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What are we measuring? A review of metrics used to describe biodiversity in offsets exchanges

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Abstract

Biodiversity offsets are increasingly employed as an approach to compensate for unavoidable development impacts. Reliance on overly simplistic metrics in assessing the impacts of development, and assigning offset requirements, generally results in offsets which fail to conserve the key ecological values they seek to protect. We conducted a cross-disciplinary quantitative review, based on 255 peer-reviewed publications from three fields of research; offsetting (n = 43), conservation planning (n = 54) and ecology (n = 158), to explore which metrics are commonly used in offsetting compared to the conservation and ecology literature. We recorded the use of biodiversity metrics from 24 categories which captured broad habitat patterns (e.g. habitat area and condition) as well as specific biological and ecological mechanisms (e.g. diversity, population density or landscape connectivity). Our review found that offset studies and programs rely heavily on habitat attributes and area-based metrics, with >70% of the offset literature having used these metrics. Habitat attributes and area-based metrics were less frequently reported in the conservation planning (56 and 59%, respectively) and ecological literature (49 and 15%). Ecological research had a higher frequency of metrics reflecting the biological and ecological processes relevant to biodiversity, such as species' population densities and species-specific connectivity. Our results also indicate a notable disconnect in how biodiversity is measured when offsets are planned compared to when their outcomes are evaluated. This demonstrates the need to re-evaluate the way offset programs value, describe and measure biodiversity, so that critical biodiversity values and important ecological processes are appropriately captured, and no net loss is achieved.

Introduction

Biodiversity offsets are becoming increasingly popular as a regulation and conservation tool aimed at reducing the impact of developments on biodiversity (BBOP, 2012). Around the world over 45 offset programs have been established and as many as 108 public policies now incorporate no net loss principles, which is often the key objective of biodiversity offsets (Bull and Strange, 2018; Madsen et al., 2011). Biodiversity offsets are highly critiqued, largely because it is unclear how effective offsetting policies are in practice (Bull et al., 2013), and whether no net loss is achievable using current frameworks (Bezombes et al., 2019). Achieving no net loss through offsetting requires implementing conservation actions that aim to balance the environmental losses caused by development with biodiversity gains (Birkeland and Knight-lenihan, 2016; Bull et al., 2016, 2013). Quantification of biodiversity values may happen at several stages in the impact assessment and offsetting process, as well as during monitoring of proposed actions and outcomes (Geneletti, 2002). One of the major challenges in the implementation of offsets is how to quantify the trading of biodiversity losses due to development for appropriate gains delivered through an offset action (Bull et al., 2013; Ives and Bekessy, 2015).

Methods and metrics used to evaluate biodiversity have important impacts on conservation strategies and resource allocation (Davies and Cadotte, 2011). However, measuring biodiversity is notoriously difficult in all fields of ecological research and generally cannot be summarise using a single-metric approach (Liu et al., 2018; Williams and Araújo, 2002). 'Biodiversity' is used as a catch-all term which encompasses any of the multiple levels of biological complexity (Ferrier, 2002). To simplify the task of measuring biodiversity, ecologists generally measure a small subset of it to act as surrogates for other features not explicitly assessed, usually based on habitat attributes (BBOP, 2012; Davies and Cadotte, 2011). Commonly used offsetting metrics tend to focus on a measure of habitat condition which is calculated and weighted across several habitat features. This is combined with the area impacted and a ratio or multiplier value which may increase offset requirements so as to deliver equitable or greater biodiversity gains (Rayment et al., 2014). The final value used for the trade is generally a summed habitat condition score which determines the amount of area of a particular quality or condition that is required to offset the losses expected through development (Gibbons et al., 2018). For example, in Victoria, Australia the 'habitat hectare' has been developed specifically for use in offsetting and incorporates seven habitat features and three landscape metrics into a weighted habitat score which is combined with site area to compute a quality-adjusted area of habitat (Parkes et al., 2003; The State of Victoria Department of Environment, Land, 2017a; Table 1.1). Similarly, in the United States, wetland mitigation ratios are based on the type of wetland affected and the size of the impact (US Army Corps of Engineers, 2014). In this approach, the habitat type and area of impact determine how extensively a developer must offset their environmental impacts. This can influence both the size of the offset required and the type of activity implemented (Bull and Strange, 2018; May et al., 2016).

The assumption in using metrics based on habitat attributes or vegetation types in offsetting programs is that by protecting or restoring these features, there will be both a direct benefit to habitat and a corresponding, but indirect benefit to plant and animal species (Cristescu et al., 2013). This, however, will not always be the case (Bedward et al., 2009). Several studies have demonstrated that metrics based on habitat attributes and vegetation type tend to be overly simplistic and do not fully capture individual species' ecological needs (Cristescu et al., 2013; Hanford et al., 2016; Kujala et al., 2015a). These metrics assign low scores to ecologically important sites which may occur in a degraded condition or in small patches (Hobbs, 2016; Maseyk et al., 2016). Moreover, smaller or more degraded sites are often considered of lesser conservation value (Wintle et al., 2019), and therefore may not be prioritised for offsetting since they are presumed to deliver fewer gains. Resulting offset sites can therefore deliver markedly different biodiversity values from those lost (Price et al., 2019), with the risk of trading away critical habitat, such as large old-growth trees, which may support rare or threatened species (Le Roux et al., 2016, 2015; Maron et al., 2012; Wintle et al., 2019). Consequently, we must understand the ramifications of using metrics which are uncoupled from the biodiversity values they are intending to capture (Cristescu et al., 2013), and identify transparent and fungible methods for assessing biodiversity impacts and offsetting requirements.

