Report for Project entitled: Biodiversity metrics, public preferences, and the cost-based approach

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Executive summary

The paper meets the *expected outcomes* 1-5 of the call in the following ways: [1]

1) *A step change in our understanding of the role that biodiversity plays in ecological function of natural capital assets*:
We have elicited UK public preferences over different aspects and characterisations of biodiversity, hence providing estimates of how biodiversity contributes to non-use values and related ecosystem services. While this does not provide information on the ecological function per se, it provides insights on how different aspects of biodiversity translate into values that people hold.

2) *Improved understanding of the full suite of values of biodiversity, which will be standardly incorporated into the valuation of biodiversity within conventional economic analyses and put into practice by decision makers*:
We focus on existence values for biodiversity and by eliciting preferences over different aspects of biodiversity, which are reflected in different measures and metrics of biodiversity commonly used for public appraisal, biodiversity footprinting and financial disclosures, we gain an understanding of which metrics or aspects of metrics are the most important in terms of public preferences and hence welfare outcomes. Above all we show that the public can form coherent preferences over complex dimensions of biodiversity. Only 10% fail rationality and consistency tests, and qualitative evidence suggests the use of reason in the face of cognitively difficult trade-offs.

3) *Provide a clear narrative on how the use and when the preservation of the natural systems needs to be balanced to underpin the economy and human health and well-being*:
Our elicitation of preferences shows the precise way in which the UK public value different aspects of biodiversity. We show that while species richness, extinction risk, intactness, distinctiveness, populations and habitat area are all important to some extent

[1] The expected outcomes of the call are documented here: `https://www.ukri.org/opportunity/synthesising-evidence-in-economics-of-biodiversity/`

(contribute to non-use values), we find that there are clear trade-offs between these aspects. Yet, importantly, extinction risk species richness and distinctiveness are by far the most important aspects. This can be seen in Figure E1 below. Key to our elicitation is that we have not forced people to make monetary trade-offs, which could have led to feelings of taboo (Tetlock et al., 2000) and unrealistic monetary valuations (Spash and Hanley, 1995; Lancsar and Louviere, 2006).

4) *Provide new evidence and data to support changed practice and improved environmental performance reporting of natural assets in the private sector*:
Mean Species Abundance, Potentially Disappeared Fractions, the Species Habitat Index and threat reduction metrics such as the STAR metric are all being proposed as metrics for evaluating the impact of corporate activity of biodiversity, prior to disclosure. Such metrics would be an acceptable disclosure for the Taskforce for Nature Related Financial Disclosures (TNFD). However, for private investors evaluating disclosures our research has shown that measures of intactness (such as the MSA and SHI) may not be a salient to concerned investors as much as extinction risk and pure species richness. Although we cannot test this yet, it is likely that focusing on the aspects of biodiversity that are more salient to individuals making decisions would be more effective. Similarly, the elicited public preferences can be used to guide public policy on meeting the Biodiversity Net Gain targets associated with the UK Environment Act.

5) *Development of new decision support tools and management approaches, co-designed by academics and decision makers*: We have not developed a decision support tool, but we have provided essential information on the biodiversity metrics and combinations of metrics that ought to appear on a dashboard of biodiversity measures: primarily species richness, extinction risk and distinctiveness, and be used in the UK in order to ensure that BNG policies can be implemented using a cost-based approach which minimises the welfare loss. Figure E2 shows the welfare losses from using single metrics rather than preferences. In short, we have identified a potential preference based metric for

measuring BNG.

6) *Further research gaps identified*:

The additional research questions arising from these findings are that in order to implement biodiversity related policies, or make financial disclosures that are salient to the public, specific measures should be used. Furthermore, more research ought to be undertaken into the ecological determinants of extinction risk and distinctiveness. Furthermore, the findings point to the use of particular metrics which either focus on extinction risk or combine extinction risk and distinctiveness aspects, such as the EDGE or ED measures of Pearse et al. (2015) or Collen et al. (2011) as being fruitful metrics for such uses. For the implementation of the cost-based approach, further information is required on the relative costs of increasing different aspects of biodiversity.

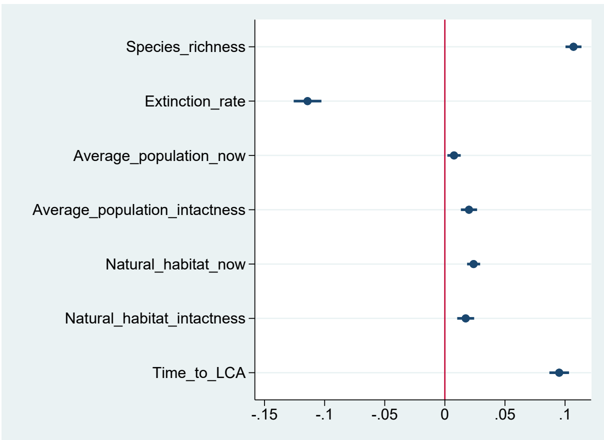

Figure E1. **The relative effect of biodiversity on well-being and choice.**

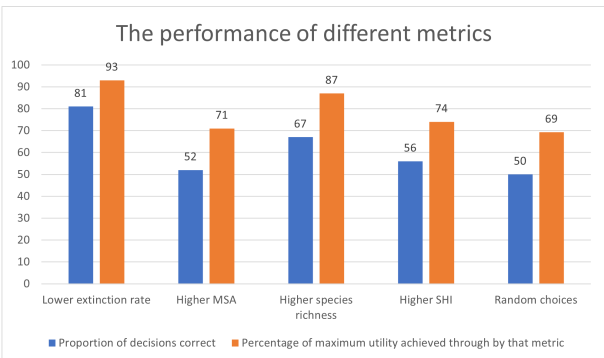

Figure E2. **The performance of *ecological* metrics of biodiversity versus *preferences* for biodiversity**.

1 Introduction

In this study we assess how best to include the value of biodiversity in economic appraisals of public policy, investment and decision-making. It is well understood that human well-being fundamentally hinges upon biodiversity (Dasgupta, 2021), and biodiversity contributes to well-being in myriad ways, for example: underpinning the production of food and clean water; sequestering carbon; and mitigating flooding (Mace et al., 2012; Mace, 2014; Paul et al., 2020). Economic decisions fundamentally affect this relationship through land-use and land-management choices, and it is relatively straightforward to establish how such changes affect ecosystem services and the economic value they generate (e.g. Bateman et al. (2013). Indeed, these monetary values are already available and reflected in guidance regarding public policy appraisal as laid out in HM Treasury's Green Book on Cost Benefit Analysis (HMT, 2020a). Yet, biodiversity is also of value to people even if they do not benefit directly or indirectly through associated ecosystem services. Indeed, the very existence of biodiversity, e.g. the absence of extinctions, contributes to people's well-being, and these "existence", "passive-use" or "non-use" values for biodiversity are evidently large, judging by the significant aggregate contributions to conservation charities (TEEB, 2010, IPBES 2021). However, public preferences for biodiversity outcomes - what the public wants in terms of biodiversity - and how this relates to operational biodiversity metrics, are little understood in relation to passive-use / non-use values. This limits the extent to which these preferences can influence policy and practice. The purpose of this study is to estimate and characterise public preferences for different aspects of biodiversity for use in public policy appraisal and design. In the process the study will be able to evaluate the extent to which lay-people can have well structured preferences over such a complex object as biodiversity, and if so, how these preferences compare with more *ecologically-based* metrics for biodiversity that typically guide policy and the flow of conservation capital (e.g. Baumgärtner, 2011; Dasgupta, 2021, ch 2).

Two approaches prevail in economics for estimating existence values for policy appraisal. The first approach is to estimate "Willingness-To-Pay" (WTP) for an increase in biodiversity as the monetised benefit in Cost-Benefit Analysis (CBA). The second approach avoids money-biodiversity trade-offs, instead using a cost-based estimate. Here, public preferences (and other strategic objectives) are reflected in a policy target for biodiversity conservation (e.g. net-gain), and the implicit value of biodiversity for the purposes of CBA derives from the cost of meeting this societal target. In both cases, knowledge of public preferences for biodiversity is required.

While addressing issues on both the WTP and Cost-based approaches, our study is motivated by the cost-based approach currently being proposed by the Biodiversity Working Group of HM Treasury as a means of including biodiversity values in the appraisal of public projects. It is also motivated by recent changes to the law enshrined in the Environment Act of 2021 which makes legally binding the target of Biodiversity Net Gain (BNG)

Nevertheless, a typical view among economists working on CBA is that policy appraisal would best reflect public preferences and well-being if based upon WTP estimates, since decisions concerning biodiversity could then be guided towards decisions where public benefits outweigh public costs. In this way decisions concerning biodiversity can be easily compared to foregone opportunities in other areas of concern in the public domain (e.g. health, education, climate), and the trade-offs between potential public policies, regulations or investments can be transparently illustrated and decisions made. Decisions made in this way are at the heart of government guidance (see HMT, 2022) and have the objective of maximising social welfare associated with the constrained purse. However, to do so requires precisely estimating WTP where in practice for biodiversity such measures are inaccurate and typically controversial.

For instance, in surveys people find it difficult to meaningfully express preferences regarding changes in biodiversity provision in monetary terms (e.g. Spash and Hanley, 1995; Richardson and Loomis, 2009), and empirical estimates of WTP for biodiversity frequently defy common sense: WTP is insensitive to greater biodiversity provision (so-called "scope insensitivity"; Veisten et al. (2004); Morse-Jones et al. (2012)); WTP changes when biodiversity is relabelled but no material change in provision occurs (e.g.

Jacobsen et al., 2008); and WTP estimates change dependent only upon what other options are available (the "decoy effect"; Bateman et al. (2008a)). The evidence suggests that when in comes to making trade-offs between money and aspects of biodiversity, the assumptions of rationality that underpin the consistency of these estimates may not hold in typical surveys. The cost-based approach to pricing biodiversity has the potential to circumvent such difficulties. It also has precedent public policy in the UK and beyond.

