is habitat condition. Indeed, in a survey of expert grassland ecologists, the interpretation of grassland survey information found no universal agreement between experts with regards to habitat classification or condition, with experts agreeing only 31% of the time (zu Ermgassen, et al., 2021). This potential for bias in the classification of habitats into condition categories only emphasises the necessity of comparing these categories to empirical data, assessing the extent to which condition categories reflect the real-life conservation potential of a site.

The Metric is designed to be a habitat-based measure of the biodiversity of a site; hence, species are not explicitly accounted for in this tool. Some condition assessment sheets contain criteria which reference the presence or absence of certain subsets of species. For example, in the condition assessment sheet for grassland, criteria seven is: 'There is an absence of invasive non-native species (as listed on Schedule 9 of WCA 1981), and undesirable species make up less than 5% of ground cover' (Crosher, et al., 2019). The condition assessments, are however, designed to focus on measuring patch quality using habitat-based criteria, rather than explicitly considering the species present within the patch. Species' requirements are therefore only reflected in the Metric scores with regard to differences in distinctiveness scores for habitat types comprising different sets of species (for example, distinct grassland sward compositions for different grassland habitat types with different distinctiveness scores), and in the condition criteria which explicitly reference species. The Metric has received critique for its focus on habitats, as it has been questioned to what extent this proxy is also reflective of species requirements (The Nature Conservancy, 2021). The use of the Metric in achieving BNG should not override existing conservation measures for species, these still remain in place (Baker, et al., 2019), yet many species remain without any conservation legislation (The Nature Conservancy, 2021), including species identified by the UK Biodiversity Action Plan (JNCC, 2022).

Therefore, the Metric does not explicitly account for impacts on species of conservation concern; this does not factor in to the score a patch receives for its condition. Whilst the Metric is not designed to measure species, nor should override existing species legislation, it has yet to be empirically examined to deduce the extent to which the Metric categories also reflect the conservation value of a site for species: defined here as the ability of a site to support pre-existing populations of protected and notable species. Simulations have been conducted comparing the ecological and economic outcomes of offsetting under both habitat metrics and species metrics, using species abundance models for certain species (Simpson, et al., 2022). However, the condition assessments of the Metric have yet to be formally examined using empirical data, to investigate how well the condition assessments reflect variation in the richness of species of conservation concern.

Aims and focus:

I compare empirical Metric 2.0 data from infrastructure developments within councils which are early-adopters of mandatory BNG policies, to records of protected and notable species in the same locations. This is in order to evaluate to what extent the Metric condition assessments provide a good proxy for the presence of protected and notable species and the ability of a habitat parcel to support their populations.

The three broad habitat types chosen as the focus of this research are 'Cropland', 'Grassland' and 'Woodland and forest'. Cropland habitats are fixed within the Metric calculation tool as 'poor condition', hence requiring no condition assessment under this methodology (Panks, et al., 2021). I aim to assess whether the Metric scoring of these habitats as 'poor' condition is reflective of the species of conservation concern these habitats may support. Grasslands and woodlands, the other habitats chosen for this study, comprise a large proportion of the UK's habitats (Nafilyan, 2015) and are some of the habitat types most affected by infrastructure development, with 2,505km2 of grassland and 1,121 km2 of arable land being converted to urban infrastructure between 1990-2015 (Wildlife and Countryside Link, 2021).

In this research, I seek to address the following hypotheses:

1. <u>Whether the Metric provides a proxy of the conservation value of a site for protected and notable species</u>

I aim to provide an insight into whether the Metric can provide a proxy for the ability of a habitat to support populations of protected and notable species. To do so, I investigate how much of the variation in the richness of protected species between habitat patches can be accounted for by different variables included in the Metric. This includes categories for: Condition, Distinctiveness, Habitat type and Connectivity, in addition to the area of the patch, to account for the species-area relationship (Wilson and MacArthur, 1967).

As the Metric is designed to measure habitats, not species, I do not anticipate consistent significant differences in richness across all Metric categories. However, significant differences might be expected between habitat types, due to different habitat features supporting different subsets of species (Ecology by Design, 2020). As condition categories are designed to distinguish habitat parcels of the same habitat type by the quality of the parcel for supporting species and ecological functions (Panks, et al., 2022), we may also expect differences in the richness of protected species across condition categories, when controlling for habitat type.

2. How LERCs and Consultancies compare as sources of species information:

Species records for the analysis are obtained from three sources: Local Environmental Records Centres (LERCs), NBN Atlas, and species surveys conducted by ecological consultancies on-site, prior to development.

I aim to investigate how two sources of species information compare: records held by LERCs and records made by Consultancies. Both datasets will inherently be incomplete records of the total species present on-site; however, I compare the records held by both sources, to deduce where these correlate, and where each lacks records held by the other.

I anticipate that species surveys conducted by Consultancies, discounting records Consultancies themselves obtain from LERCs, will record more species than held by LERCs. Consultancy surveys will be systematic surveys on-site, all by qualified ecologists, whereas LERC data is compiled from a variety of sources. This result would indicate that sharing of records made by Consultancies with LERCs would make a valuable contribution to the data held by LERCs.

Materials and methods:

The approach taken was to obtain Metric data from planned developments and match this to the location of the habitat parcels in which Metric assessments were made. This then allowed me to obtain species data for these habitat parcels, from a number of sources, then to compare the Metric and species data. (Figure 1)