Despite increased efforts to incorporate ecological processes into metrics that support offsets, such as through the use of landscape measures (Gibbons et al., 2016; The State of Victoria Department of Environment, Land, 2017b), most currently used offsetting metrics largely fail to capture landscape level impacts on populations and species (Bekessy et al., 2010; Crouzeilles et al., 2015). The inclusion of species biology or population processes (e.g. dispersal, Allee effects) adds an additional layer of complexity to biodiversity assessment (Ferrier & Drielsma 2010) and offset calculations. When the objective of offsetting is to ensure the persistence of particular species in a region, offset metrics should incorporate measures of variables that directly mediate population persistence (Cristescu et al., 2013; Drielsma et al., 2016), such as species-specific dispersal measures, or estimates of the carrying capacity, expected survival and fecundity of species in a habitat patch. Testing current biodiversity offsetting metrics and identifying realistic alternatives is not yet fully addressed in research on offsets (Maron et al., 2016; ten Kate et al., 2004).

Here, we reviewed the offsetting, conservation planning and ecology literature to identify the most common metrics being used in offsetting compared to those used for measuring or assessing biodiversity in the broader fields of conservation planning and ecological research. Understanding how biodiversity is treated in other conservation and environmental management activities may provide valuable insights into current offset metrics, where they fall short and how they could potentially be improved. The purpose of this review is therefore to highlight potential gaps in current offset metrics and identify where future research could contribute to testing alternatives.

Methods

Review design

We used a cross-disciplinary review approach which followed a step-wise search and assessment procedure (Figure A.1: Pickering & Byrne 2014). The purpose of this design was to capture the most commonly used measures across multiple disciplines. We used Scopus to collect publications from three fields; offsetting, conservation planning and ecology (See Appendix A for detailed definitions of each category). The intention of this review was to examine and characterise how these different fields measure biodiversity. We defined categories of metrics that are commonly utilised in these fields and assessed how often they were used through a quantitative literature review.

Our literature database consisted of a collection of seminal offset literature collated in the initial exploration of the subject and articles found through key-word searches in Scopus. Two searches of the literature were conducted, the first sought to identify suitable publications from conservation planning and ecology using the search terms "biodiversity" AND "metrics" AND ("ecology" OR "conservation") and resulted in 258 publications from 1999 to April 2017. The second search was aimed at gathering publications from the offsetting literature and used the terms "biodiversity" AND ("conservation" OR "ecology" OR "offsets") and resulted in 54 publications. In total, we collected 312 publications plus a further 32 articles found using the reference lists of included publications. The collected literature was assessed based on titles and abstracts to determine if they fit the review objectives and those not relevant to the research questions were eliminated (n = 40). Another 17 papers were deemed not relevant to the research objective during the detailed review and were removed from our sample. Our sample included peer-reviewed research papers, meta-analyses and quantitative reviews (n = 255) but excluded the grey literature and unpublished research.

We placed publications into one of three broad disciplines (offsetting, conservation planning and ecology**)** based firstly on the title, keywords, and journal type, then content of the paper and goal of the research (Appendix A.1). These categories were kept intentionally broad to allow for general patterns in metric use to be assessed between research fields. Our intention was not to make generalisations about what constitutes conservation planning versus ecological research, nor was it to critique the papers classed as belonging to any of the three disciplines. We aimed only to reflect on broad differences in metric use between offsetting compared to other fields of biodiversity relevant research. These publication categories were useful for creating boundaries between fields where in reality most research is not clearly segregated into a single discipline. This approach, however limited in its ability to define research disciplines accurately, was useful here to observe the trends of metric use within the literature. This was essential for examining how offsetting compares to other fields and where the gaps within current offsetting practices are most pronounced.

We also examined patterns in metric use within just the offsetting literature by separating the sample into two subjects. Modelling and methodology papers were primarily focused on planning or assessing the methods for an offset or offsetting approach. Monitoring and assessment papers were generally concerned with examining the outcomes of a specific offset, assessing the effectiveness of an offset strategy or monitoring restoration outcomes. Our intention for examining the offsetting literature this way was to determine which metrics were used at each stage of offsetting, both in the planning and testing stage and during the long-term monitoring. Metric categories were determined based on a preliminary reading of the offsetting and conservation planning literature and then further developed using a sample of publications from all three subject categories (Pickering and Byrne, 2014). We started with seven broad classes of biodiversity metrics. We also recorded the use of additional measures frequently considered in these types of publications, but which do not directly measure or characterise biodiversity or ecological processes (from here on called "other metrics", see Table A.1). After examining the first 25% of the literature we revised our categories resulting in more specific sub-categories and definitions (Pickering & Byrne 2014). These were decided based on the frequency with which each specific sub-category appeared in the literature. However, under some of the categories there were additional underlying metrics within that class (Table 2.1). For example, density was split into two sub-categories which frequently occurred in the literature; population density and biomass. All sub-categories included but were not limited to the definitions and features outlined for use within this review (Table A.2). The use of broad categories and sub-categories helped to reduce the number of metrics included in the analyses and focused the study on how frequently specific metric classes were employed in the literature.