Implementing a cost-based approach - as is used to price carbon and Quality Adjusted Life Years in the UK to circumvent controversial WTP estimates (HMT, 2022, 2021) - requires a clearly defined target. In the UK the current policy prescription is for biodiversity net-gain, but the policy does not specify a metric to determine whether biodiversity net-gain is achieved. Indeed, as Purvis and Hector (2000) highlight the concept of biodiversity is simple, yet "the challenge comes in measuring such a broad concept in ways that are useful" (Ibid., p212). As biodiversity is multifaceted, different metrics necessarily emphasise different aspects. Traditional indexes, like Simpon and Shannon-Weiner, prioritise the evenness of populations across species. Weitzman's index prioritises genetic distance, or time between shared ancestry, across the species assemblage (Weitzman, 1992). Such indices, often framed as shared evolutionary history, capture the broader concept of distinctiveness among species (Collen et al., 2011; Pearse et al., 2015). Defra's "biodiversity metric" emphasises the area of habitat that is available, its location, and type. Mean Species Abundance reflects "intactness" - how similar to a historic baseline the current species assemblage is. Mean probability of persistence emphasises individual species' extinction risk (Thomas et al., 2004). Each metric is appropriate for use in particular settings: Simpson and Shannon type measures are used to evaluate the efficacy of policy (e.g. Bateman et al., 2013; Groom and Fontes, 2021); the MSA, used in the GLOBIO model, is used to report the global impact of public and private investments and portfolios on biodiversity (Schipper et al., 2020); and estimates of extinction risk, like the IUCN Red-List and STAR measure, are often the focus of conservation organisations (Mair et al., 2021).

At present there is insufficient research concerning which metric best reflect public preferences for biodiversity, and policies and interventions are typically organised around the different measures of biodiversity outlined below. In particular there little understanding of which measure might be best-suited for a cost-based approach to biodiversity valuation. In part, this stems from an inadequate understanding of how different aspects of biodiversity contribute to well-being via the non-use/passive-use channel (Paul et al., 2020). Hence it not obvious how a net-gain policy prescription - while grounded in the scientific fact that further declines in biodiversity will have serious negative ramifications for people's welfare - should be gauged, and the extent to which the metrics currently used accurately incorporate people's preferences for biodiversity provision. While there are different views on the extent to which public preferences *should* guide BNG, understanding the congruence of public preferences and typical biodiversity metrics will be important from a welfare perspective and hence for design and implementation. Public preferences, what people want, are a key aspect of the political economy of biodiversity policy. To overcome this key challenge in implementing a cost-based approach, an online experiment was undertaken on a representative sample of the UK public to test a number of hypotheses with regard to preferences for biodiversity. The overarching research question concerns the extent to which different aspects of biodiversity are important to people, and therefore whether there exist any typical 'off-the-shelf' metrics of biodiversity that are consistent with well-being (Paul et al., 2020; Pascual et al., 2021). Importantly, in pursuing this research question the study will also explicitly test whether people, in this case members of the UK public, can have well-formed preferences over such a complex and multidimensional issue as biodiversity. Beyond this the study will also test the relative importance of different attributes of biodiversity, where the attributes of the experiment over which respondents are asked to make decisions represent different measures of biodiversity in their own right (species richness, extinction risk, abundance) as well as components of more composite measures of biodiversity, such as MSA, Shannon Indices, Species Habitat Indices and other measures of intactness. The experiment took the form of a bespoke online conjoint analysis. Preferences were elicited via stated choices which trade-off particular imagined sites containing different levels of the different aspects of biodiversity (e.g. abundance, richness, risk, abundance and so on) are affected in different ways. The experimental scenarios were carefully constructed such that the trade-offs between different facets of biodiversity that respondents make will indicate which metrics of biodiversity best reflect preferences and hence well-being. Importantly, since our objective is to inform the implementation of the cost-based approach to BNG, the study does not include a WTP element. By not requiring participants to engage in trade-offs between biodiversity and money, the study aims to circumvent the difficulties and controversies surrounding WTP estimates (IPBES, 2019).

The results of the experiment provide a clear and striking picture of the representative preferences over biodiversity in the UK. That respondents could make consistent choices, passing a series of attention and rationality checks along the way, and form consistent preferences over complex different aspects of biodiversity is our first clear finding. The second findings concern the priorities that people have over aspects of biodiversity. the choice of conservation site strongly prioritised lower extinction risk, higher species richness and distinctiveness, over abundance, habitat area and two measures of intactness (SHI MSA). These findings have strong implications for the application of the cost based approach to BNG. Policies which define BNG in terms of off-the-shelf measures of biodiversity will lead to lower welfare outcomes compared to choosing according to public preferences. These findings suggest an argument that BNG ought to be organised around the public's complex preferences over biodiversity, rather than, or more likely as well as, standard measures. The lower preference for various intactness measures also suggests that typical measures proposed for use as a measure of impact in the financial sector (e.g. MSA as in the Globio model of Schipper et al. (2020)) may not be as important to people as other, simpler measures, such as extinction risk. This would call into question the salience of such metrics for investors and related decision-makers.

2 Literature review

Biodiversity contributes to human welfare and economic benefits in myriad of ways. As (Mace et al., 2012) explains, the benefits offered by biodiversity can be categorised as being delivered through three channels. First, biodiversity may underpin ecosystem services. Second, it may provide ecosystem services directly. Third, biodiversity is a good in and of itself from which people derive value. While the value of biodiversity through its provision of ecosystem services - be those direct or indirect - can be relatively simply estimated from people's observed behaviour (i.e. through revealed preference techniques) understanding people's value for biodiversity itself - the existence value that people hold - cannot.

Instead, economists have sought to use stated preference methods to value biodiversity. These methods broadly confront respondents with hypothetical scenarios described by some ecological indices and some monetary cost of provision. From these, one can estimate the values that people hold for particular components of biodiversity. This - and related approaches - have been applied to a multitude of specific questions. Indeed, the stated preference literature on biodiversity values has grown so much, that meta-analyses focussed on specific questions are now possible. For example, Richardson and Loomis (2009) use a meta-analysis to assess the value of threatened, endangered and rare species, finding that various factors (including: the size of the species population, type of species, and whether a species is a 'charismatic megafauna'), appear to drive the values across multiple studies. The aim of this literature review therefore is *not* to provide a comprehensive review of all the work that has gone before, but rather provide a synthesis of the range of questions that have been asked within this strand of literature, and then to critically assess the shortcomings that have been highlighted in respect to stated preference studies. We then explain how the current project aims to circumvent these criticisms.

For example, Yamaura et al. (2016) uses a choice experiment to investigate the optimal number of broadleaves within conifer plantations to optimise social welfare. They find that this optimal critically depends on people's joint preferences over both broadleaved trees and bird abundance. Similarly, Steven et al. (2017) finds that recreational birders are willing to pay substantially more to visit birding locations than is currently charged (often access is free). Moreover, Steven et al. (2017) are able to categorise different birders according to their preferences over specific aspects of hypothetical birding locations:

within the overall population, some people prioritise species richness and rates of endemism more than others, while others are attracted to sites with particularly rare species. Similarly, Rodrigues et al. (2016) study the value generated from recreational scuba diving in the Medes Islands of Spain, and assess how welfare will be impacted by ocean warming and acidification. Their results suggest that the largest welfare losses will be mediated by the local extinction of gorgonians (soft coral species).

Other papers within this literature have asked broader questions regarding what determines the value of biodiversity. Bakhtiari et al. (2018) conduct a choice experiment in Sweden and Denmark to assess values derived from improvements in habitat quality and conditions in native forest. Their results highlight that welfare generated from a conservation intervention declines the further someone is from the intervention, and that there is a step change in the welfare enjoyed when the intervention is on the other side of a political boundary (country borders).

Morse-Jones et al. (2012) report the results of stated preference study in the context of the Eastern Arc mountains of Tanzania. They find that the values people hold for biodiversity are often largely accounted for by the value that they hold for particular, charismatic, species. In an open-ended survey, Albert et al. (2018) identifies the 20 most charismatic wild species. Their results make plain that people seem to value relatively large mammals much more than other species: only 2 of the top 20 are not mammals (sharks and crocodiles, ranked 14$^{\text{th}}$ and 15$^{\text{th}}$, respectively). Similarly, the results emphasise the disproportionate value of predators; at least half of the top 20 are omnivorous or carnivorous. While the Albert et al. (2018) study does not try to assess biological predictors of value directly, Miralles et al. (2019) investigates how the genetic distance from *Homo sapiens* affects values associated with different species. Broadly, they find that species more closely related to humans are valued higher than other species.

While there are numerous stated preference studies assessing specific questions in the context of biodiversity's value, there is also a large literature which highlights, and to some extent seeks to address, apparent inconsistencies in the results of stated preference methods. In the context of preferences for habitat preservation, Czajkowski and Hanley

(2009) highlight that people are often not adequately sensitive to scale - that is, how much area is to be conserved. Similarly, in the (non-biodiversity) context of values for statistical life, Balmford et al. (2019a) documents that people tend to be relatively insensitive to the scope of the risk sensitivity. That is, the value that they hold for a relatively larger risk reduction is far less than would be predicted by a linear scaling of a smaller risk reduction, and the degree of curvature that this implies in utility is implausible.

People are also frequently observed to report choices which are consistent with so-called lexicographic preferences, in which the values of particular attributes are considered by participants in some priority order. Such behaviour implies participants cannot substitute across different attributes, and therefore analysis of these preferences, including describing a utility function, is undermined Spash and Hanley (1995). Moreover, Bateman et al. (2008b) report the impact of decoy effects (or asymmetric dominance) on choice experiment results. There, people's reported preferences over different management strategies local wetlands in Norfolk (UK) are changed when they assess two options versus when they assess the same two options when a third option - slightly less good than one of the two original options - is available to them. These results call into question whether individual's preferences can then be accurately assessed given they seem malleable to seemingly irrelevant aspects of the choice environment. Similarly, Day and Pinto Prades (2010); Day et al. (2012) report the impacts of ordering effects on stated values for clean water and health. The key takeaway from the papers is that in repeated observations of someone's preferences, later observations are influenced by earlier choices. Hence, experiments which do not randomise the order in which participants face particular choice sets return estimates confounded by the particular order of questions.