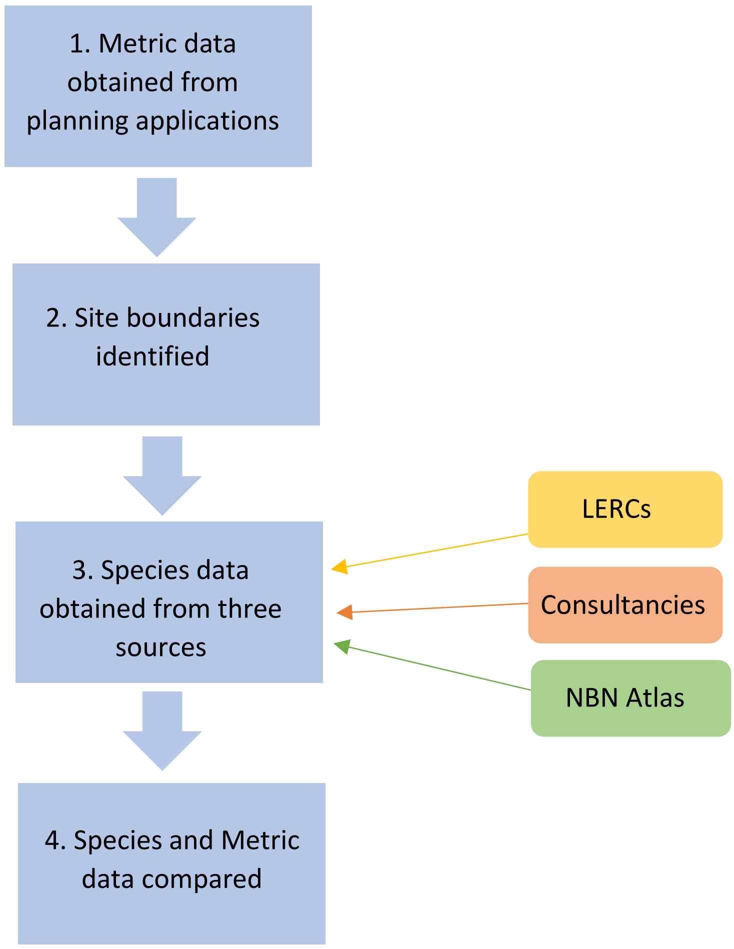


Figure 1 Key steps taken in data collection, with species data sources shown.

Data sources:

I obtained Metric data from an academic-compiled database (zu Ermgassen, et al., 2021) which comprises planning applications for infrastructure developments, where the Metric has been used to calculate biodiversity units. I collated Metric calculations from infrastructure developments in five councils which are early-adopters of BNG legislation, requiring the Metric to be used to demonstrate a net gain in biodiversity units from developments. These are: South Oxfordshire District Council; West Oxfordshire District Council; Leeds City Council; Cornwall County Council, and Vale of White Horse District Council. Online planning portals for these five councils, which comprise publicly-accessible information on individual planning applications, were also searched for all 'major' and 'minor' developments until August 2021. Planning applications which included a full Metric calculation, and included patches of grassland, woodland or cropland, were then added to our dataset. Our sample then totalled 47 planning applications across the five councils.

There were ultimately insufficient numbers of applications which had used Metric 3.0, as this version was only released in 2021 (Panks, et al., 2021), with 12 patches in our original sample using Metric 3.0, and 110, Metric 2.0. Therefore, we focus on Metric 2.0. As this has not been formally tested, the results of this research could therefore inform the development of future iterations and revisions of the Biodiversity Metric.

A total of 22 cropland patches, 26 woodland patches, and 62 grassland patches were used (Fig 2). For each patch, species records were obtained from a number of sources, to allow the comparison of the Metric condition category a patch is categorised as, and the richness of protected and notable species within that patch.

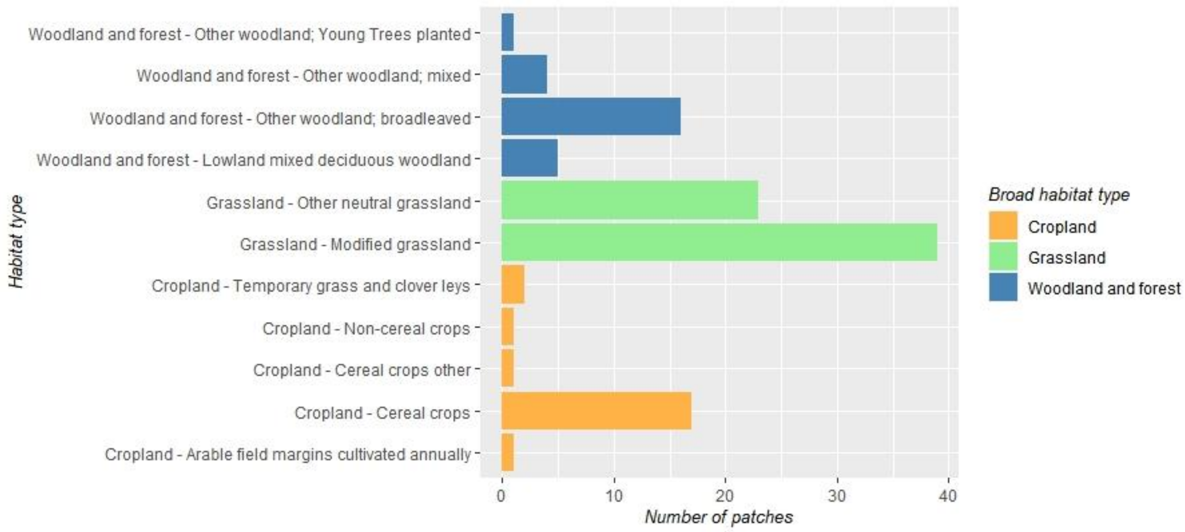


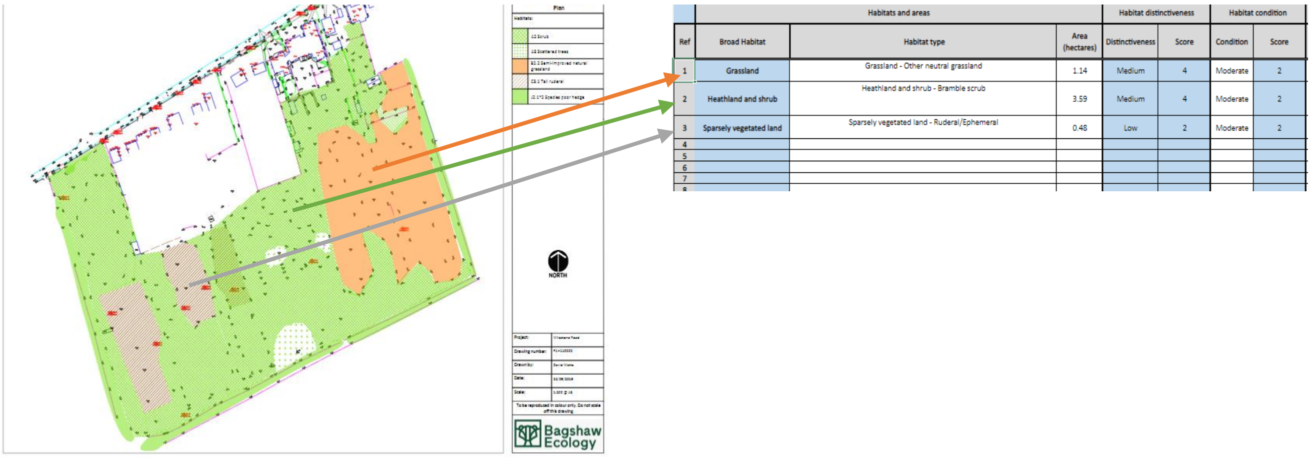
Figure 2: The habitat types our sample is comprised of, within the three broad habitat types, Grassland, Cropland, and Woodland and forest.

