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Biodiversity metric choice affects the credibility, comparability and financial viability of coastal restoration

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Article

Keywords: Beta diversity, Ecosystem accounting, environmental markets, species composition, coastal wetlands, reference ecosystems, nature-based solutions

Posted Date: June 19th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9774851/v1

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Additional Declarations: No competing interests reported.

Abstract

Restoration programs need biodiversity metrics that credibly demonstrate ecological recovery, support ecosystem accounting and inform nature-based finance. Yet assessments rely on alpha diversity metrics (e.g. species richness), which fail to measure changes in species composition. We compared eight alpha and beta diversity metrics across plant, bird and fish communities in unrestored, restored and reference coastal wetlands in eastern Australia. Metrics were evaluated for their ability to detect degradation, distinguish restored from unrestored conditions, identify resemblance between restored and reference communities, minimise variability, and reduce unrecovered monitoring costs. Beta diversity metrics consistently outperformed alpha diversity metrics. Sørensen Similarity (i.e. proportion of shared species) provided the clearest evidence of compositional recovery, showed low variability, and incurred the lowest unrecovered monitoring costs. Sørensen-based multi-diversity indices revealed clearer restoration gradients than richness-based indices. Biodiversity monitoring, ecosystem accounting, and market-based mechanisms should incorporate compositional metrics when recovery is defined by increasing resemblance to reference ecosystems.

Introduction

Biodiversity underpins ecosystem functioning and the delivery of ecosystem services, including productivity, pollination, cultural values and ecological functions [1–3]. Yet the value of biodiversity has historically been underappreciated in government policies globally [4], contributing to widespread degradation, fragmentation, and declines in ecosystem functioning [5–7]. In response, international frameworks such as Kunming-Montreal Global Biodiversity Framework, the Paris Agreement, and the United Nations Decade on Ecosystem Restoration seek to embed biodiversity more centrally in decision-making and scale up restoration and conservation efforts [8–10]. Restoration is increasingly recognised as an important pathway for recovering biodiversity and ecosystem services [11], but achieving impact at scale requires long-term investment and confidence that biodiversity outcomes are being measured, assessed and reported in ecologically meaningful ways [12,13].

Large-scale restoration and nature-based solutions are increasingly supported by ecosystem accounts and market-based mechanisms that aim to incentivise measurable improvements in ecosystem services, ecological functions and biodiversity conservation [14–16]. Biodiversity-focused mechanisms, including Australia's Nature Repair Market, the United Kingdom's Biodiversity Net Gain, conservation banking in the United States of America and ecological compensation in China, reflect growing efforts to link conservation outcomes with financial incentives. Restoration programs are also increasingly being aligned with the United Nations' System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA-EA), which provides a framework for tracking ecosystem condition, services and biodiversity through time [17–19]. These mechanisms rely on biodiversity assessments to evaluate restoration progress, ecological performance and conservation benefits [20,21]. The metrics selected to represent biodiversity therefore shape how restoration success is interpreted, compared and rewarded [22,23]. Unlike carbon, where benefits can often be expressed in a common unit such as tonnes of CO_2 stored, biodiversity is multidimensional and can be represented using metrics that quantify different ecological attributes [24]. This creates inconsistency in how biodiversity recovery is measured and can affect confidence in whether reported outcomes reflect genuine ecological change [23]. Biodiversity monitoring for restoration, accounting and valuation therefore requires metrics that are both ecologically meaningful and operationally feasible.

Evaluating biodiversity change is challenging because biodiversity is multidimensional, can be measured using many different metrics and lacks a universally accepted framework for metric selection [24,25]. Biodiversity metrics are commonly grouped into alpha and beta diversity. Alpha diversity metrics such as species richness, species abundance, and Shannon diversity, and Simpson diversity quantify local diversity within sites, and are widely used because they are simple, intuitive and relatively inexpensive to calculate [26,27]. These metrics can provide useful information on local species counts, abundance structure and evenness, but they do not necessarily reveal whether the species present are those expected in a recovering ecosystem. This is important because changes in species identity and composition are often key indicators of ecological change during restoration [28,29]. Despite these limitations, alpha metrics, particularly species richness, continue to dominate biodiversity assessments, environmental economics, ecosystem accounting and early biodiversity market protocols [26].

Beta diversity metrics, by contrast, quantify similarity or dissimilarity in species composition among sites and through time [30,31]. This makes them well suited to restoration assessments where recovery is defined by increasing resemblance between restored and reference communities. Beta diversity metrics are increasingly recognised as sensitive indicators of biodiversity change, particularly in ecosystems where species turnover and changes in community composition are dominant signals of recovery or degradation [32,33]. Despite this potential, they remain underused in restoration monitoring and ecosystem accounting because they are often perceived as analytically complex, difficult to communicate and more costly to process than alpha diversity metrics [27,34]. Few studies have systematically compared the performance of alpha and beta diversity metrics across multiple taxa, management scenarios, and when aggregated into multi-diversity indices [33,35]. Comprehensive restoration datasets are also scarce, limiting opportunities to test how different metrics perform under realistic monitoring scenarios [36]. These gaps constrain the evidence base available for selecting biodiversity metrics that can verify outcomes from restoration and other conservation interventions.