A more fundamental issue with stated preference studies in this context is that they sometimes require choices over so-called '"taboo trade-offs" (Baron and Spranca, 1997). The key concept is that there are some money - non-market good trade-offs that people are simply not willing to countenance as it would undermine their social standing or sense of self (Tetlock et al., 2000; Tetlock, 2003). Indeed, (Baron and Spranca, 1997, p. 1) explain that "People are concerned about their participation in transactions rather than just with the consequences that result.” While some of this reticence to engage in uncomfortable trade-offs may be the result of asking participants to make non-marginal trade-offs (Arrow, 1997), this explanation appears incomplete Tetlock (2003). Hence, participants are often observed to be unwilling to countenance the sort of weighing up of different factors required by stated preference studies involving money as an attribute (Tetlock, 2003).

Indeed, the potential taboo nature of money-biodiversity trade-offs may drive the behaviours observed in other stated preference studies that are inconsistent with economic theory. For example, Meyerhoff and Liebe (2009) demonstrate, in the context of forest biodiversity conservation, that people choose options which are labelled as the “status quo” at disproportionately high rates. This, they argue, may be driven by people engaging in protest votes against being forced to make awkward monetary trade-offs or handle complex previously unknown themes. Similarly, Dallimer et al. (2014) observe that estimates of monetary willingness-to-pay for urban green space only somewhat corresponds with site-level characteristics where self-reported well-being measures do so more.

As discussed, an alternative to ascertaining some value for biodiversity based upon directly estimating the value that it generates, is to instead set a science based target, and to then ascertain the cost of the marginal unit of provision necessary to meet this target. Yet, as (Purvis and Hector, 2000, p 212) explain “at first sight the concept [biodiversity] is simple too: biodiversity is the sum total of all biotic variation from the level of genes to ecosystems. The challenge comes in measuring such a broad concept in ways that are useful.” This presents a challenge to a cost based approach as not only is a target required (e.g. a 10% increase in the levels of biodiversity) so is a metric with which to measure biodiversity and measure costs.

The problem arises in that different metrics measure different aspects of biodiversity, and hence the different metric values associated with particular sites are not perfectly correlated (Baumgärtner, 2011). For example, the metrics of Weitzman (1992); Solow et al. (1993); Weitzman (1998) particularly emphasise the importance of genetic distinctiveness. The metrics used in Thomas et al. (2004); Balmford et al. (2019b); Durán et al. (2020) which suggest that the key attribute is mean extinction risk (with the papers offering slightly different ways to calculate this). And those proposed in Schipper et al. (2020); Jetz et al. (2022) highlight the perceived importance of intact habitats (henceforth 'intactness') and populations. Hence, the choice of metric will determine what biodiversity is delivered where, and different metrics will result in the provision of different biodiversity profiles, sufficient to just meet the policy target when measured with that metric.

As is highlighted by Meinard and Grill (2011) biodiversity is an abstract good, and choice experiments to date typically seek to examine the value of a particular instance of biodiversity, rather than the abstract characteristics which constitute biodiversity itself. Similarly, Bartkowski et al. (2015) argues that studies to date have been too lax in defining biodiversity, and a multi-attribute definition is required within stated preference studies. With these complex studies in mind, this study seeks to distil which attributes of the abstract good that is biodiversity are core to underpinning people's values. By this we mean, which aspects of biodiversity appear in people's utility functions, how important are they, and to what extent can off-the-shelf measures of biodiversity appeal to individuals' own assessment of their welfare? In so doing we deliberately avoid monetary comparisons and focus solely on the utility/welfare associated with physical changes in biodiversity metrics. In the context of a cost-based approach to biodiversity policy, the value for money calculation has already been undertaken and is represented in a legally-binding quantitative target.

3 Methods

3.1 Selection of biodiversity attributes

The attributes of the choice experiment were selected after an extensive search of the literature on biodiversity metrics and measures. The metrics typically used to evaluate the changes in biodiversity, and hence the success of policy interventions or the impact of land-use change or other threat factors are typically composite indicators.

The components of these indicators are usually more essential elements associated with biodiversity such as species richness, population/abundance or some element of threat risk such as the risk of extinction. From these building blocks several measures of biodiversity can be constructed (Baumgärtner, 2011).

A simple example of a measure of diversity is relative abundance: D^R. Relative abundance is dependent on species richness (n), the proportion of the population a species i makes up in any given site ($p = abundance/population\ of\ all\ species$) and a penalty for uneven distributions of populations (α).

$$D^R = v_\alpha\left(n, p\right) = \left(\Sigma_{i=1}^{N} p_i^{\alpha}\right)^{\frac{1}{1-\alpha}}$$

For $\alpha = 0$ the measure of biodiversity becomes n: species richness. For $\alpha = 1$ we hvae the Shannon-Weiner Index ($v_1\left(n, p\right) = \exp\left(-\Sigma_{i=1}^{n} p_i \ln p_i\right)$), $\alpha = 2$ yields the Simpson Index and $\alpha = infinity$ yields the Berger-Parker Index, which measures diversity solely in terms of the proportion of the rarest species in the assemblage. From this it is easy to see that measures of biodiversity that are in common use are typically composed of different aspects which are comprehensible to lay-people, but which when combined may not be. The MSA metric is another example. MSA is also composed of different aspects of biodiversity which combine to give measure of intactness: how close is the current site or ecosystem to it's pre-human state. MSA is given by:

$$MSA = \frac{1}{n_{ref}} \sum_{i=1}^{n_{ref}} \min\left(\frac{Abundance_{i,obs}}{Abundance_{i,intact}}, 100\%\right)$$

where n_{ref} is the number of species in the pre-human intact state, deviations from which are measured by the ratio for each species of currently observed ($Abundance_{i,obs}$) and intact ($Abundance_{i,intact}$) populations. In its perfectly intact state, the MSA of a site is 1 (since all ratios are equal to 100%), otherwise the MSA measure will be $0 \leq MSA < 1$. Hence the MSA reflects data on abundance and species richness (reference level) but ultimately measures intactness in terms of the existence of species (does the species still exist in the site?) and abundance (if it exists, in what number does it exist?), each of which might be interesting aspects of biodiversity in their own rights. Similarly, the Species Habitat Index (SHI) is calculated in the same way, but by looking at the area of natural habitat in a site, rather than the populations of species.

Several measures of biodiversity relate to extinction risk, either local extirpation or global extinction. At a basic level, the IUCN red list and its categorisation from Least Concern to Extinct in the Wild, are clearly rooted in the idea that prevention of extinction is an important conservation goal. Some other measures, such as the Potentially Disappeared Fraction (PDF), implicitly reflect extinction risk, with a key component being the threat a species faces and its relative vulnerability to that pressure.

Finally, species richness, intactness and extinction risk are rather blind to higher order taxa than species, such as genus, family or class. In this way, 3 species of the *Baleonoptera* genus of whales receive the same weight as 3 species from different, say, phyla. *Phylogenetic* diversity reflected in genetic *distinctiveness* among species may be important for various reasons associated with ecosystem function and resilience, and for informational reasons (e.g. Weitzman, 1992, 1998), and people's sense of existence value may well be higher for more genetically distinct species (e.g. they may think there is a greater moral case for the preservation of a monotypic taxon - like *Amborella trichopoda* the sole member of its order Amborellalesas - than there is for a grass species). In terms of individual preferences, one can imagine that people have preferences over the distinctiveness of the assemblages that are being conserved.

Our attributes are selected to reflect these different attributes or *concepts* of biodiversity that are in common use as measures of biodiversity and are often given high importance in the ecological and conservation literature. Furthermore, the attributes were selected to reflect the components of more composite measures. For instance, species richness is an implicit component in many measures of biodiversity, such as relative abundance. Extinction risk is also implicitly related to other measures of biodiversity such as intactness and abundance. Such considerations were important in our selection of attributes. With this design we are able to draw comparisons between the empirical characterisation of individual preferences over these attributes and both simple and composite metrics that are commonly in use. We are therefore able to speak directly to the question of how well different metrics capture people's preferences.

With this in mind the selection of attributes was undertaken as follows. First we reviewed the literature on the typical measures of biodiversity that are used for policy purposes or generally used in the conservation, ecology and economics literature to measure changes arising from, e.g. policies such as protected areas, or processes such as land use change. We then analysed each measure to determine its relation to some more essential definitions/conceptions of biodiversity such as species richness, (global) extinction risk, population size, habitat area and associated concepts of intactness. Table 1 shows the correspondence between the attributes selected for the choice experiment and a range of different biodiversity measures commonly used in practice. Table **??** shows the wider range of concepts, definitions and components that we considered before settling on the attributes in Table 1.

Biodiversity Measure	Species Richness	Probability of Extinction	Population Size	Population Intactness	Habitat Area	Habitat Intactness	Distinctiveness
Mean Species Abundance (MSA) (Schipper et al., 2020)	0	0	1	1	0	0	0
Potentially Disappeared Fraction (PDF) (Muller-Wenk, 1998; Schryver et al., 2010)	0	0	0	0	0	0	0
$STAR_t$ (Mair et al., 2021)	0	1	0	0	1	0	0
Shannon/Simpson (Baumgärtner, 2011)	1	0	0	0	0	0	0
Biodiveristy Hotspots (Myers et al., 2000)	0	0	0	0	0	1	0
SAFE (Newbold et al., 2016)	0	0	1	0	0	0	0
Bio Metric 3.1 (Panks et al., 2022)	0	0	0	0	1	0	0
Species Habitat Index (SHI) (Jetz et al., 2022)	0	0	0	0	1	1	0
Phylogenetic distance (Weitzman, 1992)	0	0	0	0	0	0	1
Expected phylogenetic distance (Weitzman, 1998)	0	1	0	0	0	0	1
Species-habitat extinction risk Brooks and Balmford (1995); Thomas et al. (2004); Strassburg et al. (2019, 2020); Durán et al. (2020)	0	1	0	0	0	0	0
Species-population extinction risk (Balmford et al., 2019b)	0	1	0	0	0	0	0

Note: The columns contain the attributes and the rows contain important measures of biodiversity attributes found in the literature and used in practice. The indicators illustrate how each attribute relates to different metrics, with a value of 1 illustrating that an attribute value changing will *necessarily* result in a change in the metric.