Supporting documentation containing ecological information was then extracted from the online planning portals for each application. These documents include: Ecological Impact Assessments; Preliminary Ecological Appraisals; breeding bird, bat, reptile, amphibian, botanical surveys; BNG reports. These documents contain the results of surveys conducted by ecological consultancies on the sites pre-developments, including Phase 1 habitat surveys, used to identify patches, and species surveys, used as a source of species records for the analysis.

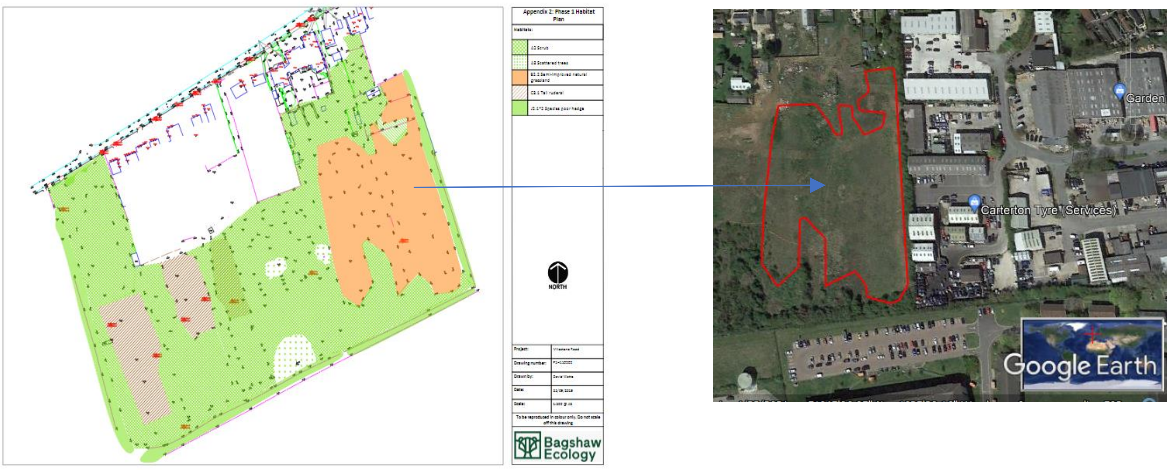
The accompanying Metric data for each patch, with each row in the spreadsheet corresponding to a habitat patch, were matched to the location of the patch on habitat maps. These maps were mainly in the form of Phase 1 habitat surveys, with the site divided into patches, with a key to distinguish the habitat type of each patch.

Once the boundaries of the patches had been identified, and matched to their corresponding row in the Metric, shapefiles were made for each individual patch, using Google Earth Pro to make a kml file, and QGIS to convert this to a shapefile. (See Fig 3 for method) Shapefiles were made in order to share site boundaries with LERCs, to obtain species records for each patch. Our sample of 110 patches only included those where the location could be confidently identified and matched to the correct row in the Metric spreadsheet.

Step 1: Each habitat patch on the Phase 1 map is manually matched to the corresponding row in the Metric spreadsheet



Step 2: Site boundaries are made for each habitat patch on Google Earth Pro, using Phase 1 habitat maps.



Step 3: The Google Earth boundary (kml file) is converted to a shapefile on QGIS.

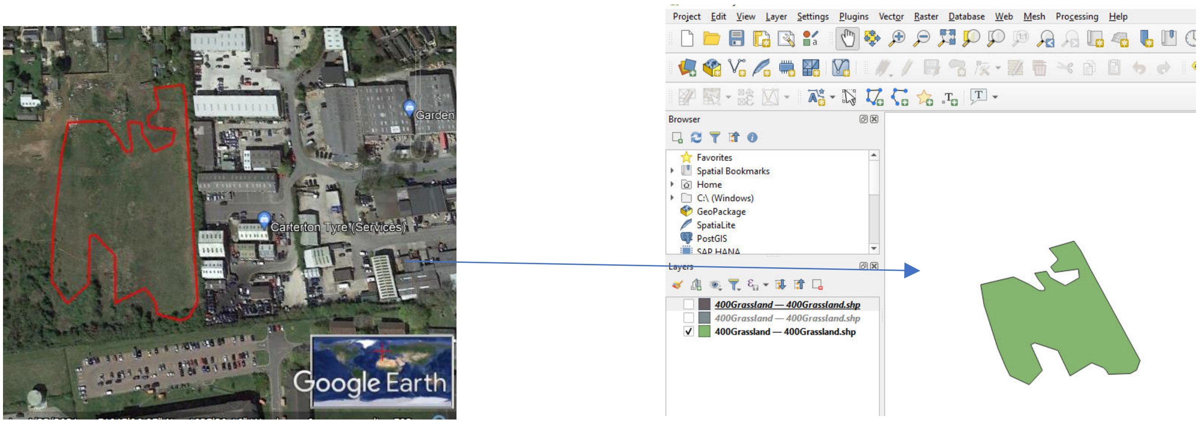


Figure 3 Steps taken to identify, cross-reference and create boundaries for each habitat patch (Metric row).

The research aimed to compare records of species found within habitat patches, to the habitat type and condition of the patch, as assessed by Metric 2.0. To obtain records of species found within patches, three main sources were used: records from Local Environmental Records Centres (LERCs); NBN Atlas, and records from ecological surveys conducted on-site prior to development.

LERCs hold records of species within the geographical area covered by the record centre. The supporting documentation accompanying planning applications, such as Ecological Impact Assessments, include species recorded within the habitat patches when ecological consultancies conducted surveys onsite pre-development. The NBN Atlas is the largest database of biodiversity information in the UK (NBN Atlas, 2022), comprising species records obtained through citizen science and a number of partner organisations. All three datasets will be limited by imperfect detection, and in the case of the LERCs and the NBN Atlas, by lack of quality assurance in data obtained from multiple sources (CIEEM, 2020). Hence, no dataset is assumed complete, and all three are used in combination.

For each council, the relevant LERC was identified, using the LERC finder from the Association of Local Environmental Records Centres (ALERC, 2022). The LERCs encompassing each council were: Thames Valley Environmental Records Centre (TVERC): for sites in West Oxfordshire District Council, South Oxfordshire District Council, Vale of White Horse District Council; Environmental Records Centre for Cornwall and the Isles of Scilly (ERCCIS): for sites in Cornwall County Council, and West Yorkshire Ecology Service: for sites in Leeds City Council.

The shapefile site boundaries for all patches were shared with the relevant LERCs, and data searches requested for species records within these patches. To standardise, records of all species from the year 2000 were requested from each centre.