Assessing biodiversity recovery in coastal wetlands requires metrics that can integrate responses across multiple taxa rather than relying on single indicator groups [15,37]. These ecosystems support diverse biological communities, including fish, birds, and plants, which represent complementary dimensions of ecological recovery and can respond differently to restoration over space and time [38–40]. Fish assemblages can respond rapidly to changes in hydrological connectivity and estuarine function, making them valuable early indicators of restoration outcomes [41,42]. Bird communities are often linked to both hydrological connectivity and habitat quality, reflecting broader habitat use and community uses [39,43]. Plant communities, as habitat-forming components of coastal wetlands, capture changes in vegetation composition and structure that underpin longer-term ecosystem recovery [38,44]. Together, these communities provide a multi-taxa perspective on biodiversity recovery. Integrating them into composite multi-diversity indices may provide a pathway toward standardised indicators for biodiversity monitoring, ecosystem accounting and restoration assessments (United Nations, 2021). However, it remains unclear how different biodiversity metrics perform across distinct communities, or how metric choice influences the interpretation of composite biodiversity indices used to support restoration reporting, ecosystem accounting and biodiversity markets [35,45].

In this study, we assessed how eight commonly used biodiversity metrics capture ecological differences across plant, bird and fish communities in a coastal wetland system undergoing restoration. We compared four alpha diversity metrics: species richness, geometric mean abundance, Shannon diversity and Simpson diversity; and four beta diversity metrics: Sørensen Similarity, Sørensen Dispersion, Bray–Curtis - Similarity, Bray–Curtis – Dispersion;

across degraded unrestored, restored and protected reference wetlands. We evaluated each metric against four performance criteria relevant to restoration monitoring: 1) eligibility, or whether the unrestored site differed from the reference; 2) effectiveness, or whether the restored site differed from the unrestored site; 3) sensitivity, or whether the restored site resembled the reference; and 4) variability, or whether the metric produced a reliable signal for monitoring decisions (Fig. 1). We also estimated unrecovered sampling, processing, analysis and overhead costs under a conservative biodiversity market scenario and constructed multi-diversity indices to test how metric choice influences composite biodiversity assessments. This framework was designed to identify biodiversity metrics that are informative, consistent and feasible for restoration monitoring across multiple taxa, while supporting conservation management, ecosystem accounting and emerging market-based mechanisms.

Methods

Study sites and experimental design

We compared faunal communities at a restoring site (i.e. Yandina Creek Wetlands) with an unrestored control (i.e. Blue Carbon Pilot Project Site) and reference site (i.e. Coolum Creek Environment Reserve) within the Maroochy River estuary in eastern Australia (Fig. 2). The unrestored control is a 40 ha former sugarcane and cattle farm that is targeted for future restoration actions. The site is comprised of a mixed community of invasive and native grasses, reeds and forbes and is bordered by remnant riparian mangrove and supratidal communities [46]. The restored site is a ~200 ha former sugar cane and cattle farm that been the focus of passive restoration actions since April 2018. Restoration involved the opening four tidal gates to allow ingress of the tides, and it is currently comprised of areas of recruiting mangroves, tidal marsh and supratidal communities [38,47]. The Coolum Creek Environment Reserve is a designated environmental reserve that is comprised of remnant mangrove, tidal marsh and supratidal forest ecosystems. All three sites are positioned within one kilometre of each another, thereby offering comparable geomorphic and estuarine contexts [47]. Biodiversity surveys were conducted during two sampling events: winter 2022 and summer 2023 to account for seasonal differences in ecological communities.

The biodiversity of plant, birds and fish assemblages was monitored across our two sampling events at nine fixed monitoring locations at each wetland (Fig.2). These fixed survey locations were evenly stratified by ecosystem type including mangroves, tidal marsh and supratidal forest (i.e. n = 3 sites per ecosystem) at the restored and Reference Sites and by elevation including low (0 to 0.5 m Australia Height Datum (AHD)), medium (0.5 to 0.75 m AHD) and high (>0.75 m AHD) (i.e. n = 3 sites per elevation bin) at the unrestored site to represent likely areas for target ecosystem expansion.

Biodiversity surveys

The identity and cover of plant communities was quantified within three 10 x 10 m quadrats at each fixed monitoring location (n = 27 quadrats per site and event). Each quadrat was positioned between 50 to 100 m apart to limit spatial autocorrelation whilst maintaining a consistent representation of the fixed monitoring area. These quadrats were recorded with a Garmin GPS and marked with stakes to ensure surveys were performed consistently across events.

Bird communities were sampled at each fixed monitoring location (n = 9 per site and event) in approximately 2 ha and 20 minutes in the mornings (within 4 hours post sunrise) [48]. Bird species and their relative abundance were identified visually and acoustically and were only counted if they were found using habitats on each site (i.e.

individuals flying overhead were not counted). Bird surveys were also performed 2 hours within low tide to maximise the likelihood of waders, and the visibility of wader and water bird species residing at each site (e.g. pied stilts *Himantopus leucocephalus*, little pied cormorant *Microcarbo melanoleucos*, black necked stork *Ephippiorhynchus asiaticus*, etc).