Table 1: Choice Experiment Attributes and their relation to common metrics of biodiversity

Once the attributes were decided upon we chose the number of levels and the levels themselves, as shown in Table 2. The choice of attribute levels drew from the science of each attribute in the context of existence values for bird diversity within a tropical forest. We chose bird diversity as an accessible context for respondents to consider the complexities of biodiversity, and that of a rainforest so as to ensure that a focus on existence values only could be justified. We chose a fractional factorial orthogonal design for our experiment, as has been standard in the conjoint analysis literature. 7 attributes were selected in total, four with 4 levels and three with 3. The fractional design reduced the number of possible choice cards from over 6900 permutations to 128, which were arranged in 4 orthogonal blocks of 16 binary choices. Table 4 shows an example of the type of binary choice card that emerged from the orthogonal design.[2]

	Level 1	Level 2	Level 3	Level 4	Units
Species richness	50	100	200	300	number
Probability of extinction	1	5	10	25	% species per 1,000 yrs
Population size	25	50	100	200	number
Population intactness	0.1	0.5	0.9		number
Habitable area	250	500	1000	2000	ha
Habitable area intactness	0.1	0.5	0.9		number
Distinctiveness	25	50	75		million years ago

Note: The metrics were selected to ensure cover the key concepts of biodiversity in common use, and hence so that they could be related back to as many different measures of biodiversity (used in practice) as possible.

Table 2: **Choice Experiment Attributes: Aspects of Biodiversity**

3.2 The context for biodiversity in the choice experiment

Given the complexity of biodiversity as a concept, its various definitions and measures, and our focus on non-use values, we deliberately chose a parsimonious framing for our experiment. Our aim in doing so was to minimise confusion and, given the potential for non-familiarity with some, or indeed any conceptions of biodiversity,

[2]The orthogonal design was of resolution V allowing identification of the main effects of our attributes and certain interactions.

provide simple explanations of the concept of biodiversity and its measurement. To avoid informational/framing biases we provided only concise textual descriptions of the attributes, rather than engaging in long descriptions of the global significance of biodiversity and its decline in recent decades. We also refrained from visualisations of the attributes of biodiversity for fear of introducing any framing bias. 3 shows the text that we used to explain our attributes. After each explanation, comprehension and attention checks were undertaken to ensure that respondents had understood the information, and were paying attention. Failure of 2 comprehension checks led to termination of the respondent's session, and exclusion from the survey. Participants who failed two or more attention checks were excluded subject to experimenter discretion. Only about 10 participants failed these checks, but from their written responses elsewhere were clearly paying attention. After the explanations of biodiversity attributes our hypothetical scenarios asked people to imagine two sites of interest for biodiversity described entirely by the levels of the attributes as in Table 4. However, due to our desire to test the essential elements of biodiversity via a range of attributes, and so as to not overload our respondents, we limited the number of attributes in the choice cards to 5 by combining 4 of the 7 essential attributes into 2 composite attributes. Population size and population intactness were combined to create average population proportion, while habitat remaining and habitat intactness were combined to make proportion of natural habitat. These coincide with the MSA and SHI measures of proportional intactness respectively (e.g. Schipper et al., 2020). To make concrete the application of the different attributes of biodiversity, we framed them in terms of bird species in different sites. The precise nature of the sites: the type of habitat, location, and so forth, was left to the respondent to imagine. To focus respondents on non-use values, they were told prior to the choice that the site would not be one that they could visit, a point that was also tested in comprehension and attention tests.

Attribute name	Definition
Species richness	Species richness is the number of different species that there are within a location. A species is a group of organisms which can interbreed and produce fertile offspring. For example, a robin is a different species to a blackbird. Globally, there are thought to be roughly 10,000 species of birds.
Expected extinction rate	The extinction rate is the percentage of species that are expected to go extinct in a particular timeframe. If a species goes extinct it means that globally all of the individuals belonging to that species have died. As it is a prediction, it is **uncertain** that exactly that percentage will go extinct - it could be more or less, but the expected rate represents the best estimate. Some extinctions occur naturally, not caused by humans. This is referred to as the **background extinction rate**. This background extinction rate has been between 0.02% and 0.1% of species lost every 1,000 years. Given there are 10,000 bird species, this means that in 1,000 years we would expect somewhere around 2 to 10 bird species to go extinct naturally.
Average population proportion	The average population **size** is the average number of individuals per species. It is found by dividing the number of individuals in a location by the number of species in that location. For instance, if there are 10,000 individual birds and 200 different species in the location then there are 50 birds per species on average. That is the average population size. This study will present you with the average population **proportion**. That is the average population size in a location now, over the average population size in that location before humans: Average population size now/Average population size before humans For instance, the average population size in a location now may be 100 birds per species, and the average population size before humans may have been 1,000 birds per species. For this example, the average population proportion would be presented as: 100/1,000
Proportion of natural habitat	The **area** of natural habitat is the area of land within a location that can be considered natural vegetation. It is likely to be less than the total area of a location, given that some land has probably been converted to agriculture or built infrastructure. The area of natural habitat in this study will be shown in hectares (ha). One hectare is roughly 1.5 football pitches. This study will present you with the **proportion** of natural habitat. That is the area of natural habitat in a location now, over the area of natural habitat in the location before humans: Area of natural habitat now/Area of natural habitat before humans For instance, the area of habitat in a location now may be 1,000ha, whereas the area of natural habitat in the location before humans may have been 10,000 ha. For this example, the proportion of natural habitat would be presented as: 1,000ha/10,000ha
Time to last common ancestor	**Background information** Genes can be thought of as the instructions to make an individual organism, and each species has a different set of genes. This is why some species have specific traits (e.g. peacocks have elaborate tails) and other species do not. Any group of species will share some of, but not all, their genetic material. The more they share, the more closely related are the species within the group. We can draw species on an evolutionary tree, in the same way we can represent familial relations on a family tree. Moreover, we can think of last common ancestors among species just as we can about the last common ancestor between family relations. For example, in the group of you, your brother, and your aunt, the last common ancestor is your grandparent. In another group of you, your mother, and your great uncle, the last common ancestor is your great grandparent. **Time to last common ancestor definition** One way to summarise the distinctiveness of a group of species is through their genetic distinctness as measured by the time from now until the last common ancestor of a group of different species was still alive. The longer ago this is, the more distinct are the species in that group. This study will present you with the time to last common ancestor for the bird species that are present in a location. For reference, all bird species in the world share a common ancestor roughly 75 million years ago. By this measure a group of birds whose most recent common ancestor is 40m years ago contains less genetic distinctiveness than does a group with a last common ancestor 70m years ago.

Note: This table displays the definitions of the attributes of biodiversity as shown to participants. They were required to read the definitions and then answer comprehension questions to check understanding. The definitions were also available through the task by clicking on an "i" symbol next to the attribute name on the choice card.

Table 3: Attribute definitions given to participants

Finally, after Respondents were then asked the following question: "If you could only choose one site to be conserved, which would it be?". Beyond the attendance and comprehension tests, and the parsimonious design to avoid framing effects, the choice experiment was also designed to avoid ordering effects: a systematic tendency among respondents to fix one's preferences on the first attribute in the choice card (Bateman et al., 2008b). To avoid such biases, the order of attributes in the choice cards (see Table 4) was randomised across respondents. The rubric of the choice experiment also contained additional attention and comprehension tests. Finally, following recommendations from the literature (which are surprisingly infrequently followed), as a check on the consistency of the way in which choices were made the choice experiment included a further 4 binary choices (in addition to the 16 of the orthogonal design) at the end of the survey (e.g. McIntosh and Ryan, 2002). The additional choices were designed to contain two 'rationality' type tests. The first tested whether obviously dominated choices were not chosen: the dominance test (Tervonen et al., 2018; Shah et al., 2015). The second tested for transitivity of choices (McIntosh and Ryan, 2002; Carlsson and Martinsson, 2001).[3] In our view, these rationality tests are an important test of consistency and coherence of preferences. This is particularly relevant in the context of biodiversity where one argument to eschew public preferences in the determination of biodiversity policy is the notion that biodiversity is informationally too complex for lay-people to properly form preferences, have coherent welfare effects associated with different policies, and therefore guide policy in the first place. There are arguments on both sides for excluding those who fail the rationality test (Lancsar and Louviere, 2006). We undertake robustness using the full and smaller sample of 'rational' agents. The survey then elicited behavioural traits such as risk and time preferences, so that the motivations for different choices could be tested in relation to other essential preference traints. The survey concluded with a charity donation exercise

[3]A rational choice is non-transitive if a person prefers choice a to b, b to c, and then c is preferred to a. This is a typical test for rationality failure of which would mean that preference relations could not be represented by a utility function. One sense in which Such preferences would be irrational is that they could lead to the person holding the preferences being traded into poverty.

3.3 Pre-testing and sampling

We undertook several modes of pre-test before the final study was undertaken. First, we tested out our choice experiment concept with several experts in the field of choice experiments and biodiversity. This allowed us to compare our approach to current work in the area, and refine both our focus group studies and the overall design of the survey instrument.[4] We then ran 3 focus group sessions in April 2022 with students from varied academic backgrounds from the University of Exeter. These sessions helped improve the description of attributes, the language used (for instance, we removed the term 'assemblage' and replaced it with 'group') and the overall understanding of the biodiversity attributes and the choice task. Finally we ran two pilot sessions to ensure that the lessons from the focus groups had been successfully translated to the survey and choice experiment, and respondents were able to complete the study in a straightforward manner. The pilots also served as a check for the general smooth running of the survey on our survey platform: Prolific. The first pilot was undertaken on a random sample of 10 respondents from the Prolific panel of representative citizens of the UK, while the second pilot extended that sample by another 90. Each pilot was analysed separately prior to the main survey as a sense check for the interpretation of the attributes of biodiversity, and qualitative remarks were also analysed. In short, the signs of the estimated parameters were sensible: positive sign for species richness, negative sign for extinction risk, positive sign for distinctiveness and so forth. The qualitative remarks were almost uniformly positive, displaying interest, engagement and understanding of the task at hand. Section 5.2 describes the qualitative remarks in detail.