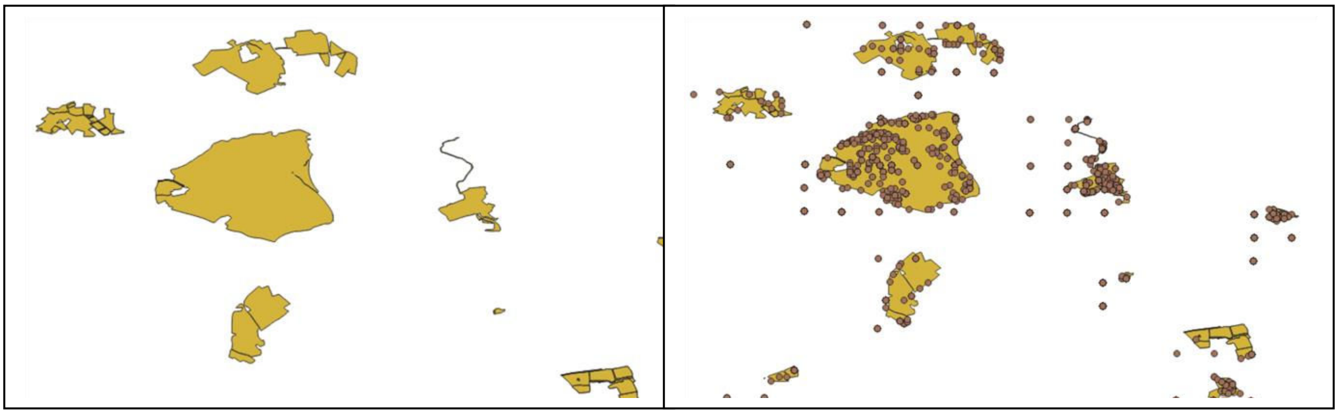


Figure 4: Shapefiles were shared with LERCs to obtain species records (shown as points) within each patch .

To collect NBN Atlas data, shapefiles created were uploaded in the 'species search' tool in the online NBN Atlas. Datasets, in the form of Excel spreadsheets containing species records and metadata on recorder, record type, and data, were downloaded for all patches possible.

To obtain species records from ecological documentation, the accompanying documents were systematically reviewed for all planning applications. Records of all species recorded within the relevant habitat patches on site were extracted. These species records are those which were recorded by charted ecologists conducting baseline ecological surveys on-site, prior to development.

Many ecological consultancies not only conduct their own on-site surveys, but also conduct a biological records search from the LERC. These records, when included in the supporting documentation, were treated separately from the species noted during the on-site surveys, as these have a different source of origin. Species records obtained from on-site surveys prior to development are labelled 'Consultancy', and records originating from a data search conducted by the consultancy are distinguished by the label 'LERC, via consultancy'.

Data collation:

Habitat data extracted from the Metric spreadsheets for each habitat patch within a planning application comprises the following data: patch ID, council, planning application number, broad habitat type, habitat type, area (ha), condition category, distinctiveness, connectivity. For each habitat patch, the species records obtained from the NBN Atlas, the LERC, and from the ecological supporting documentation, were compiled into a database which matches these species records to the habitat patch they are found within.

These species records are classified according to: the document type or source the record was obtained from; the number of records, where applicable; taxa type; confidence in location of record. For some species records, location was not explicitly stated, and had to be inferred. The approach taken was to discount records where the documentation said a species was recorded 'within 2km/1km of site', with no further information given, as this was deemed insufficient to conclude a species had been observed on-site, let alone a specific patch. Certain records were also described at whole-site level; where there was insufficient descriptive information to match a species to the specific patch in which it was observed, these were also not included.

The date the species was recorded within the patch was also recorded. For multiple records of the same species, spanning multiple years (for example, records of a common species every year from 2000-2022) the most recent record was taken. The ecological surveys carried out by consultancies occasionally involved an update survey, based on information collected in surveys in previous years. In these cases, the date of the most recent survey was given. The month and year in which the Metric assessment was carried out was also reported, with the month of completion being used if this survey period spanned multiple months.

The research aimed to match records of protected and notable species to Metric data. The next stage, therefore, was to review all species records according to their conservation classifications, with a view to identifying species that could be considered "protected" or "notable". The conservation classifications used were obtained from the JNCC list of UK conservation classifications (JNCC, 2022), and are summarised in figure 5. Species classified under any of these designations were encompassed within our subset of 'protected and notable' species.

Conservation classification:	Description:
Biodiversity Action Plan species	Species identified as being the most in need of conservation action under UK Biodiversity Action Plan. These are selected based on level of international threat, decline in the UK, and other important factors such as evidence of an extreme threat to the species, such as restriction of geographic range or decline in a specific habitat or food type, or a threat of disease (JNCC, Joint Nature Conservation Committee, 2019).
Birds of Conservation Concern (UK)	This designation describes that status of all regularly-occurring birds in the UK, Channel Islands and Isle of Man. This is compiled by a coalition of the UK's bird monitoring and conservation organisations, and includes all birds which breed or overwinter in the UK. The 5th review was published in 2021, and is the version used (RSPB, 2021).
EU Birds Directive	This designation describes the level of protection required for birds in the European Union, according to the Annex (1, 2.1, 2.2), birds are classified under (Williams G, 2005).
Habitats and Species Directive	This designation is a European directive, the means by which EU member states meet the obligations agreed in the Bern Convention, to protect Europe's most endangered species across the entirety of their range across Europe (EU, 1992).
IUCN Red List of species	International designations of conservation concern, based on criteria relating to population size, demographic trends, geographic range (IUCN Species Survival Commission (SSC), 2012).
NERC Act Priority Species	These species (Section 41 species, in England) are rare and threatened species listed in the 2006 Natural Environment and Rural Communities (NERC) Act (UK Government, 2006). This places responsibility on local and government authorities to conserve such species.
UK Wildlife and Countryside Act, 1981	The original act designates protection to native animal and plant species and prevents release of non-native species (UK Government, 1981).

Figure 5: The conservation designations used by the JNCC, against which our sample of species were assessed.

Data analysis

Aim one:

For my main question, I aimed to investigate the effect of each of the Metric variables on the richness of protected and notable species, and to determine between which categories significant differences in the mean richness of protected species are observed.

To do so, I used general linear models, with the richness of protected species as the response variable, and the Metric variables as explanatory variables. The local authority (Council) the patch falls within is also included as a co-variate, to partially account for geographical variation in species, or differences in data stored by different LERCs, which each cover different sets of councils.

The Metric variables considered were: Broad habitat type; Condition, Distinctiveness, Connectivity.

‘Distinctiveness’ is a means of comparison between habitat types, accounting for the type and distinguishing features of a habitat (Panks, et al., 2022). Distinctiveness is pre-determined by Natural England for each specific habitat type, based on a number of criteria including UK and EU priority status of habitat type (Crosher, et al., 2019) (JNCC, 2019).