Fish communities were sampled using fyke nets; a standard apparatus to survey estuarine fish assemblages in tidal wetlands [49]. One fyke net was deployed at each fixed monitoring location (n = 9 per site and event). All fyke net surveys were standardised to be deployed at high tide and within the same monthly spring tide, facing upstream, at the mouth of intertidal creeks, channels or farrows within approximately 0.5 m water depth. Nets were made of 6 mm mesh, fixed to four 0.7 m x 0.7 m frames and two 3 m x 0.7 m wings. All captured fish species were identified, counted and released *in situ.* Specimens that were difficult to identify in the field were photographed, released and classified in the laboratory.

Biodiversity metrics

Eight biodiversity metrics were selected based on the following criteria; 1) they are commonly used in ecological studies and biological conservation to inform management decision making; 2) represent a unique aspect of biodiversity; and 3) calculated as alpha or beta diversity. Four alpha biodiversity metrics were selected including species richness (i.e. species diversity), Simpson diversity (i.e. species evenness), Shannon Diversity (i.e. species evenness & abundance), and geometric mean abundance (i.e. species abundance & evenness). Four beta biodiversity metrics were selected including; Sørensen Similarity (i.e. species identity), Sørensen - Dispersion (i.e. species variance), Bray-Curtis - Similarity (i.e. species identity & abundance) and Bray-Curtis – Dispersion (i.e. species abundance & variance) (Table 1).

All biodiversity metrics were calculated in R [50], Simpson Diversity and Shannon Diversity, Sørensen- Dispersion, Bray-Curtis – Similarity and Bray-Curtis - Dispersion were calculated using the *vegan* package [51]. Sørensen Similarity was calculated using the *betapart* package [52].

We used generalised linear models (GLMs) in R to test the interaction of sampling event (fixed factor; 2 levels: 2022 Winter and 2023 Summer) and site (fixed factor; 3 levels: Blue Carbon Pilot project Site, Yandina Creek wetlands & Coolum Creek Environment Reserve). The models were checked for normally distributed residuals, homogeneity of variance, outliers, and over-dispersion, and were consistently deemed best-fit when fitted with cloglog beta family distribution (i.e. for asymmetric data between 0 and 1) [53]. Sidak post-hoc pairwise analysis calculated the statistical significance between each pair of sampling event and site with the *emmeans* package [54].

Performance Tests and Unrecovered Costs

To evaluate metric performance for restoration monitoring and accounting contexts, we applied four criteria: 1) eligibility: the ability to detect significant differences between the unrestored site and the reference site; 2) effectiveness: the ability for a biodiversity metric to detect a significant difference between the unrestored and restored site; 3) sensitivity: the ability for a biodiversity metric to initially detect resemblance between the restored site and the reference site; and 4) variability: the mean standard error for each biodiversity metric as a measure of statistical consistency) (Fig. 1 & Fig. S1). Each metric performance was scaled between 0 (poorest performing metric) and 1 (best performing metric) for each test and event and then averaged to produce an overall performance score.

Unrecovered costs were evaluated under a conservative scenario in the context of a biodiversity market where estimated sampling expenses for each taxa and event were recouped only once a metric indicated (i) significant differences between the unrestored site and both the restored and reference sites, and (ii) ecological resemblance between the restored and reference site were achieved (Fig. 1 & 3). This was to emulate the likely goals needed to receive a biodiversity certificate or credit for a restoration project. We calculated the per-event costs for each biodiversity metric and ecological community by totalling estimated field sampling, data processing and analysis and overheads costs. All values are standardised to USD, but these costs will vary depending on currency conversion rates, the taxa monitored, local employment conditions, country, survey effort, number of replicates, sampling methods, institutional overheads and logistical requirements. This approach provides a straightforward and conservative, approach to determine the monitoring costs of each metric that could be used within potential biodiversity market frameworks, assuming field, processing, analysis and overhead expenses must at least be recovered for schemes to be viable.

Multi-Diversity Index Creation

To assess overall biodiversity, change across communities, we constructed multi-diversity indices for each site and event. These indices were calculated by averaging the values of species richness and Sørensen-Similarity across plants, birds, and fish to compare the influence of metric selection on composite biodiversity between each wetland site. These indices serve as integrative tools aligned with biodiversity assessment reporting and ecosystem condition reporting is environmental economic accounting.