Table 1: *Final categories and sub categories selected*

Data analysis

Since most of the studies we examined used more than one metric in the methods or analysis, the standard categorical measure usually used in quantitative reviews (Pickering and Byrne, 2014) could not be utilised easily here. We therefore recorded the presence and absence of each metric within a paper using a one to

Category	Sub-Category
Abundance	Species Abundance
	Taxonomic abundance
Area	Area
Habitat	Habitat attributes
	Distributions
Connectivity	Connectivity indices
	Landscape metrics
Density	Population density
	Biomass
Distinctiveness	Phylogenetic distinctiveness
	Functional distinctiveness
Diversity	Diversity Indices
	Functional Diversity
	Genetic diversity
	Phylogenetic diversity
Richness	Species Richness
	Taxonomic Richness
Other	Complementarity
	Disturbance
	Threat/risk
	Rarity/irreplaceability
	Uncertainty
	Persistence
	None/Other

indicate the metric was present and a zero to indicate the metric was absent. We also collected information on the year of publication and location of the research. All data were summarised using RStudio statistical software (The R Foundation for Statistical Computing, 2017).

Results

Extent of literature reviewed

Across 255 publications we identified 24 metric sub-categories (Table 2.1). Of the 255 papers reviewed, 158 came from the ecology literature, 54 from conservation planning and 43 from offsetting. The number of publications in all three fields increased from 1999 to April 2017, and followed the same trends, with a spike in publications between 2012 and 2017 (Figure A.2). The literature in all three fields was widely distributed around the world. However, as expected, developed regions were better represented in our sample particularly in the offsetting category (Figure 1).

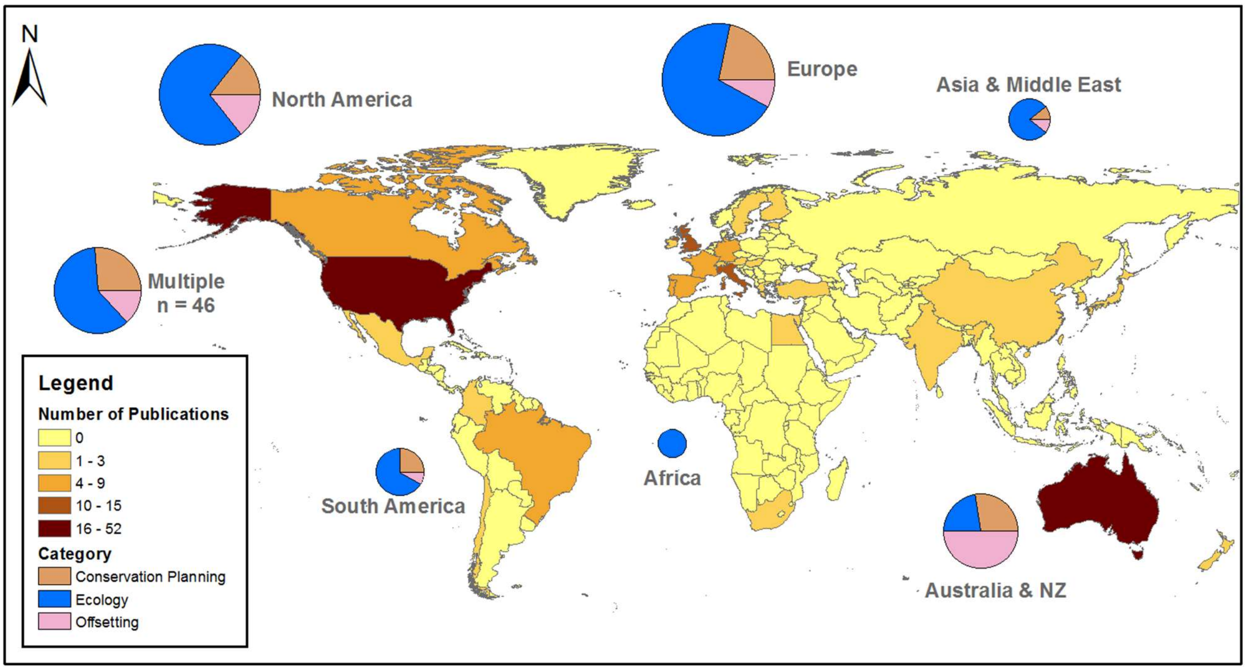

Figure 1: Number of publications sampled across countries. Yellow to red shading shows the number of publications by country, while the pie charts give the breakdown of sampled publications across the three literature disciplines for each continent. The size of the pie charts reflects the number of publications examined in each continent. A 'Multiple' category (n=46) was used to characterise papers which did not have a set geographic origin and had sites in multiple regions or authors from several countries.