‘Connectivity’ is the proximity to similar habitat. Guidance originally stated that connectivity should be determined from distinctiveness (Crosher, et al., 2019), with a Connectivity Tool later being developed (Natural England, 2019). Strategic significance scores are given in Metric 2.0 based on whether the location of the habitats involved in development were identified as significant for nature in local plans.

Habitat types are defined and described according to the UK Habitat Classification (UKHab, 2020). Condition is assessed on the basis of criteria, specific to each habitat type, then assigned to a condition category, based on the number of criteria passed: ‘Poor’, ‘Moderate’ or ‘Good’. ‘Fairly Poor’ and ‘Fairly Good’ are used at the discretion of the ecologist for habitat patches not deemed to fit within other condition categories. Multipliers are given based on categories, and affect the total “biodiversity units” calculated. See Fig 6 for all variables and multipliers.

Attribute:	Categories and multipliers:		
Condition	Poor **(1)**	Moderate **(2)**	Good **(3)**
Distinctiveness	Low **(2)**	Medium **(4)**	High **(6)**
Connectivity	Low **(1)**	Medium **(1.1)**	High **(1.15)**
Strategic significance	Low **(1)**	Medium **(1.1)**	High **(1.15)**

Figure 6: Metric 2.0 categories for each attribute, with multiplier scores shown in parentheses

However, collinearity is observed between some of the explanatory variables: distinctiveness category is assigned according to habitat type. Distinctiveness is assigned based on specific, rather than broad, habitat type; however, this relationship means there is collinearity between broad habitat type and distinctiveness. For example, 21/22 Cropland patches are ‘Low’ distinctiveness, and the only ‘High’ distinctiveness habitats in our sample are Woodland. Hence, any potential effect of Distinctiveness may be masked by the effect of habitat type.

Distinctiveness and connectivity may also be co-linear, as previous guidance for using Metric 2.0 suggested determining connectivity from distinctiveness (Crosher, et al., 2019) Whilst this guidance has now been replaced (Natural England, 2019), it is unknown whether some consultancies were following this guidance when determining connectivity; hence, only distinctiveness is considered in this model.

Likewise, there is collinearity between habitat type and condition. For example, all Cropland patches are pre-assigned to ‘Poor’ condition, and the only ‘Good’ condition patches in my sample are Woodland. Hence, stronger effects of condition could also be masked by including habitat type as an explanatory variable.

Therefore, model 1 included broad habitat type, with a second model considering the effect of Area, Condition, Distinctiveness and Council, removing Broad habitat type as a variable in order to determine if this masked any effect of condition or distinctiveness.

Model one: $model1 < -\, lm(data = df, log(Total + 1) \sim Area\ +\ Broad.habitat.type\ +$ $Condition\ +\ Distinctiveness\ +\ Council)$
Model two: $model2 < -\, lm(data = df, log(Total + 1) \sim Area\ +\ Condition\ +$ $Distinctiveness\ +\ Council)$

Aim two:

I compared the records of protected species from surveys conducted by consultancies to records obtained from LERCs, considering records made within two years of the Metric survey having been conducted. In doing so, I aim to compare how well these two sources of species information correlate, and where each has gaps, relative to the other.
In aim one, only patches using Metric 2.0 were compared (totalling 110). However, as I am here comparing only species records, rather than the Metric, I included the 12 patches using Metric 3.0, totalling 122.

Results:

Aim One: To investigate how good a proxy the Metric is for the conservation value of a site for protected and notable species:

Model one found a significant effect of broad habitat type (p = 0.041), with preliminary evidence for a significant difference in mean species richness between Cropland and Grassland (p= 0.128), with the adjusted mean for Grassland being 0.49 species fewer than in Cropland.

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Analysis of Variance Table

                   Df  Sum Sq Mean Sq F value  Pr(>F)
Area                1   5.215  5.2152  4.4799 0.03688 *
Broad.habitat.type  2   7.663  3.8315  3.2913 0.04145 *
Condition           4  13.122  3.2806  2.8180 0.02931 *
Distinctiveness     2   1.213  0.6063  0.5208 0.59569
Council             4   7.403  1.8508  1.5899 0.18323

Residuals          96 111.758  1.1641
Coefficients:
                                     Estimate Std. Error t value Pr(>|t|)
(Intercept)                          1.731546   0.318733   5.433 4.19e-07 ***
Area                                 0.011268   0.007998   1.409   0.1621
Broad.habitat.typeGrassland         -0.496429   0.323719  -1.534   0.1284
Broad.habitat.typeWoodland and forest 0.090609  0.468595   0.193   0.8471
ConditionFairly Poor                 0.650095   0.383553   1.695   0.0933 .
ConditionModerate                   -0.303713   0.284225  -1.069   0.2879
ConditionFairly Good                -1.498459   1.141742  -1.312   0.1925
ConditionGood                       -0.695107   0.853588  -0.814   0.4175
DistinctivenessMedium               -0.061334   0.322527  -0.190   0.8496
DistinctivenessHigh                 -0.032189   0.673766  -0.048   0.9620
CouncilLeeds                        -0.519629   0.335986  -1.547   0.1253
CouncilSouth Oxfordshire             0.320264   0.288366   1.111   0.2695
CouncilVOWH                          0.026125   0.475929   0.055   0.9563
CouncilWest Oxfordshire             -0.023086   0.354630  -0.065   0.9482
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.079 on 96 degrees of freedom
Multiple R-squared:  0.2365,  Adjusted R-squared:  0.1331
F-statistic: 2.287 on 13 and 96 DF,  p-value: 0.01118
```

Figure 7: Analysis of variance table and summary output, for Model One.

Using model 2, a significant effect of area (p= 0.039) and preliminary evidence for a possible effect of Condition (p=0.076) were detected. The summary output of model two provides preliminary evidence for a significant difference in mean species richness between 'Poor' and 'Fairly Good' condition categories (p=0.0817), with the mean richness being lower in 'Fairly Good' than 'Poor' (mean difference= 1.989 species) , contrary to what we might expect if the Metric condition categories provide a good proxy of the conservation value of a site for protected species. More data may be required to provide a clearer result. No other significant pair-wise differences are observed.

Whilst the effect of the co-linear variable, habitat type, has been removed, there is no evidence to indicate significant differences in the richness of protected species between patches in different distinctiveness categories (p=0.839).

Here, there is evidence to indicate that the council a patch is found within has an effect on species richness (p=0.030). The summary output is also suggestive of a potential significant difference in species richness between councils Cornwall and Leeds (p= 0.086) and Leeds and South Oxfordshire (p= 0.100), with pairwise comparisons also indicating a significant difference between Leeds and South Oxfordshire councils (p=0.011). The adjusted mean differences indicate Leeds has a mean 0.58 fewer species per patch than Cornwall, and a mean 1.05 fewer species per patch than South Oxfordshire. When the model is adjusted so that the LERC supplying records replaces Council as an explanatory variable, the same trend is observed, with the pairwise comparisons indicating an adjusted mean 0.84 fewer species detected per patch for patches where West Yorkshire Ecology Service supplied records (patches in Leeds city council), compared to where the Thames Valley Environmental Records Centre supplied records (Vale of White Horse council, South and West Oxfordshire councils), p= 0.014.