Results

Detection of biodiversity differences and ecological resemblance among sites

Differences in biodiversity between sites varied substantially among metrics, taxa, and sampling events (Fig. S2; Table S1). The four alpha diversity metrics - species richness, Shannon diversity, Simpson diversity, and geometric mean abundance did not show significant differences for plant and birds communities between the sites in 2022. Only fish communities showed clear contrasts, with consistently lower richness and diversity at the unrestored site than at either the restoration or reference sites across both years, indicating that alpha-metrics captured broad disturbance effects but were less sensitive to recovery or resemblance among sites (Fig. S3, Table. S2) In 2023, modest responses in alpha diversity emerged for birds and plants, but patterns remained inconsistent. Bird alpha diversity was significantly lower at the unrestored site than at the reference site (except for Simpson diversity), while values at the restored site were intermediate and statistically similar to the unrestored site. For plants, Shannon diversity and geometric mean abundance were slightly higher at the reference than at the Unrestored Site, yet no clear resemblance was detected between the restoration and Reference Sites. Overall, alpha metrics showed some differences associated with the Unrestored Site but showed limited sensitivity to restoration recovery, rarely satisfying all three performance criteria simultaneously.

By contrast, beta diversity metrics produced clear and consistent signals across taxa and sampling events (Fig. S2; Table S1). Sørensen Similarity revealed strong compositional differences between the Unrestored Site and both the Restoration and Reference Sites, while also capturing increasing resemblance between the restoration and Reference Sites for plants and fish, providing evidence of progressive ecological convergence. Bird communities, however, remained compositionally distinct between the Reference Site and both the Unrestored and Restoration sites, indicating limited recovery toward the reference state (Fig. S3, Table. S2). Bray–Curtis Similarity

reflected similar patterns but showed slightly less temporal stability, likely due to its greater sensitivity to fluctuations in the abundance of taxa. Dispersion-based metrics provided complementary insights into within-site variability. Sørensen dispersion indicated higher heterogeneity at the Unrestored Site than at Reference Sites for plants and fish, consistent with unstable ecological communities, whereas bird assemblages showed equally high dispersion, limiting their sensitivity. Bray–Curtis Dispersion behaved similarly, highlighting strong contrasts between the impact and Reference Sites for plants and partial recovery signals for fish.

Comparative performance of alpha and beta diversity metrics

Across all taxa and criteria, beta-diversity metrics consistently outperformed alpha-diversity metrics in eligibility, effectiveness, sensitivity, variability, and financial efficiency (Fig. 3 & Fig. S5). Sørensen Similarity ranked highest overall (performance score = 0.74) and incurred the lowest unrecovered costs (USD $15,887) (Fig S1, Table S2). It met eligibility, effectiveness, and sensitivity criteria across taxa and years and was the only metric to achieve full cost recovery for both fish and plant communities (Fig. S4).

Sørensen - Dispersion and Bray–Curtis - Dispersion were the next highest-performing metrics (0.67 each), with moderate unrecovered costs (USD $33,717). They effectively detected between-site contrasts and within-site variability but were less reliable in identifying restoration–reference resemblance. Bray–Curtis - Similarity ranked lower (0.60) and had the highest unrecovered costs (USD $44,222), reflecting sensitivity to abundance fluctuations and sampling variability.

Alpha-diversity metrics performed modestly to poorly. Species richness and geometric mean abundance showed moderate performance (0.51) and moderate unrecovered costs (USD $35,023), largely detecting disturbance effects but rarely capturing recovery. Shannon and Simpson diversity were the weakest indicators (0.47 and 0.45), frequently failing to discriminate restoration from reference conditions and accumulating the 2nd highest unrecovered costs (USD $43,843 and $35,023).

Influence of metric choice on multi-diversity indices

Metric selection substantially altered the outcomes of composite multi-diversity indices (Fig. 4). Indices constructed from species richness produced differentiation between the unrestored site and both the restored and reference site scoring 32% and 24% respectively). However, minimal differentiation among the restoration and reference sites were found after yielding equivalent scores in 2022 (52%) and similar values in 2023 (51% and 60%) despite compositional differences. This insensitivity reflects the limited ability of richness-based measures to detect turnover of species during recovery. In contrast, indices based on Sørensen Similarity captured distinct ecological gradients consistent with observed restoration trajectories. The reference site exhibited the highest community resemblance (82–83%), the restored site intermediate (55–58%), and the unrestored site consistently low (21% in both years). These results highlight the responsiveness of beta diversity metrics for tracking biodiversity recovery in contrast to alpha diversity metrics between restoration and reference sites in particular.

Discussion

Biodiversity assessments are increasingly embedded in restoration planning, ecosystem accounting, and market-based mechanisms [16,24]. As these systems expand, the selection of biodiversity metrics becomes a pivotal determinant of their ecological credibility and operational feasibility [27,55]. Our results show that the metric used to assess biodiversity recovery can fundamentally change the interpretation of restoration success. Across plant,

bird and fish communities, species richness and other alpha diversity metrics often detected broad differences among sites, and were less able to distinguish compositional recovery and differentiation. By contrast, beta diversity metrics provided clearer evidence of whether unrestored communities differed from reference ecosystems and whether restored communities increasingly resembled them. This matters for conservation because restoration success is often judged by whether ecosystems recover appropriate species assemblages, not simply by whether local species counts increase. These findings underscore the importance of selecting biodiversity metrics that align with ecological recovery objectives, conservation management, ecosystem accounting and market-based schemes.