Metric use within three research fields

Across all papers reviewed, occurrences of metrics relating to genetic, functional and phylogenetic diversity, distinctiveness measures and taxonomic richness was low (under 20% occurrence recorded). Habitat attributes, species richness, species abundance, landscape metrics, area and distributions, respectively, were the most commonly used metrics throughout the review (Figure 2). Habitat and area-based metrics occurred most often in offsetting studies (86 and 74%, respectively) with lower proportional occurrence in conservation planning (56 and 59%, respectively) and even lower in the ecological literature (49 and 15%, respectively).

Furthermore, species richness and species abundance, the next most common metrics, had the highest proportional occurrence in the ecological literature (56 and 57% respectively). Conservation planning literature commonly utilised species richness (48%) but species abundance less often (24%). Richness and abundance metrics were less frequent in the offsetting literature (37 and 19% respectively). Of the three fields, literature within ecology used the largest number of different metrics to measure and characterise biodiversity.

Our results indicate a gradient between categorised fields. At one end, the ecological literature was much more driven by ecologically focused metrics, such as abundance and connecitivity which may provide information on the processes important to persistence. In contrast, the offsetting literature generally only measured patterns of biodiversity, such as habitat attributes, which may not necessarily capture the processes driving biodiversity patterns in the landscape or those likely to influence survival and persistence. The conservation planning literature fell somewhere in between, with use of both ecologically focused metrics and measured patterns of biodiversity.

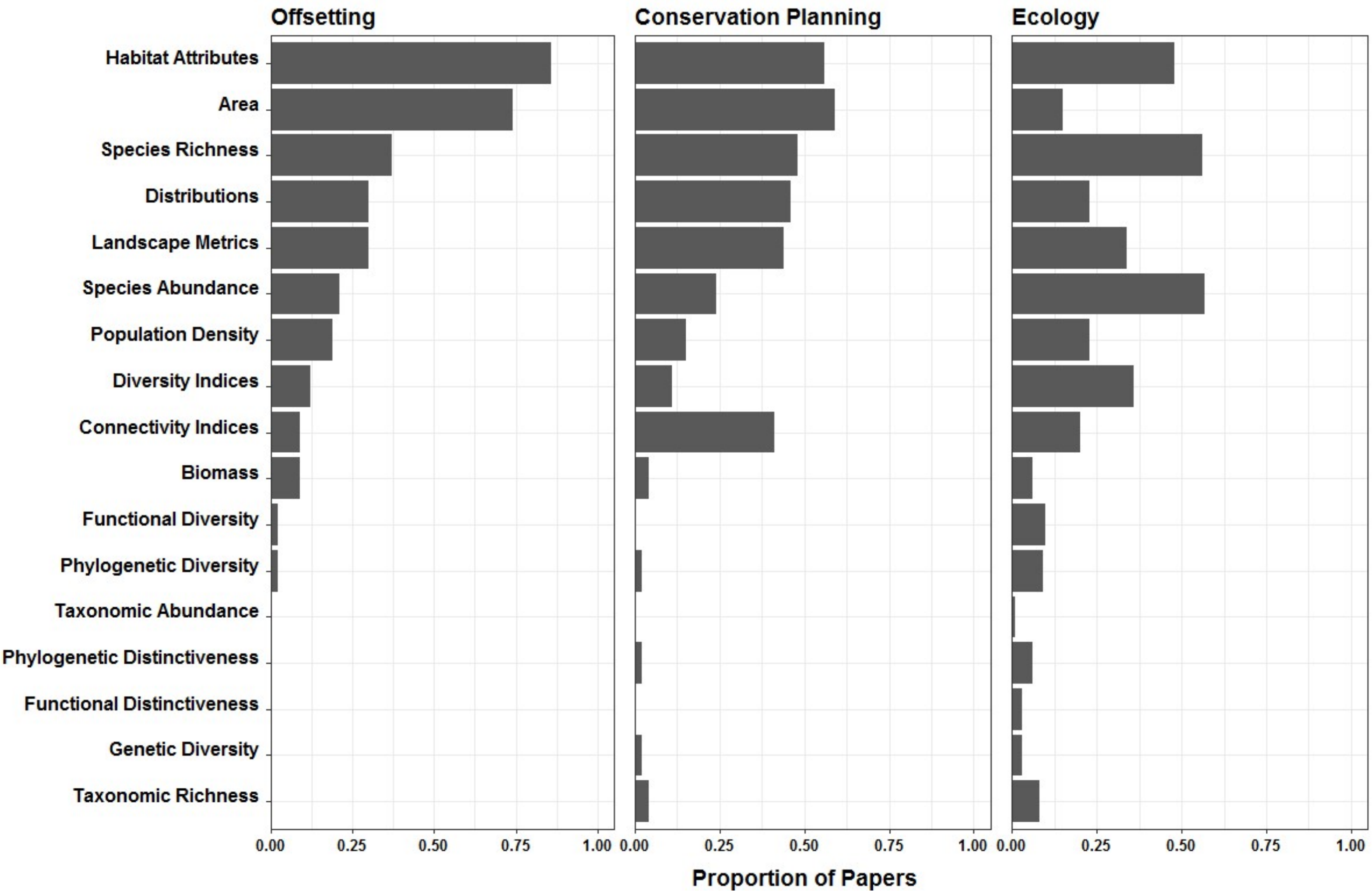

Figure 2: Proportion of papers (x-axis) within offsetting (n=43), conservation planning (n=54) and ecology (n=158; three panels) which measured or used the listed metrics (y-axis). Definitions of each category and their sub-categories is given Table A.2.