The second pilot produced similarly intuitive results and positive remarks. Among pilot 1's respondents, all passed the rationality tests and none failed the attention and comprehension checks. In Pilot 2, X people failed the rationality checks, and Y people failed some of the comprehension checks. Nevertheless, these responses were an extremely small proportion of the overall sample (z%) and inspection of their responses suggested nothing particularly unusual. Our conclusion from the focus group and pilot phase was

[4] We are particularly grateful to Pr. Nick Hanley for his input on our study and for sharing some unpublished current work with us.

that the experimental design was working, and respondents were able to make consistent decisions using the information provided and therefore reflect their preferences well in the experiment. Furthermore, robustness ought to be undertaken on those that fail the rationality tests, in line with the literature (Carlsson and Martinsson, 2001; Shah et al., 2015).

3.4 The main survey

For the main survey we again used Prolific to obtain a representative sample of the UK public. Since our purpose in undertaking the study is to investigate whether preferences for biodiversity are well-formed and therefore relevant for the delivery of the cost-based approach to Biodiversity Net Gain (BNG), as outlined by the Treasury Biodiversity Working Group, a representative sample is required. A representative sample also provides the broadest test of the coherence of preferences for biodiversity among different sectors of the population. The survey ran for 3 days on Prolific during the week commencing June 6th 2022. A sample of 996 was collected. The key results of the study are reported in the Results section.

	Option A	Option B
Species richness	50	200
Expected extinction rate	5%	10%
Average population proportion	$\frac{200}{400}$	$\frac{50}{56}$
Proportion of natural habitat	$\frac{250\text{ha}}{2500\text{ha}}$	$\frac{500\text{ha}}{1000\text{ha}}$
Time to last common ancestor	75MYA	25MYA

Note: Each respondent faced 16 such choices where the attribute levels in each case step from a 4 block orthogonal fractional design.

Table 4: An example choice card

4 Empirical Methods

4.1 Empirical approach: conditional logit

The choice experiment provides data on the 16 (+ 4 rationality tests) binary choices made by each respondent as a function of the attributes of the choices made. We model these choices as a Random Utility Model (RUM) following the seminal work by (e.g. McFadden, 1974), as is largely standard in the literature. The RUM model models each choice as a utility maximising decision determined by obervable determinants of utility (the experiment attributes of the choice) and a random unobservable component of utility.

The Random Utility Model

We model choices as the outcome of a utility maximisation process based on observable and unobservable (random) characteristics of the choices. In the binary context each alternative j for each individual i is assumed to provide utility, U_{ij}, which is in turn defined by a matrix of observed characteristics, $\mathbf{X}_{ij}$, a vector of associated and unknown preference parameters, β, which make up the deterministic part of utility, $u(\mathbf{X}_{ij}, \beta)$ and a random element associated with choice for individul i, ε_{ij} :

$$U_{ij} = u(\mathbf{X}_{ij}, \beta) + \varepsilon_{ij}$$

A utility-maximizing individual i will choose alternative $j = 1$ rather than $j = 2$ if:

$$\begin{aligned} U_{i1} &= u(\mathbf{X}_{i1}, \beta) + \varepsilon_{i1} > U_{i2} = u(\mathbf{X}_{i2}, \beta) + \varepsilon \\ &\rightarrow \\ U_{i1} - U_{i2} &= u(\mathbf{X}_{i1}, \beta) - u(\mathbf{X}_{i2}, \beta) + \varepsilon_{i1} - \varepsilon_{i2} > 0 \\ &\rightarrow \\ u(\mathbf{X}_{i1}, \beta) - u(\mathbf{X}_{i2}, \beta) &> \varepsilon_{i2} - \varepsilon_{i1} \end{aligned}$$

The experiment yields data on which choice was made, Y_{ij}, as follows:

$$Y_i = \begin{cases} 1 & if \quad U_{i1} > U_{i2} \\ 0 & if \quad U_{i1} < U_{i2}. \end{cases}$$

The parameters in the vector β reflect the parameters of the utility function, which we assume to be linear:

$$u\left(\mathbf{X}_{ij}, \beta\right) = \mathbf{X}_{ij}\beta \equiv \sum_{k=1}^{m} X_{ijk}\beta_k$$

where k indexes the number of attributes contained in each choice. Together with a distributional assumption on the random components the binary choices can be modelled as a conditional logit model which predicts the probability of a particular option being selected as a function of the alternative's attributes and the attributes of all the other alternatives in the choice set. If $(\varepsilon_{i1} - \varepsilon_{i2})$ has a distribution function $F\left(\mathbf{X}_i\beta\right)$, then the expected value of Y_i can be modelled as follows:

$$E\left(Y_i \left| \mathbf{X}_{i1}, \mathbf{X}_{i2}\ \beta\right.\right) = F\left(\mathbf{X}_i\beta\right)$$

where $\mathbf{X}_i = \mathbf{X}_{i1} - \mathbf{X}_{i2}$.

Where individuals i make decisions over choices j on the basis of alternative specific attributes: $\mathbf{X}_{ij}$ (rather than individual specific attributes, and each respondent has elicited multiple binary responses, then conditional or 'fixed effects' logit model is appropriate. The conditional logit model assumes the following structure for the probability $F\left(\mathbf{X}_i\beta\right)$:

$$P_{ij} = F_j(\mathbf{X}_i\beta) \equiv \frac{\exp\left(\mathbf{X}_{ij}\beta\right)}{\sum_{k=1}^{n} \exp\left(\mathbf{X}_{ik}\beta\right)}$$

where $\beta = [\beta_1, ...\beta_n]$ is the vector of utility parameters specific to each of attribute k, but do not vary across choices, j. A likelihood function follows naturally from this and Maximum Likelihood can then be used to estimate the parameters. The interpretation of the parameters is simply the marginal utility of the attribute.

$$\frac{\partial U_{ij}}{\partial X_{ijk}} = \beta_k$$

The marginal effect of attribute k on the probability of selecting a particular option j is given by the $F_j'(\mathbf{X}_i;\beta)\,\beta_k$. Odds ratio interpretations also flow naturally from this approach.

We use STATA's conditional logit routine *clogit* to estimate the parameters of the utility function. The estimated parameters of the Random Utility model can be presented in several different intuitive ways. First, the direct estimates of the β_k parameters represent he marginal utilities associated with the attributes, as described above. Second, the estimates can be presented as the marginal effect on the odds ratios: the ratio of the probability of choosing option $j = 1$ over the probabiitu of choosing option $j = 2$.[5] Finally, for comparative purposes, the elasticities of parameters with respect to the probability of choosing an option can be presented. Here the interpretation is: what percentage change arises from a % change in the attribute in question. All representations are interesting and so we present all interpretations. The standard errors of the estimation were clustered at the level of the individual, reflecting the typical assumption that that responses are independent across respondents, but not within.

5 Results

One of the chief hypotheses of this study is that the biodiversity, being a multi-faceted and complex concept, is far too complicated for people to be able to form consistent preferences. Coupled with the difficulties of eliciting consistent preferences over the existence values per se (e.g. Spash and Hanley, 1995; Bateman et al., 2008b; Shah et al., 2015), the focus of this study, this complexity suggests that decisions and policies with respect to biodiversity ought not to be guided by elicitation of such preferences. Better, it is argued, to leave it to ecology and ecologists. For this reason, before describing the quantitative results of the choice experiment and the estimated preferences for

[5]Note that the odds ratio is given by: $P_j/(1-P_j)$.

biodiversity, we present the results of the rationality tests. These act as a check on the consistency of preferences over the concepts of biodiversity being tested in this study. Relatedly, we then briefly describe some of the qualitative evidence and discuss the levels of understanding associated with the choice task and the concepts/aspects of biodiversity presented. We then present the quantitative results of the study based on the subset of respondents that passed the rationality tests.

5.1 Dominance and transitivity pass rates

A discussed, two rationality tests; A dominance test and a transitivity test, were undertaken using 4 additional binary choices following on from the 16 binary choices made from the orthogonal design. Table 5 shows the results of these tests. From our sample of 996 respondents, 87.6% passed the dominance test: correctly chose an option that was clearly *better* than another option. 92.1% passed the transitivity test whereby respondents avoided orderings where option a was preferred to option b, and option b preferred to option c, and then, option c was preferred to option a, creating a cycle of preferences. A failure rate of approximately 10% in terms of these rationality test is in line with rates found in other experimental situations in which preferences are elicited. For instance, in field and lab experiments using, e.g. multiple price lists to elicit risk and time preferences, re-switching rates, an indication of non-rational responses, typically lie in the range of 8-10% (Holt and Laury, 2002; Cavatorta and Groom, 2020). Such studies seldom use representative samples as we do, rather tending to focus on convenient student samples. Our conclusion from this is that our experiment introduced no additional difficulties for respondents in terms of their ability to provide consistent orderings over sites that vary in the levels of 5-7 biodiversity attributes.

	Dominance test	Transitivity test
Pass rate	87.6%	92.1%
Fail rate	12.4%	7.9%

Table 5: Dominance and transitivity pass rates

5.2 Qualitative evidence on the choice experiment design and biodiversity preferences

Given concerns about the complexity of the subject, and the potential difficulty people may have in understanding biodiversity concepts, forming preferences and making decisions, qualitative evidence can provide insights and a sense check. Beyond assessing the randomness of stated preferences in terms of statistical significance and rationality, qualitative evidence can be important to understand how the stated preferences were arrived at: the process of decision-making, as well as the overall comprehension of the tasks at hand. The experiment culminated with some open ended questions on the respondents experience and perception of the survey, its topic and design.

On understanding concepts and the tasks in the experiment: We asked two questions relating to understanding. **Q1:** "Could you understand the attributes, and what was being asked of you?"; and, **Q2:** "Was there something you didn't understand that could have been explained better?"