Sørensen Similarity was the highest-performing biodiversity metric in our assessment, providing the clearest and most stable signal of compositional recovery and differentiation. Because it quantifies the proportion of shared species between sites, it directly measures whether restored communities are becoming more similar to reference assemblages. This makes it particularly useful during early stages of restoration, when colonisation, species turnover and community convergence are often dominant ecological processes [31,33,56]. Its reliance on presence-absence data may also reduce noise associated with short-term fluctuations in abundances, which can be pronounced for mobile taxa such as fish [40]. This improves both the stability of ecological trends and the interpretability of results for practitioners. By contrast, alpha metrics can detect broad differences in local richness, abundance or evenness, but they do not identify whether the species contributing to those values are those expected in reference ecosystems. This limits their ability to track compositional recovery and can obscure important ecological changes during restoration[29,57]. Sørensen Similarity is therefore well suited to restoration assessments where recovery is defined by increasing resemblance to reference communities, and where transparent, repeatable and policy-compatible indicators are needed for monitoring, reporting, ecosystem accounting or market based mechanisms [24].

As biodiversity metrics are increasingly used to inform restoration decisions, ecosystem accounts and market-based mechanisms, their operational feasibility must be evaluated alongside ecological sensitivity. Presence-absence beta diversity metrics performed well against both criteria in this study. Sørensen Similarity required relatively simple data processing because it uses species occurrence data and does not require abundance transformations or functional trait databases. It also consistently met eligibility and effectiveness criteria, reducing the likelihood that monitoring investment would remain unrecovered under our cost-recovery scenario. The metric can be calculated using widely available R packages such as '*betapart*' and '*vegan*', which enhances its accessibility and scalability across monitoring programs [51,52]. Bray-Curtis Similarity, is conceptually similar but incorporates abundance data, making it more sensitive to short-term abundance fluctuations, sampling effort and analytical decisions about data transformation [58]. Dispersion-based metrics provided useful information about community variability, but were more difficult to interpret in restoration contexts because they do not directly indicate directional progress toward reference conditions [30]. This limits their communication value where managers, regulators or investors require transparent evidence of site eligibility and restoration success. Alpha diversity metrics were generally straightforward to calculate and communicate, but were less effective for detecting compositional recovery, especially for bird and plant assemblages. Collectively, these findings support a shift beyond richness-centred monitoring where restoration objectives include recovery of species identity and community composition [27,29,57].

Substantial methodological effort has been devoted to constructing multi-diversity and ecosystem condition indices, including decisions about how biodiversity scores are weighted, aggregated and spatially bounded across

sites, ecosystems or management units [26,59,60]. However, these indices often rely on simple alpha diversity measures as their primary biodiversity inputs. Our findings show that the choice of input metric can materially change the interpretation of composite biodiversity assessments. Species richness-based indices failed to distinguish restored from reference sites, whereas indices constructed using Sørensen Similarity revealed clear compositional gradients consistent with known restoration trajectories. The ecological credibility of a composite index therefore depends not only how scores are aggregated, but also on which biodiversity metric underpins them. As biodiversity markets, ecosystem accounts and restoration programs seek standardised and defensible indicators, metric choice should be treated as a central design decision rather than a technical detail.

While this study provides a comparative assessment of biodiversity metric performance across taxa, management scenarios, and sampling events, several limitations warrant consideration. Our assessment was based on two sampling events, which restricts our ability to evaluate long-term metric stability. Evidence from parallel temporal studies suggests that some indicators may change in performance over time, underscoring the need for longitudinal comparisons across multiple taxa and restoration pathways [35]. Our study focused on a single passively restoring coastal wetland system; extending similar comparisons to other ecosystems and restoration interventions will help identify context dependencies in metric performance [36,61]. Sørensen Similarity was highly effective in this context, but it may be less informative in highly diverse landscapes or systems with naturally low compositional overlap or when reference sites are incompatible with restoration sites, reducing its capacity to detect convergence between restored and reference communities [33,62]. Functional and trait-based diversity metrics were outside the scope of this comparison, but it may be useful in highly diverse systems and can provide complementary insights into ecosystem functioning and resilience [63,64]. Future research should explore how functional, trait-based and compositional metrics can be integrated to improve sensitivity and ecological relevance across different restoration contexts. Incorporating stakeholder perceptions and policy acceptability will also be critical for the broader adoption of biodiversity metrics in restoration monitoring, conservation assessments and ecosystem accounting.

Overall, our findings demonstrate that beta diversity metrics, particularly Sørensen Similarity, were more sensitive, reliable, and cost-effective indicators of biodiversity recovery for multiple ecological communities than commonly used alpha diversity metrics. Integrating compositional metrics into biodiversity monitoring and accounting frameworks can improve the ecological credibility of restoration reporting and market-based mechanisms by ensuring that assessments capture change in species identity, not only local species counts. We recommend that restoration practitioners, policymakers, and environmental economists incorporate presence-absence beta diversity metrics into restoration effectiveness assessments, particularly where recovery is defined by increasing resemblance to reference communities. These metrics should complement broader ecosystem condition indicators and functional assessments when designing biodiversity monitoring, ecosystem accounting and biodiversity credit frameworks.