Of the measures included in our "Other" category, those that assessed threat or risk were the most common, followed closely by disturbance and persistence (Figure 3). Some metrics from this category were disproportionately high in some bodies of literature compared to others as these fields rely on them more heavily. For example, the use of complementarity in conservation planning (Figure 3) was high (44%) compared to offsetting (7%) and ecology (1%). Within offsetting literature, the most commonly occurring 'other' metrics described threats and disturbances, rarity or irreplaceability of the targeted biodiversity values but also uncertainty often associated with the offsetting approach or models of offset outcomes. However, none of the other metrics were particularly common, with any single metric occurring in less than a quarter of all reviewed literature.

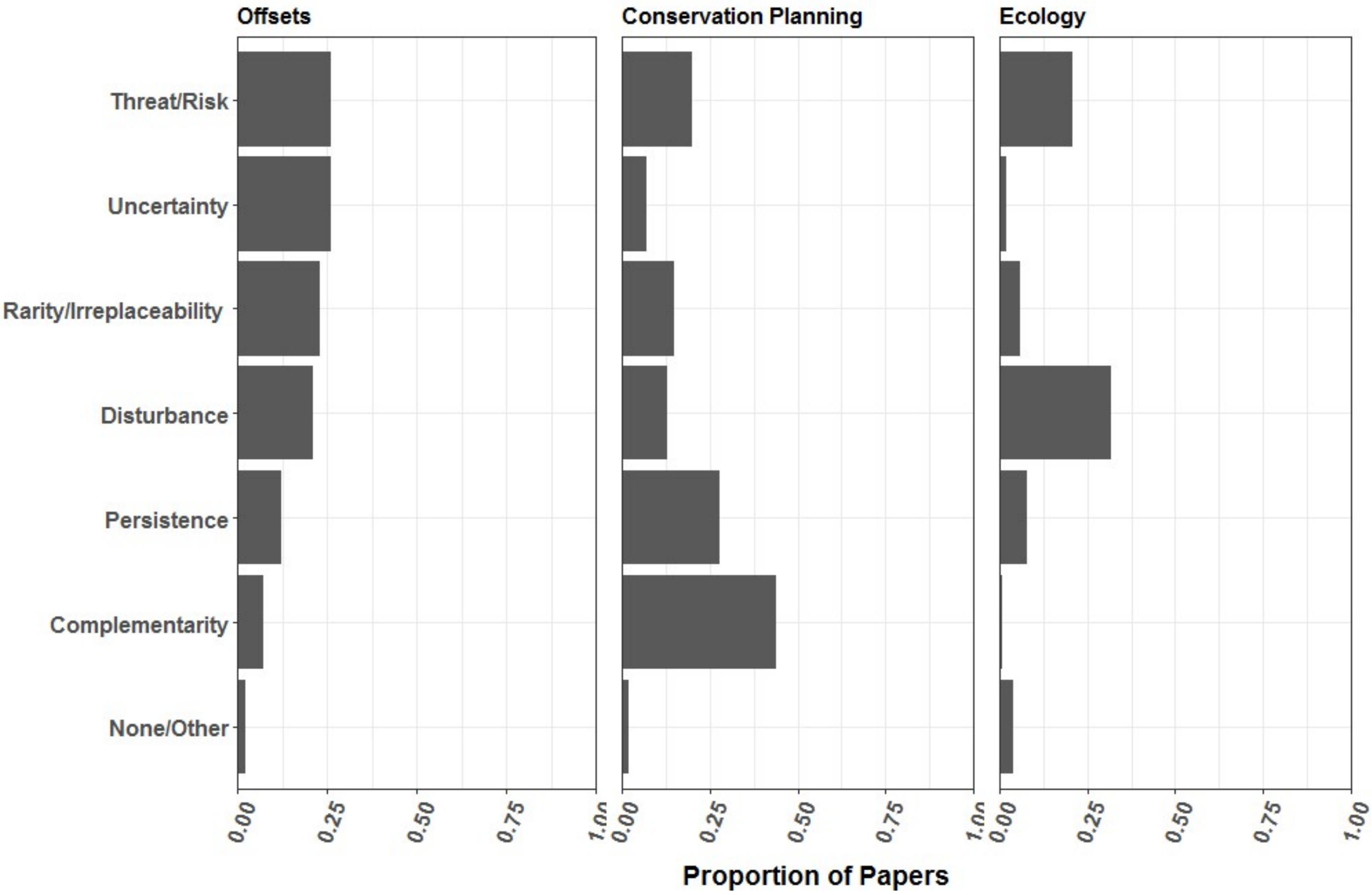

Figure 3: Proportional occurrence of metrics in the 'Other' category considered in this review.