```
Analysis of Variance Table

                Df  Sum Sq Mean Sq F value  Pr(>F)
Area             1   5.215  5.2152  4.3724 0.03911 *
Condition        4  10.443  2.6107  2.1888 0.07579 .
Distinctiveness  2   0.420  0.2101  0.1762 0.83875
Council          4  13.406  3.3516  2.8100 0.02955 *
Residuals       98 116.890  1.1928


Coefficients:
                          Estimate Std. Error t value Pr(>|t|)
(Intercept)               1.396908   0.220397   6.338 7.13e-09 ***
Area                      0.014740   0.007745   1.903   0.0599 .
ConditionFairly Poor      0.408535   0.368903   1.107   0.2708
ConditionModerate        -0.431215   0.277203  -1.556   0.1230
ConditionFairly Good     -1.981155   1.126141  -1.759   0.0817 .
ConditionGood            -0.381148   0.829127  -0.460   0.6468
DistinctivenessMedium     0.109250   0.267596   0.408   0.6840
DistinctivenessHigh       0.530474   0.557972   0.951   0.3441
CouncilLeeds             -0.579919   0.334008  -1.736   0.0857 .
CouncilSouth Oxfordshire  0.469226   0.282916   1.659   0.1004
CouncilVOWH              -0.007711   0.478176  -0.016   0.9872
CouncilWest Oxfordshire  -0.067006   0.350025  -0.191   0.8486
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.092 on 98 degrees of freedom
Multiple R-squared:  0.2014,   Adjusted R-squared:  0.1118
F-statistic: 2.247 on 11 and 98 DF,  p-value: 0.01753
```

Figure 8: Analysis of variance table and summary output, for Model two.

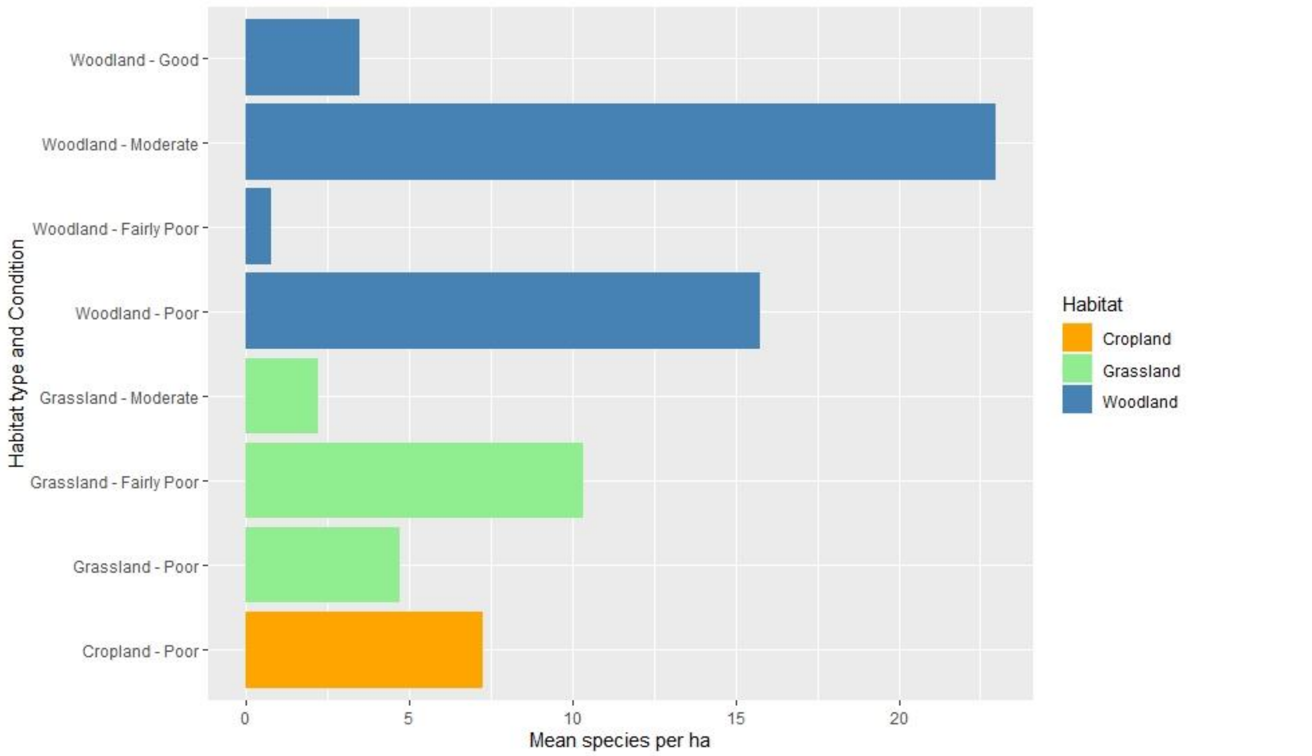

Figure 9: The mean richness of protected species per ha for patches in different broad habitat types in different condition categories. These means were calculated using species data from all our sources. Note, there were only two patches of 'Good' condition Woodland.

<u>Aim 2: Comparing LERCs and Consultancies as sources of species information:</u>

I find that the number of protected species records held by consultancies are greater than or equal to that of a LERC in >90% of patches surveyed. Species surveys conducted by consultancies detect more protected species than were listed for the same site by the LERCs in 74 patches, and equal numbers to LERCs in 38 patches. In only 10 patches do LERCs hold more protected species records than the Consultancies do. (Figure 10).

Across all patches, I find that for the 581 records of protected species the Consultancies do detect, only an additional 31 species total were not detected by Consultancies but recorded by LERCs: an average of one species missed every 3.95 patches. Therefore, in >90% of patches in our sample, Consultancy surveys identify more protected species than currently exist on Record Centre databases.

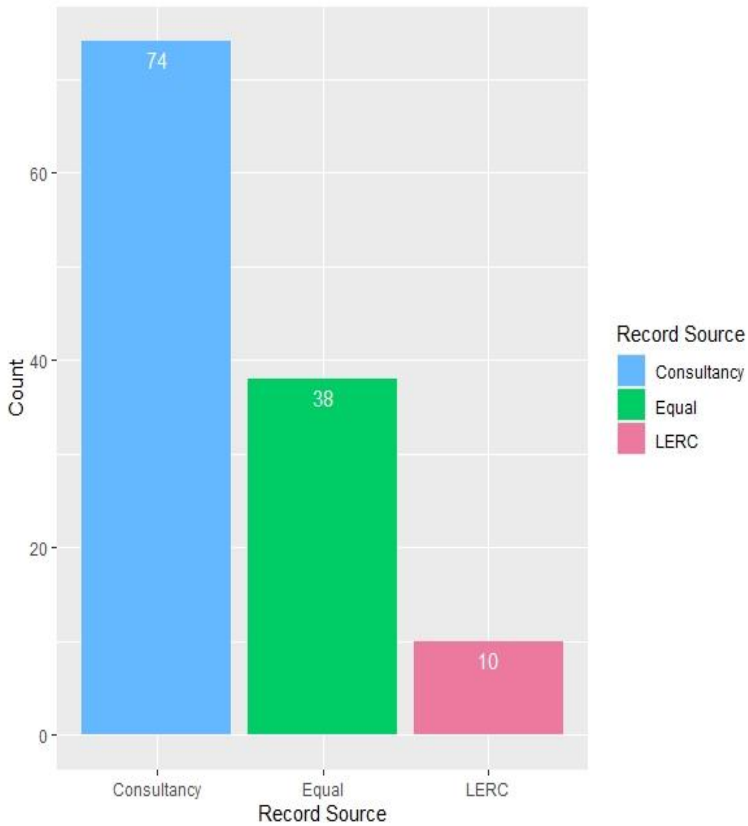

Figure 10: The number of patches in which each record source, Consultancy or LERC, detects more protected species.

Discussion:

Evaluating measures of biodiversity:

The multi-layered nature of biodiversity necessitates the use of proxies to measure changes and progress towards biodiversity goals (Baker, et al., 2019), with no single measure able to capture the entirety of biodiversity (Harris, et al., 2021). These proxies must reliably measure changes in relevant biodiversity indicators, in order to inform action taken to reverse biodiversity loss. The UK's DEFRA Metric provides a habitat-based proxy, measuring changes in habitats post development, compared to a reference baseline (Panks, et al., 2022). Taking this Metric as a case study, I highlight the importance of empirically evaluating biodiversity measures, to deduce the boundaries of biodiversity these can provide a proxy for. The limited evidence for broad habitat types and Metric condition categories providing a proxy for the richness of protected species, and lack of evidence for distinctiveness categories doing so, indicate more work is needed, to provide a clearer indication of the boundaries of biodiversity for which the Metric can be a reliable proxy for.

The Metric as a proxy for protected species:

Detection of a significant effect for broad habitat type in explaining variation in the richness of protected and notable species was not unexpected, with different habitat features having the ability to support various protected species (DEFRA, 2022). Preliminary evidence for fewer species in Grasslands than Cropland, when accounting for differences in condition, area, distinctiveness and council, could potentially indicate that cropland is systematically under-valued by the current Metric approach, being automatically assigned to 'poor' condition, and majority 'low' and 'medium' distinctiveness. Hence, cropland receives lower Metric output scores. Consequently, these findings could indicate that greater flexibility may be needed under the current approach to account for species rich cropland areas.

Evidence to indicate a significant effect of condition does not provide evidence to support the hypothesis that condition categories provide a reliable proxy of the ability of a habitat patch to support protected species, in contrast to my expectations,. The preliminary indication of more protected species in 'Poor' condition patches, compared to 'Fairly Good

’ is unexpected, as ‘condition’ can be considered to be the ability of a patch to support species and functions compared to the perceived optimum for that habitat type (Crosher, et al., 2019). It is possible that condition assessments are simply not good measures to capture richness of species of conservation concern, having not been designed for this purpose. In such as case, we would not expect to detect significant effects; hence, investigating this further is vital.

The lack of evidence for a significant effect of distinctiveness may indicate that this is not a good proxy for variation in richness of protected and notable species. Distinctiveness reflects the rarity and conservation status of habitats (Crosher, et al., 2019); hence, this may be a better reflection of structural diversity and species’ ranges, rather than richness. This has yet to be investigated, and would be an important next area of research.