Declarations

Author contributions

A.J.R., A.D.O., J.C.R.S., H.K. and J.D.M. conceived the study. A.J.R., J.D.M., H.P.B., C.J.H., B.L.G., J.J.H., J.C.M., L.G.G. and A.D.O. collected field data. A.J.R. analysed the data and prepared the first draft. A.J.R., A.D.O., B.L.G., R.M.C., F.A., V.H., C.E.L., J.C.R.S. and H.K. contributed to interpretation and manuscript development. All authors reviewed and approved the final manuscript.

Acknowledgements:

We thank Unitywater and Sunshine Coast Council for their funding and support to complete this project; K.Couch, E.Newton, and G.Webb for providing information about the unrestored and restored site; and N.Ortodossi, N.Yabsley, T.Jones, F.Osbourne, and L.Clay for assistance in the field. This work was completed in accordance with guidelines set by Queensland Department of Agriculture and Fisheries General Fisheries Permit (194400 & 211626).

Data availability

The processed datasets required to reproduce the analyses, including plant, bird and fish community matrices, site and event metadata, biodiversity metric outputs and cost assumptions are available from the corresponding author on reasonable request.

Code availability

The R scripts used to calculate biodiversity metrics, fit statistical models, generate performance scores, estimate unrecovered costs and produce figures can be made available on GitHub.

Competing interests

The authors declare no competing interests.

Funding Declaration

This work was funded by Sunshine Coast Council

Grant Number: 0980027214

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Table

Table 1 Summary of alpha and beta diversity metrics contrasted for performance and cost-effectiveness.

Metric	Type	Description
Species Richness	Alpha	Number of unique species within a sample.
Simpson’s Diversity	Alpha	Probability that two randomly chosen individuals belong to different species; emphasizes species evenness.
Shannon’s Diversity	Alpha	Log-scaled probability that two randomly chosen individuals belong to different species; more sensitive to rare species, emphasises evenness and diversity.
Geometric Mean Abundance	Alpha	Log-scaled average species abundance; more sensitive to variations in rare species compared to arithmetic mean.
Sørensen – Similarity	Beta	Mean proportion of species shared between pairs of sites, using presence/absence data.
Sørensen – Dispersion	Beta	Mean variation in the proportion of shared species (presence/absence) between sites; quantifies community variability.
Bray–Curtis – Similarity	Beta	Mean similarity in species composition between sites, weighted by abundance.
Bray–Curtis – Dispersion	Beta	Average variation in abundance-based species similarity between sites.