Metric use within the offsetting literature

The offsetting literature was dominated by habitat attribute and area metrics with over 70% occurrence in each of these categories (Figure 2). All other metrics were used in <30% of the reviewed literature; however, there was greater use of species richness, abundance and density metrics than was expected from the preliminary reading. When the offsetting literature was assessed independently, we found that species focused metrics tended to occur more frequently where the subject of the paper was monitoring or assessing the results of offsetting or restoration actions (Figure 4). These publications (n = 16) still used traditional metrics of habitat and area but also frequently relied upon alternative metrics such as abundance, density, richness, and connectivity to determine the species- or population-specific outcomes of offsets (Figure 4).

They also tended to rely less on habitat and area focused measures alone and used instead a combination of metrics to quantify offset impacts on species.

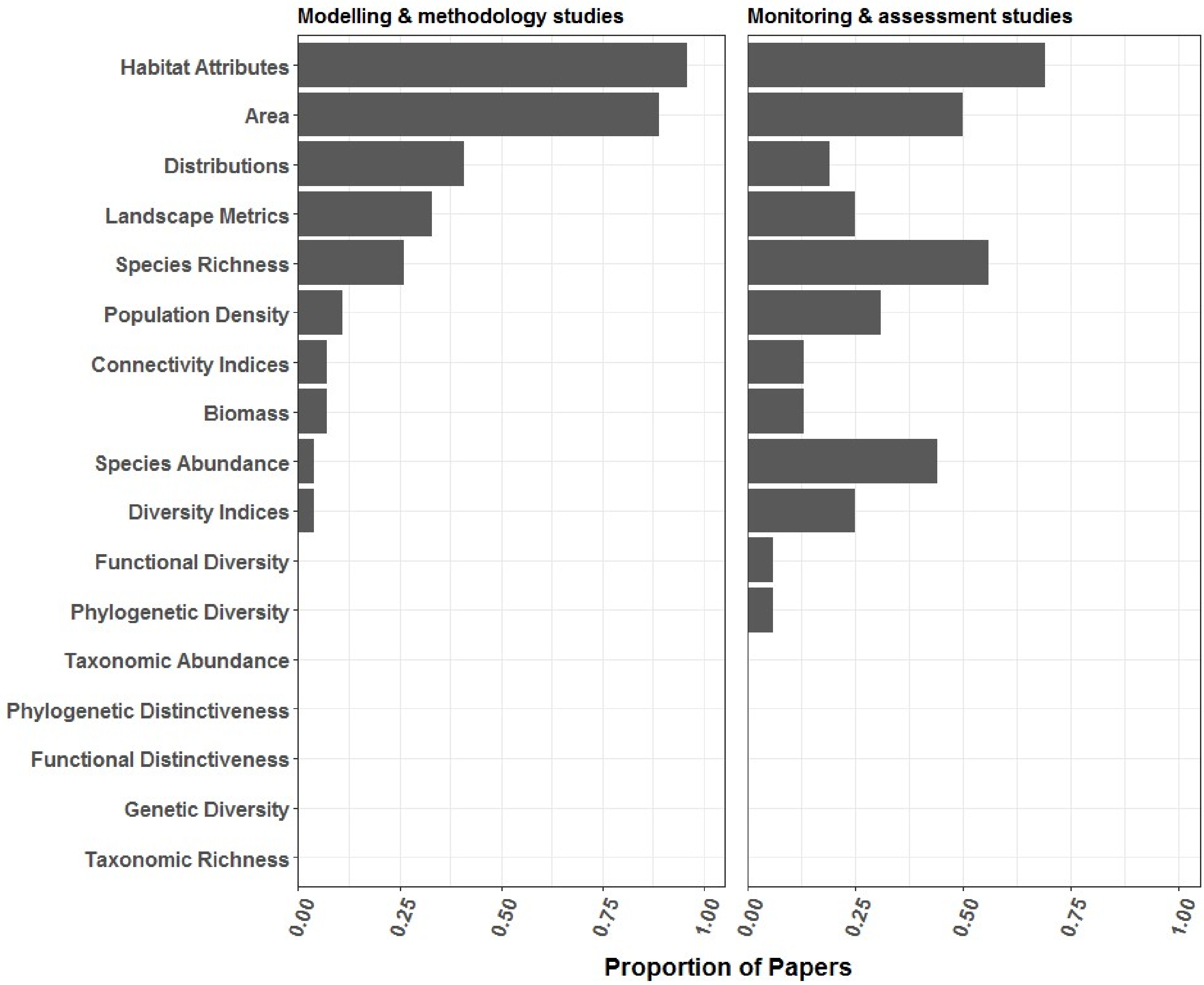

Figure 4: Proportion of papers (x axis) within two broad classes of the offsetting literature (n=43), modelling and methodology (n =27) and monitoring and assessment (n =16), which measured or used the listed metrics (y-axis). Definitions of each category and their sub-categories is in Table A.2.