Likewise, deducing how connectivity scores were given for each patch would allow us to determine whether connectivity has been based off distinctiveness score, leading to collinearity, or whether this can be investigated independently.

These findings highlight the need for further investigation into the ability of the Metric to go beyond its original intention and act as a proxy for the richness of protected species.

Consultancies and LERCs as sources of species information:

Datasets from LERCs and consultancies are both inherently incomplete. LERCs collate data from multiple sources, with inherently patchy coverage and variable sampling effort and expertise (CIEEM, 2020). Species detection is also imperfect due to factors such as species rarity, confounding environmental conditions, and observer error (Kellner, 2014). However, accounting for this, my observation that Consultancies detect more protected and notable species in a patch than LERCs hold records for, in >90% of patches in a sample, highlights the value of on-site consultancy surveys as a source of species information. This reinforces the importance for consultancies of following best practice and conducting their own on-site surveys (CIEEM, 2021), rather than relying on records searches from LERCs as a sufficient source of species information for making decisions about development. Furthermore, these results highlight the value of reciprocal information sharing between Consultancies and LERCs: particularly, the importance of consultancies sharing species records with LERCs, as recommended in best practice (CIEEM, 2020) (Partnership for Biodiversity in Planning, 2019). Currently, this appears an important gap, as the species records produced by the consultancies would be of greater use if accessible from a record centre database, for use by environmental organisations, developers, academics, and the public.

Limitations and future work:

My sample used the richness of all protected and notable species. I had planned to repeat the analysis to deduce if results could be replicated using just protected plant species, as detection is likely to be more stochastic for motile taxa such as birds and mammals (Morelli, et al., 2022), included in this sample. However, in my sample, there was an insufficient range in the richness of protected plant species per patch (0-8) to conduct robust statistical analysis. Therefore, there is scope to expand upon this study, repeating the methods and models for subsets of different taxa, to determine if results can be replicated when controlling for the motility of species. Furthermore, this could also provide a valuable insight into which taxa the Metric condition categories may or may not provide a good proxy for the richness of. In doing so, further analysis may also benefit for distinguishing taxa by their current legal protection, providing valuable insight into whether the Metric provides a good proxy for species with no legal protection, in addition to those already protected. A finding that the Metric provides a good proxy for species already protected, but does not for those without legal protection, for example, would have significant policy relevance in determining what further protection should be afforded to such species.

Conclusion:

England's BNG policy, requiring measurable gains in biodiversity from development, is an important opportunity to reconcile the government's competing development and biodiversity aims. It is therefore essential that BNG policy does succeed in leaving biodiversity in an improved state, and that the tools used are able to aid in achieving this. Assessing one such tool, I provide the first published empirical evaluation of how well DEFRA's Biodiversity Metric provides a reliable proxy for the richness of protected species sites support.

My preliminary findings indicate the necessity of further evaluation of the Metric, with habitat type, and area, having significant effects on the richness of protected species a patch supports. Less clear is the significance of Condition categories in explaining variation in the richness of protected species, as we have yet to detect a significant difference between categories, in the direction expected. Hence, so far, we have insufficient evidence to conclude that the condition assessments of Metric 2.0 do provide a good proxy of richness of protected species, which only emphasises the necessity of further study to provide a clearer indication as to whether significant differences can be detected.
I focus on Metric 2.0: my results are, however, an important empirical baseline for development of the Metric. Indeed, once Metrics 3.0 and 3.1 are more widely used, this study could provide the basis for an evaluation of these newer iterations. This would be an important next step, as Metric 3.1, or a closely-related successor, will become the standard metric for measuring BNG across the whole of England from 2023. Investigating the extent to which this tool reflects changes in real-life biodiversity, is imperative in ensuring that real gains for biodiversity are achieved, and the opportunity presented by BNG capitalised upon.

Using England and the DEFRA Metric as a case study, this empirical evaluation ultimately highlights the necessity of reviewing measures of biodiversity. Understanding the boundaries for which metrics can provide reliable proxy measures of biodiversity, is vital in ensuring that biodiversity measures are sufficiently robust to reliably reflect progress towards biodiversity goals.

Acknowledgements:

I would like to thank Professor E.J. Milner-Gulland, Dr Sophus zu Ermgassen, Dr Jo Treweek, Dr Julia Baker and Henry Grub for their supervision and guidance with this project; Dr Joe Bull and Dr Sophus zu Ermgassen for their guidance on the database used in this work, and the whole ICCS Group for their support. The concept for this work was adapted from my grant proposal (2020), with the same supervision.

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Project management report:

Summer 2021:											
Formulation of project plan, writing of request for participation, and contacting colleges for permission to do fieldwork on their land. Training courses in preparation of this (using the UKHab classification, using Biodiversity Metric 2.0)											
4th year. Week:	-2	-1	0	1	2	3	4	5	6	7	8
Michaelmas											
Pre-fieldwork scoping, including site visits and safety/fieldwork forms.											
Work on database of planning applications: inputting data											
Exploration of sources of species data and initial data searches											
Site selection and creation of shapefiles of site boundaries											(and over Christmas)
Hilary:	-2	-1	0	1	2	3	4	5	6	7	8
Creation of shapefiles of site boundaries											
Data searches requested from LERCs											
Review of ecological documentation to extract species records											
Review of species records and their conservation designations.											
Trinity:	-2	-1	0	1	2	3	4	5	6	7	8

Review of species records and their conservation designations.	(over Easter)										
Creation of final dataset	(over Easter)										
Preliminary data analysis and visualisation	(over Easter)										
Data analysis											
Writing up											

This project was split into five main sections : scoping and pre-data collection; data collection; data review and organisation; data analysis, and the writing up.

The project did undergo some significant changes in methodology from the initial plan. The initial plan for the project, formulated in summer 2021, was for me to collect habitat-based field data myself, alongside a supervisor, with species data being obtained from biological records centres. This habitat data collection would have involved visiting a number of sites around Oxfordshire, selected from the estates of four Oxford colleges: Merton, Magdalen, Trinity and Jesus. These colleges were contacted prior to the start of the year, with a formal request for participation in the study, and all agreed for fieldwork to be conducted on sites within their Oxfordshire estates. In early Michaelmas, and the two weeks before term, a number of potential sites were visited across Oxfordshire, to select those which would be able to be part of the study, and to meet the landowners. The planned fieldwork would have involved visiting these sites, and carrying out DEFRA Metric condition assessments, to obtain data on the 'condition' of habitat patches.

However, this plan then had to be adapted, as there was no supervisor available to accompany me to field sites and provide guidance on how to use the DEFRA Metric condition assessments. These assessments would usually be conducted by ecologists with multiple years experience in the field; hence, without guidance, I would have been unable to carry out these assessments or obtain accurate and meaningful data. Attempts to obtain external support were ultimately unsuccessful, hence I made the decision to alter the methodology of the project. I then chose to use an alternative source of data, obtaining habitat data from a database comprising planning applications accompanied by DEFRA Metric calculations. In doing so, I was able to acquire the same form of data ('condition' data of habitat patches, measured using the DEFRA Metric) that I had originally planned to collect myself. In the decision to use this database, I was able to expand the scope of my study not just across Oxfordshire, but incorporating sites in five councils across the UK, totalling 122 habitat patches, a significantly greater number than I would have been able to include had I collected data in the field myself. Another important factor in the alteration of the methodology was to ensure the data I was using was accurate and reliable. The DEFRA Metric data from the planning applications in the database I used was collected by qualified, experienced ecologists. Hence, I was able to have greater confidence in the accuracy and reliability of these data than data I would have alternatively attempted to collect myself without guidance.

After adapting the methodology, the first stage of the project involved the identification of sites from the database and their relevant Metric data. In order to obtain species records through searches conducted by Local Environmental Records Centres, it was necessary to create shapefiles of the selected sites, so that these boundaries could be sent to the records centres to extract records of species found in these areas. This formed the pre- data collection stage, where site boundaries were created using GIS, and sent to records centres to obtain species records.

The data searches conducted by the records centres took varying times to complete; hence, whilst waiting for these records to be returned, I began the second stage of data collection. This involved a systematic review of ecological documentation accompanying the planning applications in the database, to extract species records. During this time, I also extracted species records from the online NBN Atlas, using the shapefiles of the site boundaries to conduct this search in the most efficient way.

Following the collection of species data, and the return of data from the records centres, I moved on to the third stage: data review and organisation. This involved the compilation of the Metric (habitat based) data and the species data I had obtained from the different sources, into a single database, which matched the records of species to the habitat patch in which they were recorded, and the Metric data to the patch for which the survey was conducted. Once the data sources were matched in a single database, the species data were systematically reviewed, which each record assessed to deduce if it met a number of conservation designations. This allowed me to finalise a dataset of species considered to be 'protected or notable', found within 122 patches for which Metric calculations had been conducted.

In the final two stages, across the third term, these data were analysed to answer my objectives, and the write up of the report was completed.