The responses included were overwhelmingly positive, yet ranged from the extremely positive such as: "The explanations were very good throughout." to the more straightforward "I understood what was being asked of me". Other comments recognised the complexity of the topic, but how they were able to handle the detail, e.g. "This was very detailed but understandable", while others recognised that cognitive work required in assimilating information and making decisions, e.g. "I understood but had to concentrate deeply to make sure that I was fully grasping the concepts". Others made proposals for simpler expositions, e.g. "Diagrams might help for visual learners". Most comments had the following sentiment: "yes understood all the different biodiversity attributes and when presented with two locartions[sic], how to use them to pick a preferred area". Some comments documented particular difficulties associated with comprehension, interpretation and then trading off of attributes, e.g. "The population ratio was a little tricky to get my head around because of having to consider dividing several numbers to work out what it means in terms of the number of individuals and the number of species", while others were even more candid about how they revisited the definitions (a special feature of the online experimental design) to ensure comprehension e.g. "I clearly understood most of the information. I just had to double check when I was about to reply to questions in order to making[sic] sure I was interpreting the given information correctly". Overall, we find that the qualitative evidence does not raise any particular alarm bells in terms of either the design, the comprehension of the choice task or the understanding of the different aspects of biodiversity. Despite around 10% of negative or uncertain comments, We found the qualitative evidence to be encouraging overall.

On thought processes in undertaking the decision task. We asked a further question on thought processes. **Q3:** "Please briefly explain how you made your decisions". The responses were candid and varied, reflecting different priorities and hence heterogeneous preferences. For instance, one response was "I prioritised the different attributes starting from extinction rate, species richness and time to last ancestor". Another response was even more precise: "i[sic] was mainly looking at the number of species and the extinction rate", Others had different individual priorities, e.g. "-I was most concerned with extinction rates and the size of the natural habit in conjuction [sic] with the amount of species living within it. So I attempted to make decisions wherein the extinction rate was lower than in the other but only if there was enough land for the amount of species". Each comment reflects a clear ordering of preferences over attributes and is suggestive of reason being deployed in the formation of preferences. Similarly, other responses reflected a more general overview of priorities, e.g. "Based on what I thought was best for the majority of species". Yet others focused on the aspects that they found most cognitively difficult to interpret and explained their approach, e.g. "For the habitat questions I tried to see what would overall preserve more life/be better for the habitat itself though it was oftenb[sic] difficult to come to a decision as understandably each of the factors play into each other", which also suggests a higher order preference for survival of species and habitat, and an understanding that the different aspects of biodiversity might not be unrelated to one another. Finally, some comments suggested more economic appraisals underpinning preferences, e.g. "Weighing up costs and benefits over long term". Clearly, since our experiment contained no information on costs, the cost-benefit analysis on display here reflects some internal accounting process.

Our reading of these comments is that preferences are heterogeneous and people have different priorities, and yet species richness and extinction risk feature strongly in peoples reasoning. Such focus seems reasonable per se, and is certainly not, for instance, an artefact of the order in which the attributes were presented in the decision task, since the order was randomised for each individual. Again, we find the comments encouraging.

5.3 Public preferences for biodiversity: Quantitative results of the choice experiment

Table 6 shows the results of the analysis of the choice data using the conditional 'fixed effects' logit model described in Section 4. The estimated parameters represent the mean preference across the sample of 996 respondents as estimated from their 15936 choice decisions. Column 1 shows the estimated β_k parameters of the linear utility function. Each estimate of β_k represents the marginal utility of a unit change in attribute k. Column 2 shows the marginal effects on the odds ratio. A coefficient of 1.2 (0.95) for attribute k in column 2 means that a marginal change in attribute k would lead to a 20 (5) percentage point increase (decrease) in the odds of choosing an option. A reduction in the odds of choosing an option stems from the negative marginal utility that the attribute yields. In 6 the standard errors are in parenthesis.[6] The interpretation of Table 6 is as follows. The first thing to notice is that all the attribute parameters precisely estimated and are statistically significant at the 1% level. None of the aspects of biodiversity were seen, on average, to be uninteresting to the respondents, and on average in the representative sample as a whole, each attribute had a significant influence on utility and hence the probability of choosing a conservation option. This result mirrors, to some extent, the qualitative evidence discussed in the previous section. Secondly, the estimated parameters

[6] In the Appendix, Table 7 shows the same results only with p-values in parenthesis rather than standard errors. Similarly, the results for the subsections of the sample which passed the rationality checks, are reported in 8.

are easy to interpret and make a lot of sense. For species richness, each additional 1 (10) species raised the odds of choosing an option by 0.37 (3.7) percentage points. A 1 percentage point increase in the extinction risk *lowers* the odds of choosing a particular option by 5 percentage points. Average population size, the population intactness, area of natural habitat, habitat intactness and distinctiveness all have positive effects on utility and hence are in this sense valued by the representative sample on average. Overall, these findings suggest that the preferences for biodiversity can be complex and that individuals are able to make trade-offs among different aspects of biodiversity in choosing their preferred conservation sites. None of the aspects of biodiversity were insignificant and hence none were absent from the utility functions of individuals. This is an important empirical result on the issue of preferences over biodiversity.

The results so far are suggestive of a representative and well-ordered preference elicited using standard stated preference methods. Both the qualitative and quantitative results point towards this conclusion. Less clear at this point is the relative importance of different attributes in determining utilities and welfare. While the results in Table 6 show that all biodiversity attributes presented play some role in determining individual utility in the sense of being statistically significant determinants, are all attributes significant in practice, or are some attributes more important than others? Figure 5.3 shows the change in the probability of choosing a particular conservation side (in percentage points) as a result of a 1% change in the level of the biodiversity attribute.

The general interpretation of Figure 5.3 is as follows. As aspects of biodiversity, species richness, extinction risk and distinctiveness (as measured by time to Last Common Ancestor (LCA)), are proportionally more important determinants of utility than habitat or population intactness or levels. The estimated parameters for species richness, extinction risk and distinctiveness are clearly further from zero than than the other 4 attributes. For instance, a 1% reduction in extinction risk increases the probability that a conservation site will be chosen by approximately 12 percentage points, compared to between 1-2% points for a 1% increase in intactness, population or habitat area. For species richness and distinctiveness the proportional increase is around 10 percentage

Outcome: Choice of A vs B (0/1)	(1)	(2)
Species richness	0.0037***	1.0037***
	(0.00015)	(0.00015)
Extinction rate	-0.0503***	0.9510***
	(0.00239)	(0.00227)
Average population now	0.0004***	1.0004***
	(0.00016)	(0.00016)
Average population intactness	0.2099***	1.2336***
	(0.03851)	(0.04750)
Natural habitat now	0.0001***	1.0001***
	(0.00002)	(0.00002)
Natural habitat intactness	0.1828***	1.2006***
	(0.04067)	(0.04883)
Time to LCA	0.0103***	1.0104***
	(0.00058)	(0.00058)
N	31648	31648
No. clusters	989	989
Pseudo- R-Squared	0.1465	0.1465
Log Likelihood	-9361.3	-9361.3
Log Likelihood (with constant only)	-10968.4	-10968.4
Chi- squared	959.1	959.1
Chi- squared p-value	0.0000	0.0000

Note: Standard errors in parentheses. The sample used in estimation excludes those who failed the rationality tests for dominance or transitivity.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Preferences for biodiversity: Marginal Utilities (1) and odds ratios (2)

points. The conclusion here is that while on average the representative sample has expressed a clear set of preferences over biodiversity, with each attribute presented contributing to utility, some attributes are clearly more important than others through the lens of individual utility and welfare.

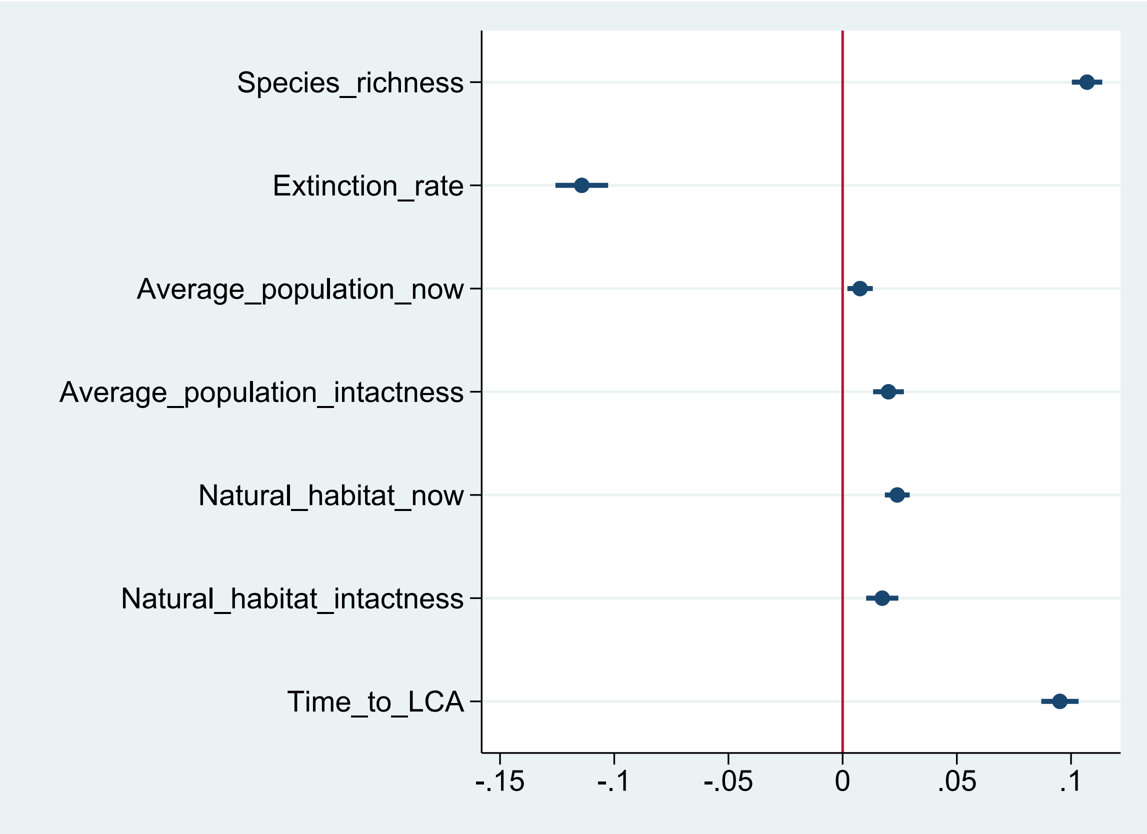

Figure 1: **The relative effect of biodiversity on well-being and choice.** *Note:* The parameters reflect the effect of a 1% change of biodiversity attribute on the odds ratio measured in percentage points on the x-axis. The parameters are estimated using STATA's clogit command followed by the margins command with the *dyey* option. The point estimates are estimated at the mean values of the attributes and are shown with 95% confidence intervals. Standard errors clustered at the individual level.