Within our sample of 'monitoring and assessment' focused offsetting literature, habitat attributes and area were measured in 69 and 50% of the papers, respectively. In contrast, the modelling and metholdogy papers (n = 27) used habitat attributes and area in 96 and 89% of the sample, respectively. Species richness, species abundance, population density and diversity indices were the next most commonly used metrics in the monitoring and assessment sample (56, 44, 31 and 25% respectively). Conversely, the modelling and methodology portion of our offsetting sample did not exceed 26% use in any of these metrics (Figure 4). These types of metrics tend to reflect the objectives of monitoring and assessment papers, which seek to assess outcomes for populations and species. For example, our monitoring and assessment focused offsetting literature consisted of nine publications (56 %) which were focused on restoration success at managed sites, six (38 %) exclusively examined proposed or candidate biodiversity offset sites or procedures, and one (6 %) which assessed both restoration success and offset feasibility.

Discussion

Our results demonstrate that the definition of biodiversity remains notably narrower in commonly-used offsetting metrics compared with metrics used in the broader fields of conservation and ecology (Figure 2), which is concerning given how widely offsets are now applied (Bull and Strange, 2018; Gordon et al., 2011). The primary implication of our research is that current offset metrics are likely to be limited in their capacity to capture all the biodiversity values that are generally of interest in offsets. This was particularly clear when comparing offsetting papers on modelling and methodology, which lean heavily on simple habitat and area metrics, to those which assess offset outcomes, where attention is more targeted towards population and species level impacts (Figure 4). This result might indicate that biodiversity metrics which assess populations and species are seen as more useful than habitat and area attributes alone for measuring the outcomes of offset activities. However, this is not reflected in the planning and methodology phases of offsetting. The metrics used to assess and approve developments and offsets prior to impacts are different to those used to evaluate the performance of offsets, illustrating a disconnect between the two stages. This may go some way to explaining the paucity of documented successful offsets in the academic literature (zu Ermgassen et al., 2019). It also indicates that, even within the offsetting literature, the currently used habitat and area-based metrics are not considered as adequate to report on all the biodiversity objectives important to managers and society.

The prevalence of simple habitat and area-based metrics within the offsetting literature probably reflects, at least in part, the greater availability of data on landscape or habitat patterns, and the relative ease with which these measures can be collected and analysed, compared with complex ecological or population processes (Dorrough et al., 2019; Ferrier and Drielsma, 2010; Fleishman et al., 2006; Goetz et al., 2009). While ecological or species-level inferences can be drawn from data on landscape and habitat pattern, this is almost never attempted in the offsetting literature (Figure 2). In comparison, the ecological literature, and to a lesser extent the conservation planning literature, showed a higher occurrence of metrics that are more directly based on ecological and species population processes such as species diversity, abundance, density and connectivity, or in some cases species and population persistence (Figure 2). Including such metrics in biodiversity offsets could capture the ecological processes driving biodiversity patterns, and better reflect the social objectives behind offsets (Budiharta et al., 2018; Griffiths et al., 2019; Maron et al., 2018).

Finding the right combination of sophistication and ease of use, while avoiding an overly complicated metric is a challenge in biodiversity offsetting (Goncalves et al., 2015; Maseyk et al., 2016), but it is essential to ensure that offsets meet their no net loss targets. Whilst not all the biodiversity metric categories assessed in this review would be useful or feasible within offsetting, some may offer insights into how current offsetting metrics may be improved. For example, diversity and richness metrics, which were common in the ecological and conservation planning literature, capture a suite of species at once and could be used to complement impact assessments and compare proposed offset sites and activities (Gallardo et al., 2011; Oliver et al., 2014; Perring et al., 2015). Diversity metrics, such as functional and phylogenetic diversity, are increasingly used for validating restoration success (Khalil et al., 2017; Spake et al., 2015) and could be useful for assessing offset outcomes (Sonter et al., 2016). The caveat is that diversity and richness metrics still measure patterns of biodiversity in the landscape without capturing the ecological processes driving them (Fleishman et al., 2006; Gascón et al., 2009). As summary metrics they also come with the risk of concealed trades, particularly for species that naturally occur in environments of low richness and diversity (Kujala et al. 2015a), and do not capture the social preferences for conserving rare and threatened species (Ainsworth et al., 2018). Species richness and diversity metrics have been incorporated into some offset policies already (Gibbons et al., 2018; The State of Victoria Department of Environment, Land, 2017b), but it remains unclear whether these policy changes have improved offset outcomes for species in practice.

Species-specific metrics, which were infrequent in the offsetting literature but pervasive in the conservation planning and ecological literature (Figure 2), may be the next obvious place to start improving offset metrics. Abundance and density metrics provide a direct measure of benefits to the species managers are aiming to conserve, unlike habitat attributes that are assumed to affect them (Cristescu et al., 2013; Hanford et al., 2016). Since abundance and density are influenced by changes in demography, metapopulation structure and ecosystem processes (Otto et al., 2014; Yoccoz et al., 2001), their use in biodiversity offsetting allows biological processes influencing species and populations to be accounted for. These metrics may become more feasible as abundance and demographic data is more routinely collected and shared between researchers and land-managers, allowing better estimates of the long-term outcomes of offsets on species and the likelihood of the species persisting (Andrello et al., 2014; Bedward et al., 2009).