Figures

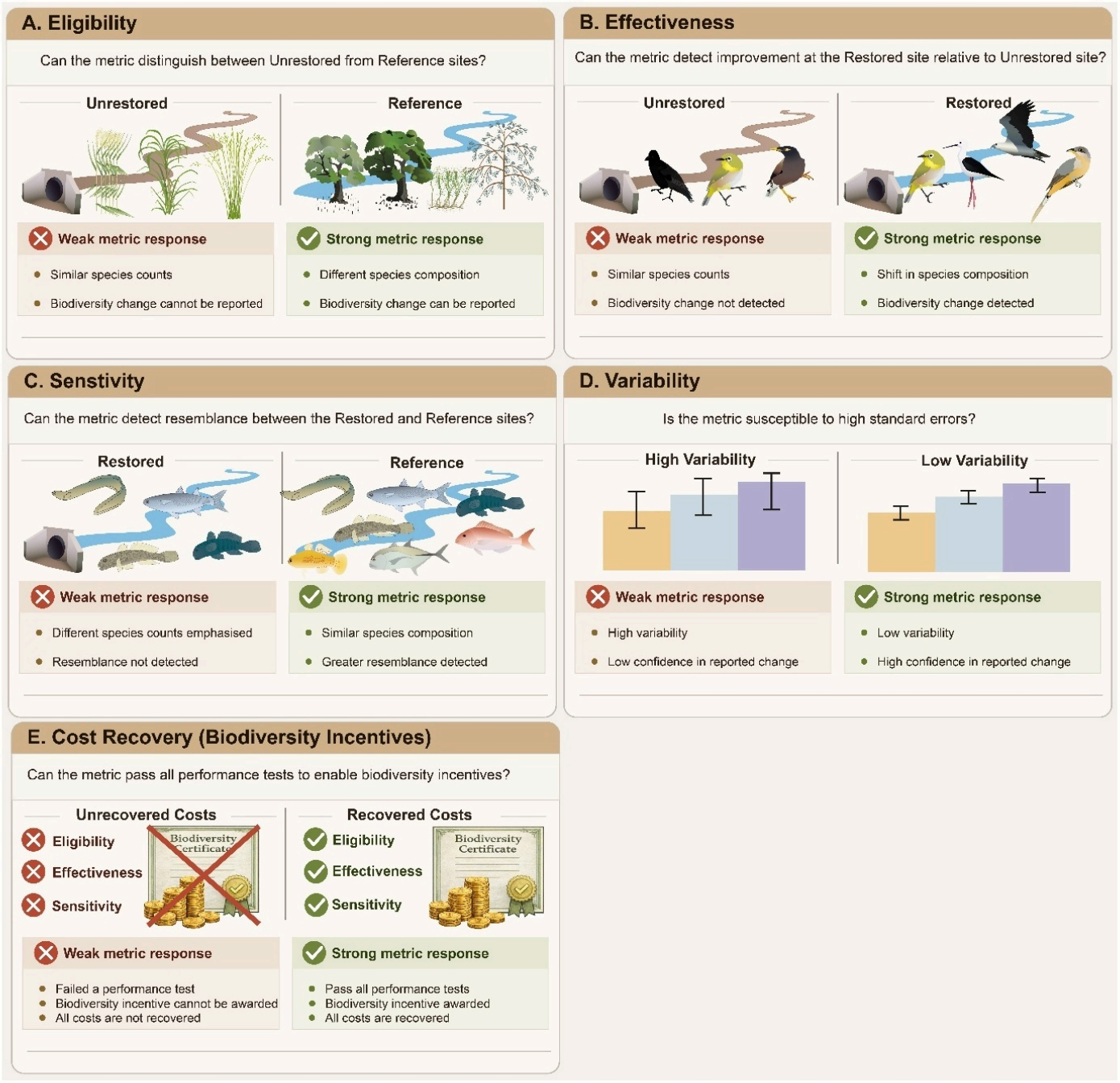


Figure 1

Conceptual framework for evaluating biodiversity metrics in restoration monitoring and biodiversity credit systems. Panels illustrate five key performance criteria used to assess the ability of biodiversity metrics to detect ecological change and support decision-making. (A) Eligibility: metrics must distinguish unrestored from reference conditions to establish baseline differences. (B) Effectiveness: metrics must detect change between unrestored and restored states. (C) Sensitivity: metrics must detect resemblances between restored and reference communities. (D) Variability: metrics should produce consistent results with low uncertainty across replicate samples. (E) Cost recovery (biodiversity incentives): only metrics that meet all performance criteria across

ecological communities enable the generation of biodiversity credits and trigger the recovery of all associated costs.