5.4 *Ecological* biodiversity measures versus *preferences* for biodiversity

In this section we ask the question, do the representative public preferences for biodiversity correspond to any *ecological* measures of biodiversity, or otherwise are there any ecological measures that make for a good approximation to the public preferences? [7] On the one

[7]We use the term *ecological* metric purely to distinguish from the preferences over biodiversity.

hand if some metrics mirror preferences well then there might be good arguments for using these measures in public policy to define overall objectives and measure policy success or in the in a cost-based approach. If the approximation is poor, on the other hand, we should be able to evaluate the extent of the welfare loss of using poor approximations to preferences. Whichever perspective is taken, this is useful information for policy design. Figure 5.4 provides the results of 5 choice simulation exercises that we used to answer this question using the estimates of preferences from the previous section and Table 6.

The 5 choice simulations assume that the choice experiment undertaken by the representative sample is undertaken by a hypothetical policy-maker whose objectives are reflected by; 1) extinction risk; 2) MSA (population intactness); 3) Species richness; and, 4) The Species Habitat Index (SHI) (habitat intactness). The final simulation assumes that conservation choices in the choice experiment are made randomly. Figure 5.4 illustrates how successful these conservation approaches are compared to the choices that would have been made by the representative public preferences as measured by 2 metrics: proportion of correct decisions and level of utility.

Consider the first two columns of Figure 5.4 concerning extinction risk. The blue column shows that compared to the choices made by the public preferences, choosing conservation outcomes that solely minimise extinction risk, ignoring all other aspects of biodiversity, will coincide 81% of the time, selecting a different conservation site (choice A or B in 4) 19% of the time. The orange column shows the utility associated with this minimising extinction risk policy approach, which is 93% of that obtained following the public preferences. The remaining columns can be understood in these terms. In summary, what Figure 5.4 shows is that a policy that focuses solely on extinction risk or species richness, these being the most important attributes in the representative public preferences, would closely approximate the choices made by the representative public preferences. A policy that chooses conservation sites according to population or habitat intactness (MSA or SHI respectively) does little better than a policy that chooses sites at random in terms of correct choices and utility.

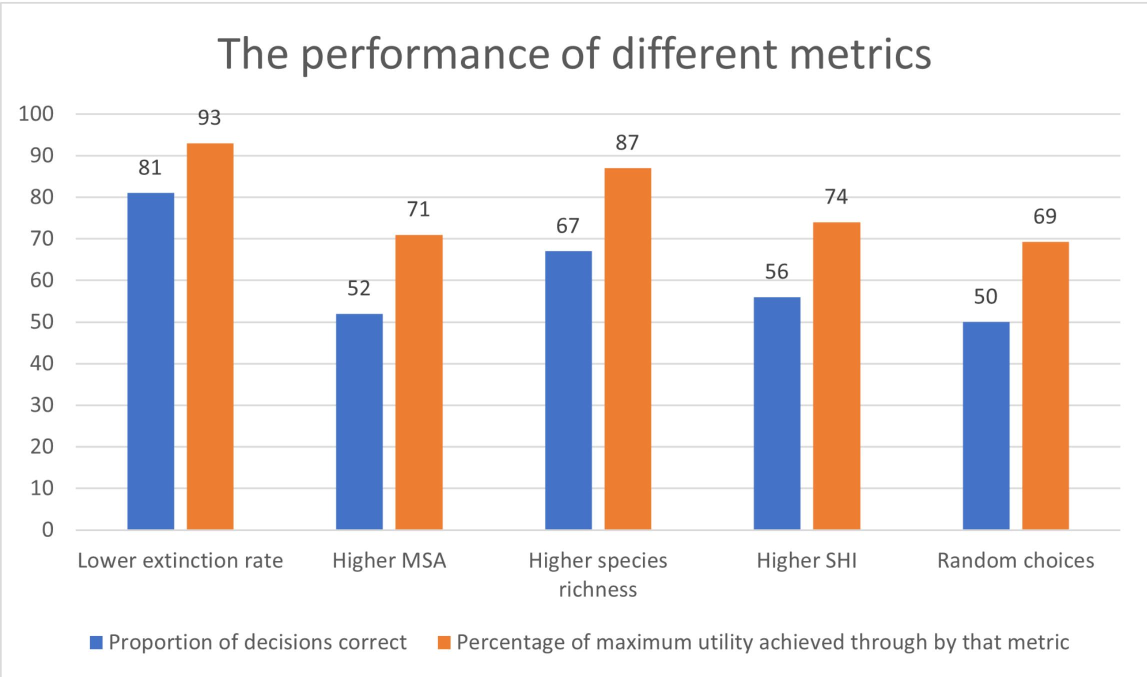

Figure 2: **The performance of *ecological* metrics of biodiversity versus *preferences* for biodiversity**. *Note:* The 5 simulations compare the conservation choices made in the choice experiment by a utility maximising agent (using the estimated parameters) to those made by an agent that chooses conservation sites according to a single metric of biodiversity: extinction risk, MSA, species richness and SHI, or else chooses conservation sites randomly.

6 The cost-based approach to biodiversity

One may consider the cost-based approach - rather than direct valuation of the welfare that it generates - within cost benefit analysis for a number of reasons:

- Biodiversity can be a component of the natural capital stock, an ecosystem flow, and final economic good, and has an important non-use component;
- The science connecting biodiversity, natural capital and ecosystem services is still uncertain about many such relationships;
- The economic value of biodiversity is often extremely difficult to evaluate because: i) of the uncertain relationship to natural capital, ecosystems and ecosystem services; and, ii) methodologically, estimating economic values of biodiversity, particularly non-use values is unreliable;
- Economic valuation remains an important tool for decision making and comparing alternative interventions (policies, programmes and projects);
- Therefore, organise the pricing of biodiversity around legislation which reflects a societal evaluation of the importance of biodiversity, and use the cost of meeting that target to inform CBA and decision-making.

We next turn to consider exactly how a target and cost-based approach to biodiversity in CBA would be implemented, and the impact of this research on siad implementation. The cpst- approach abides by the policy target for biodiversity (e.g. no net loss or net gain) and uses the cost of maintaining this target as the shadow price/cost of biodiversity, rather than a valuation of biodiversity. By doing so the cost-based approach ensures the target is met, and that biodiversity is not given a zero value in CBA of policies, programmes and projects. The approach draws upon the expertise of ecologists to determine a biodiversity target (e.g. net gain), and economists to ensure that the target is met in a way that maximises social welfare / social value for money, taking into account all other environmental and welfare changes and the public's preferences over biodiversity, all in accordance with the current best practice for CBA implementation.

A target and cost-based approach recognises the key role that biodiversity has in underpinning natural capital and the plurality of values, including economic values. It takes the view that a national physical target for biodiversity reflects society's agreed valuation of biodiversity, and the cost-based approach reflects the costs of ensuring public interventions achieve that target. Pricing biodiversity in this way will deter some projects that have high impacts on biodiversity or incentivise their redesign. It will also allow consistent appraisal of policies purely designed to protect or increase biodiversity through something akin to cost effectiveness analysis.

The Carbon Precedent: There is a precedent for such an approach. Here, a target-compatible Marginal Abatement Cost approach is used to avoid the complexities, uncertainties and disagreements associated with estimating the Social Cost of Carbon (SCC). The policy target is to reach net zero by 2050, which is enshrined in the Climate Act of 2008 and 2017. This is a political target, the motivation for which is that the benefits of action are perceived to outweigh the costs, a position backed by studies such as the Stern Review (Stern 2007). The Dasgupta Review (Dasgupta, 2021) makes an equivalent point about biodiversity which can be used to motivate this approach. The lack of fungibility and spatial heterogeneity of different 'biodiversity features' (species number, species diversity, habitat, landscapes) makes the cost-based approach to biodiversity more difficult, but the principles are similar; the compensation cost in a given spatial context reflects a target-compatible biodiversity price.

Unlike carbon, biodiversity does not lend itself easily to an obvious metric upon which to assess whether the target is met. This paper fills that gap. If we wish to maximise the benefits enjoyed by the public stemming from existence values for biodiversity, the utility function derived in this paper is then the metric by which this target should be evaluated. Moreover, the results of this paper also suggest a clear ranking in the welfare that is delivered by different, simpler, metrics. For instance, a cost-based approach with a target defined in terms of no net increase in mean extinction rates would deliver higher welfare than a similar target for no net loss in habitat area. Of course, these metrics not only have implications for the welfare that is generated, but also for the marginal costs of provision. *A priori* it is unclear which direction these effects will be in.