Whilst improving offset metrics to better promote the long-term persistence of threatened flora and fauna is essential, it is also important to consider the current constraints influencing metric choice. On-ground practices may necessitate more simplistic habitat-based metrics (Birkeland and Knight-lenihan, 2016; Maseyk et al., 2016). Complicated ecosystem assessments or abundance surveys are often considered too time-consuming to carry out within the development and assessment time constraints (Kiesecker et al., 2009). This should not mean lowering the burden of proof for developers (Birkeland and Knight-lenihan, 2016); however, it may require that policy stipulated targets are made more explicit so to ensure that offset assessments can be carried out, and the metrics chosen in a manner that work towards these targets (Bull and Brownlie, 2015; Maron et al., 2018). The proliferation of offset related policies on various jurisdictional levels has resulted in diverse and often vague definitions of no net loss, and often developments trigger impact-specific offset policies that target only a narrow set of specific habitats and species (Maron et al. 2018). In addition, the different stages of impact assessment, offset design and monitoring are often regulated by several policies that do not share their definitions of biodiversity or requirements for metric use. Lack of consistency between the different stages make it difficult to determine the long-term effectiveness of the biodiversity metrics used during offset exchanges (Miller et al., 2015; Thorn et al., 2018). Together these may, to some extent, explain the inconsistent use of biodiversity metrics observed between implementation and assessment of offset outcomes (Figure 4).

Despite the challenges, we see several avenues forward. Firstly, metrics should be made consistent throughout offsetting procedures from impact assessment to monitoring, otherwise it is not possible to track how effectively offset gains are delivered. This requires that e.g., features included in the metric are also automatically monitored (Jacob et al., 2016). Consistent use of metrics allows better comparison of alternative offset activities and a more informed starting point for further metric development (Bezombes et al., 2019; Carver and Sullivan, 2017). Secondly, metrics used must be transparently linked to the features of interest. Ideally, offset metrics would directly measure the target features (e.g., number of individuals of a threatened species). But where surrogates are used (e.g., large trees used as a surrogate for hollow-dependent species), there must be documented estimates, preferably supported by evidence, on how the selected surrogate translates into gains for the target features, in addition to which the no net loss of target features themselves should still be monitored (Travers et al., 2018). Thirdly, metrics should be selected to meet the targets of the policy under which offsetting is done. Since many policies have vague targets, the selected metric, its expected benefits and how these work towards achieving overarching policy targets should be explicitly stated (Maron et al., 2018; May et al., 2016). This would provide clarity on metric choice and usage under different policies and force proponents to think more about the metrics they choose. Ultimately, requiring explicit statements of how specific metrics built towards policy targets will increase pressure to change these policies to be more explicit about their objectives.

Lastly, any offset metrics must ensure the long-term persistence of the feature in question. Assessing persistence is not trivial and may require novel approaches for offset design and assessment. Quantitative tools such as species distribution modelling, population viability analysis, back- and forecasting, and spatial prioritisations (Bezombes et al., 2019; Budiharta et al., 2018; Kujala et al., 2015b; Peterson et al., 2018) may help improve our ability to predict the long-term outcomes of offsets, and to ensure that the delivered outcomes match policy and society aspirations. Equally important is the need to review existing offset-triggering policies to ensure they do not restrict metric choice in a manner that prevents more accurate and comprehensive measuring of biodiversity. Understanding how offset metric choice influence biodiversity at the landscape level and in the long-term should be one of the research priorities to inform future offset policies.

Although our review strived to be as comprehensive as possible, there are inevitable biases stemming from uneven geographic distribution of peer-reviewed literature (Figure 1), choice of key words, search criteria and human error that may have resulted in the loss of some publications from our sample, or the mis-categorisation of publications and metric use. Particularly, it is important to acknowledge that documentation of many offset projects is only available in the grey literature and thus were not included here. We chose to exclude the grey literature on biodiversity offsets as it has been shown to results in large variations in data quality, particularly between regions (Bull and Strange, 2018; Theis et al., 2019; zu Ermgassen et al., 2019), and because obtaining comparable samples from all three fields of science was not feasible. Based on initial exploration of both scientific and non-scientific literature, we do not believe our results to be particularly sensitive to the exclusion of grey literature, but that the peer-reviewed literature adequately represents the prevalence of different offset metrics in practice. Nevertheless, some nuances might not be captured in our review.

Conclusion

Despite the increasing use of biodiversity offsets worldwide there remains little quantitative evidence to support they deliver their claimed benefits. Achieving no net loss of biodiversity depends strongly on how biodiversity is defined and measured. We found that within the offsetting literature the definition of biodiversity remains much narrower, in terms of the complexity and breadth of biodiversity features measured, than in the closely related fields of ecology and conservation planning. We also observe a disconnect between the metrics used to plan for offsets and those used to measure their outcomes, the role of which in explaining some of the inconsistencies in offset success warrants further exploration. Ultimately understanding how we can equate what is lost during development to what we are aiming to compensate is essential for slowing the rate of biodiversity declines globally. For offsets to deliver desirable conservation outcomes, offset metrics need to be consistent across the various stages of impact assessment, implementation and monitoring, build towards explicit policy targets, and capture the critical biodiversity values and processes which are most important to ensure species persistence. The ecological and conservation planning literature provides insights into how offsetting metrics could be improved to better represent and support the components of biodiversity that offset policies set out to protect and maintain.

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