7 Discussion

The research in this paper has addressed an essential issue in the application of economics to public policy for biodiversity. Central guidance on Cost Benefit Analysis (CBA) in the UK (and many other countries besides) advocates that departments evaluate investments, policies and regulatory changes by assessing the costs and benefits of such interventions. Underpinning this guidance is an objective of improving social welfare and obtaining value for money in the use of public funds. While the guidance is clear on the assessment of many environmental benefits and ecosystem services - and there is a long history of evaluating direct (e.g. recreation and health) and indirect (e.g. improvements in productivity of soils or water quality) - evaluating the economic benefits of biodiversity is complex because of the way biodiversity interacts with natural capital and ecosystem services, and methodologically suspect when it comes to existence values. There is concern among ecologists and conservation scientists that *decentralising* the desiderata for biodiversity policy to the CBA framework, and hence the preferences of individuals either experiencing or considering the existence of biodiversity may miss out on some crucial ecological aspects of biodiversity. Hence there appears to be an impasse with economists' objective or organising policy around welfare and utility (the C and B in CBA) and natural scientists and conservationists concerned with what they perceive to be important when it comes to biodiversity. Our concern in this research has been to address this impasse on two levels and our research suggests the following conclusions. First, focusing exclusively on existence values for biodiversity, our stated preference choice experiment suggests that simple informative explanations of the different concepts and measures of biodiversity are sufficient to allow people to form consistent and coherent preferences over biodiversity. Since the experiment was undertaken on a representative sample of the UK public, the findings are potentially policy relevant in the UK context. Rationality checks and qualitative evidence on comprehension and decision-making thought processes attest to the consistency of preferences within this sample. Second, the representative (average) preferences do not coincide perfectly with any typical measure of biodiversity that is currently in use in policy analysis. Taken literally and from a pure welfare/utility perspective, choosing conservation sites (as described in our experimental choice cards) according to some typically-used biodiversity metrics, often barely improves upon random selection of sites. Furthermore, there are considerable welfare losses associated with policies organised around particular metrics. This is particularly so when it comes to biodiversity measures that are organised around the concept of intactness, such as Mean species abundance (MSA), or the Species Habitat Index (SHI). Some measures of biodiversity perform better in this regard. Choosing sites solely on the basis of their lowest extinction risk leads to 81% of choices coinciding with public preferences, and generates 93% of the welfare of choices determined by public preferences. Species richness also performs well (67% and 87% respectively). These results are simply a reflection of the fact that, while our representative sample was able to form preferences and make trade-offs around the different concepts and measures of biodiversity, some aspects clearly featured more in the representative utility function than others. In terms of % changes, the percentage point change in the likelihood of choosing a particular conservation site increases by 15% for a % reduction in extinction risk, whereas a % increase in intactness only increases this likelihood by about 2%. Species richness and distinctiveness are similarly proportionally more important to people. It is tempting to conclude here that people focus in on the most intuitive aspects of biodiversity: number of species and extinction, since these are easy to interpret, and probably familiar to most respondents. Nevertheless, the relatively higher importance of genetic distinctiveness, as measured by time to Last Common Ancestor, was by and large a new concept according to the qualitative evidence, suggests simplicity and familiarity are incomplete explanations for the nature of these preferences.

The implications for policy are as follows. Firstly, the choice of biodiversity metric for policy evaluation or policy objectives can have welfare implications, and people have preferences over different aspects of biodiversity that are not the primary concern of these metrics. Secondly, our estimation of public preferences takes a demand-side view of biodiversity. The actual optimal implementation of biodiversity policy will depend on the economic supply side too: the costs of provision of biodiversity, and specifically the marginal costs of providing a change in each metric of biodiversity. For instance, increasing species richness may be much less costly than reducing extinction risk, or increasing intactness or distinctiveness. Nevertheless, the results in Figure 5.4 are still indicative of the potential distortions to welfare that could arise from targeting single metrics of biodiversity and ignoring preferences, holding marginal costs equal. However, when it comes to evaluating the cost-based approach to BNG, as proposed by the Treasury Biodiversity Working Group, the costs of achieving BNG will certainly differ depending on the metrics used and hence the nature of the net gain required. Further research will show how these policy targets would be most efficiently met for each metric, and the implications of this in terms of cost and spatial land-use decision. Overall though, in terms of the UK government targets, reducing extinction risk appears key, and this research clearly illustrates that this aligns quite closely with UK public preferences according to our findings. In the realm of financial disclosure for biodiversity, and the recommendations of disclosure mechanisms like the Taskforce for Nature Related Disclosures (TNFD), if salience to investors and clients of financial institutions is important, metrics that reflect or purport to reflect extinction risks might well do better to shift the demands of capital allocation (e.g. the metrics in Thomas et al. (2004); Strassburg et al. (2019); Durán et al. (2020)), than more commonly proposed metrics like MSA (as used in the Corporate Biodiversity Footprint) or PDF (as used in the Biodiversity Footprint for Financial Institutions approach). Again, the advice that follows from our findings here depends on the precise purpose of the footprinting exercise in question. Our findings are suggestive of the need for a dashboard of disclosure indicators, one of which should chime with public preferences.

More generally, the findings here force us to think more carefully about the metrics that we propose to evaluate BNG or use as metrics for financial disclosure. For instance, metrics like MSA and SHI are used for various reasons, but the claim is often made that they are useful because they relate to extinction risk and species richness. Yet these claims are not quite the case. For instance, at first glance intactness seems to be related to extinction risk, and this is captured for populations (MSA) and habitat area (SHI) in their construction. Each is related to species richness and extinction risk, however the functional relationship contained in these metrics does not align well with what is known about area-species-extinction risk or population-extinction-risk relationships Brooks and Balmford (1995). One issue is linearity: the relationship between habitat area and species richness is typically a non-linear, concave relationship. Another stem from the aggregation. For instance, the extinction risk of a given species depends on its individual intactness: how many of a given species remain compared to pre-human levels. Yet the MSA metric takes an average of these intactness measures over all species in consideration, losing the connection between individual species risks via aggregation - introducing an error stemming from Jensen's inequality. A similar argument can be levelled at the SHI, which aggregates over habitat intactness measures. Each measure loses the direct connection with species richness and extinction risk. None are directly concerned with distinctiveness. If we are to be concerned with public preferences for the reasons of, say, welfare, political economy and salience discussed above, then other measures of biodiversity might well be better placed in the public discourse, given our findings. Firstly, Balmford et al. (2019b) specifically model the species-population-extinction risk relationship and propose a metrics according to a stylization of empirical findings. Brooks and Balmford (1995), Thomas et al. (2004), Strassburg et al. (2019) and Durán et al. (2020) look explicitly at species-habitat-extinction risk relationships. In each case the relationship between habitat or population and extinction risk is non-linear, with declining marginal effects: the first additions to population or habitat intactnesses have larger effects on extinction risk than the last additions. From the perspective of our estimated public preferences, these metrics seem to better capture non-use values than the aggregated intactness measures: MSA and SHI. Further, some metrics embody both extinction risk and distinctiveness: e.g. Pearse et al. (2015) and (Collen et al., 2011). For similar reasons, these metrics might also be closer to the aspects that people value, compared to either single metrics or the intactness metrics. With regard to future work and ways forward. Certainly, there is much more work to be done on these data with respect to the heterogeneity of individual preferences for biodiversity. Random parameters logit models will be deployed to evaluate the variability and distribution of the preference parameters for each aspect/attribute.[8] Proper simulations of the implications for the cost based approach of public preferences would also help to display the practical implications of our findings. Above all, though, the research here has contributed to the debate as to whether directly illicited preferences over different aspect of biodiversity, rather than estimates of Willingness-to-Pay should play a role in public policy at all. Those from a CBA tradition may accept that people may not be able to make reliable trade-offs between money and aspects of biodiversity given the difficulties with hypothetical bias in WTP studies. Similarly, the introduction of a familiar good (money) may mean that respondents simply give up try to understand more unfamiliar goods (population size, genetic distinctivness) and hence the introduction of money may even distort the estimated trade-offs across different biodiversity aspects. Yet our study avoids WTP questions and reveals more primary preferences. Should these be used in public policy, or should we solely rely on metrics stemming from the ecological side of the debate to guide us? This research shows that estimating public preferences is potentially promising: 1) preferences are consistent for the majority; 2) qualitative evidence provides sensible and intuitive accounts; 3) rationality tests provide robustness to the results. In our minds, this provides some evidence against the argument that the topic is too complicated for sensible preferences to be formed. Furthermore, on the one hand the economic preferences do not explicitly take into account the functionality of different aspects of biodiversity and the roles they play in ecosystem services and so forth. On the other hand, ecological measures pay no attention to the public preferences for biodiversity. In this regard, we have shown that certain ecological measures score highly on welfare. It remains to be seen as to whether preference approaches score well in terms of ecological aspects that are important to the good functioning of ecosystems and so on. Yet the overlap strongly suggests that there is room for a compromise between welfare and ecology in this difficult

[8]Initial model results suggest that even the tightly estimated parameters associated with extinction risk, species richness and distinctiveness have a certain amount of heterogeneity.

area of public policy.

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A Appendix

A.1 Additional results tables

	(1)	(2)
chose this alternative		
Species richness	0.0037***	1.0037***
	(0.000)	(0.000)
Extinction rate	-0.0503***	0.9510***
	(0.000)	(0.000)
Average population now	0.0004***	1.0004***
	(0.008)	(0.008)
Average population intactness	0.2099***	1.2336***
	(0.000)	(0.000)
Natural habitat now	0.0001***	1.0001***
	(0.000)	(0.000)
Natural habitat intactness	0.1828***	1.2006***
	(0.000)	(0.000)
Time to LCA	0.0103***	1.0104***
	(0.000)	(0.000)
r2		
N	31648	31648

p-values in parentheses
Clogit notes
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Results

	Full sample	Passed dominance test	Passed transitivity test	Passed both dominance and transitivity test
Outcome: Choice of A vs B (0/1)				
Species richness	0.0037***	0.0044***	0.0038***	0.0044***
	(0.00015)	(0.00017)	(0.00016)	(0.00018)
Extinction rate	-0.0503***	-0.0672***	-0.0517***	-0.0691***
	(0.00239)	(0.00246)	(0.00254)	(0.00260)
Average population now	0.0004***	0.0006***	0.0005***	0.0006***
	(0.00016)	(0.00018)	(0.00017)	(0.00019)
Average population intactness	0.2099***	0.3437***	0.2056***	0.3339***
	(0.03851)	(0.04292)	(0.03995)	(0.04462)
Natural habitat now	0.0001***	0.0002***	0.0001***	0.0002***
	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Natural habitat intactness	0.1828***	0.2887***	0.2021***	0.3191***
	(0.04067)	(0.04551)	(0.04324)	(0.04841)
Time to LCA	0.0103***	0.0121***	0.0108***	0.0127***
	(0.00058)	(0.00066)	(0.00061)	(0.00069)
N	31648	27712	29152	25632
No. clusters	989	866	911	801
Pesudo-R-squared	0.1465	0.2080	0.1530	0.2161
Log Likelihood	-9361.3	-7606.1	-8557.4	-6964.1
Log Likelihood (with constants only)	-10968.4	-9604.2	-10103.3	-8883.4
Chi- squared	959.1	1337.7	913.8	1286.5
Chi- squared p-value	0.0000	0.0000	0.0000	0.0000

Standard errors in parentheses

Clogit notes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 8: Results