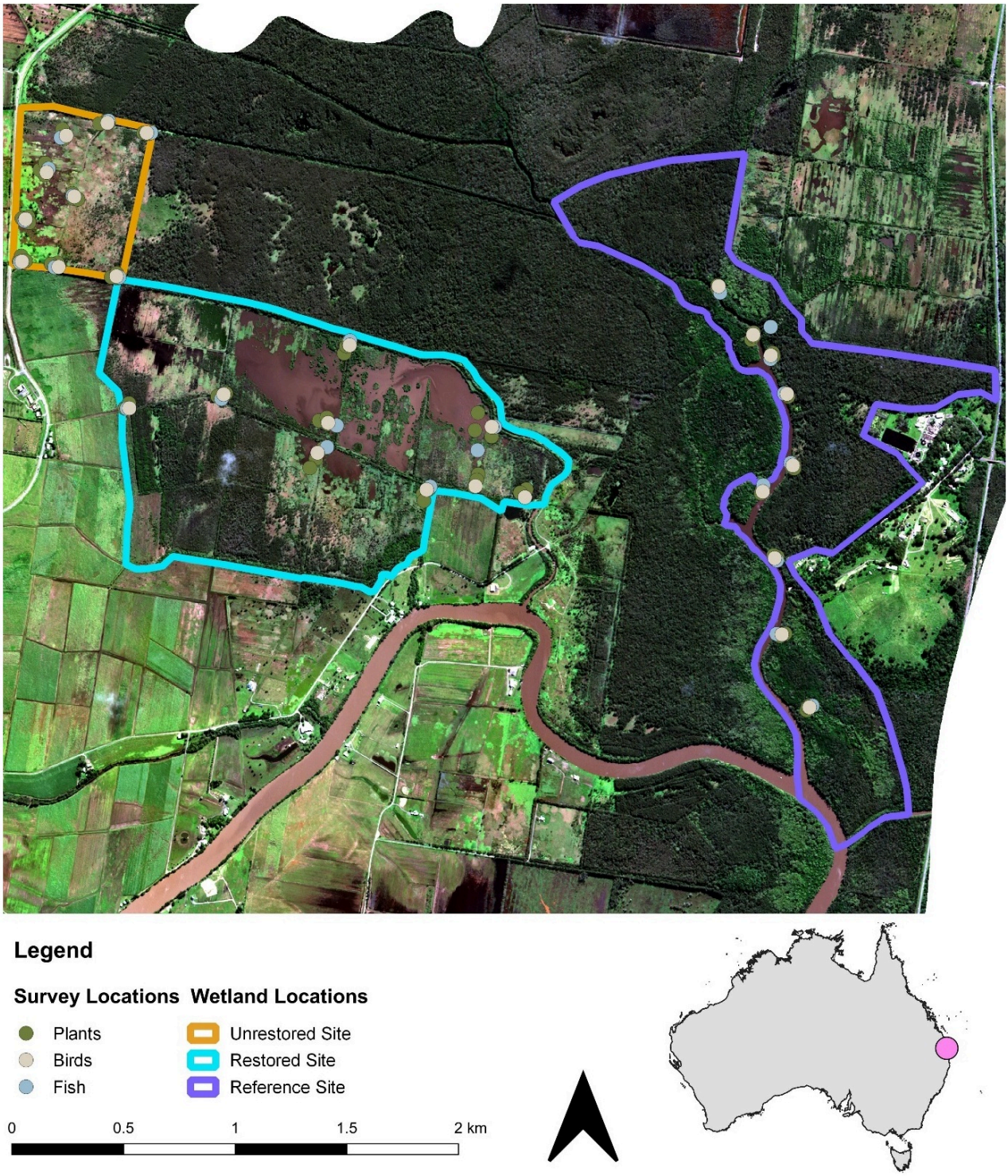


Figure 2

Distribution of fish, bird and plant survey locations at the Unrestored Site, Restored Site, and the Reference Site.

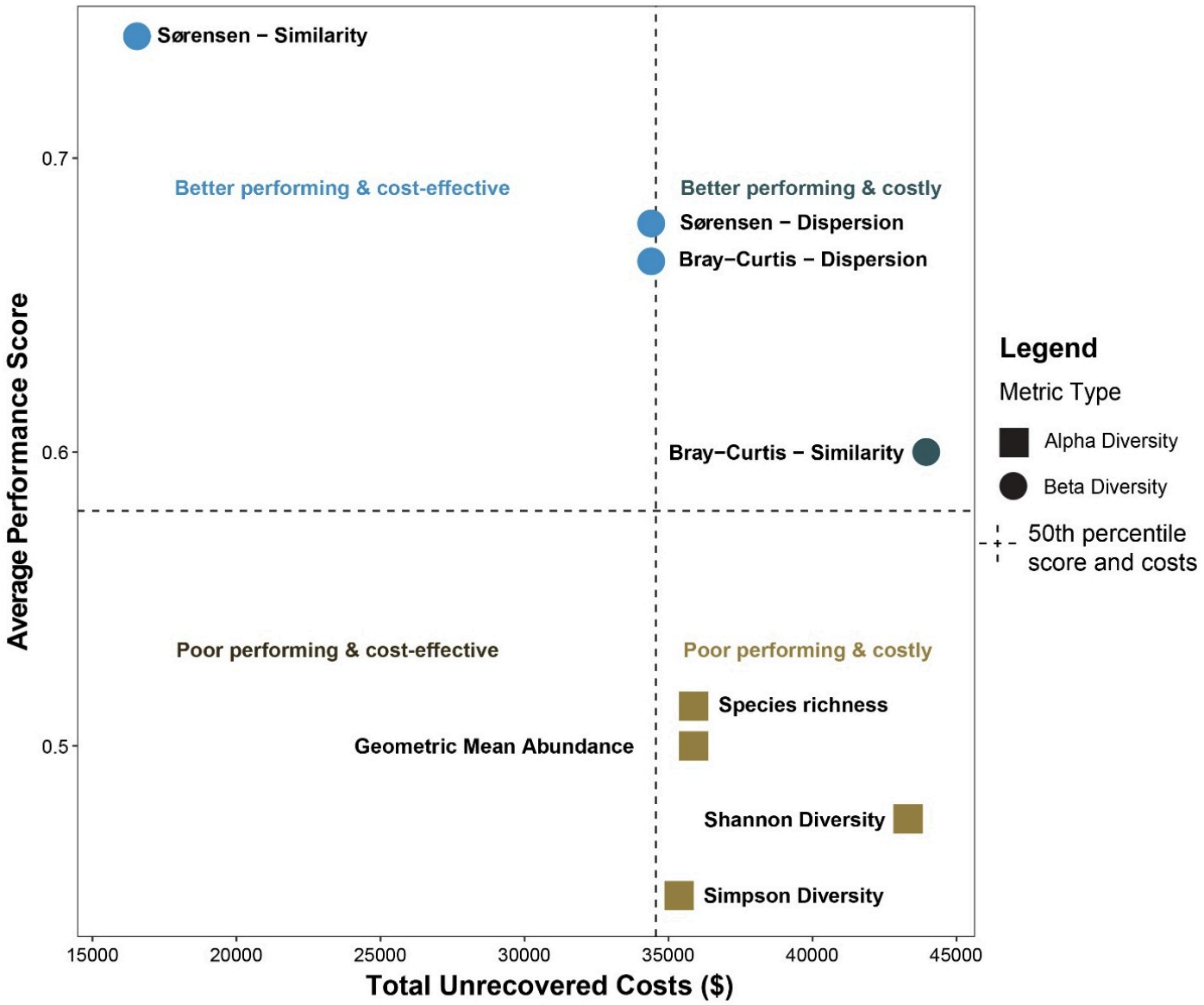


Figure 3

Bi-plot plot visualising the average performance score and total unrecovered costs for each biodiversity metric. Square points represent alpha diversity measures, whilst circle points represent beta diversity measures. Dashed lines indicate 50th percentile values of performance scores and unrecovered costs. Metrics to the top left of the plot represent best performance and cost recovery.

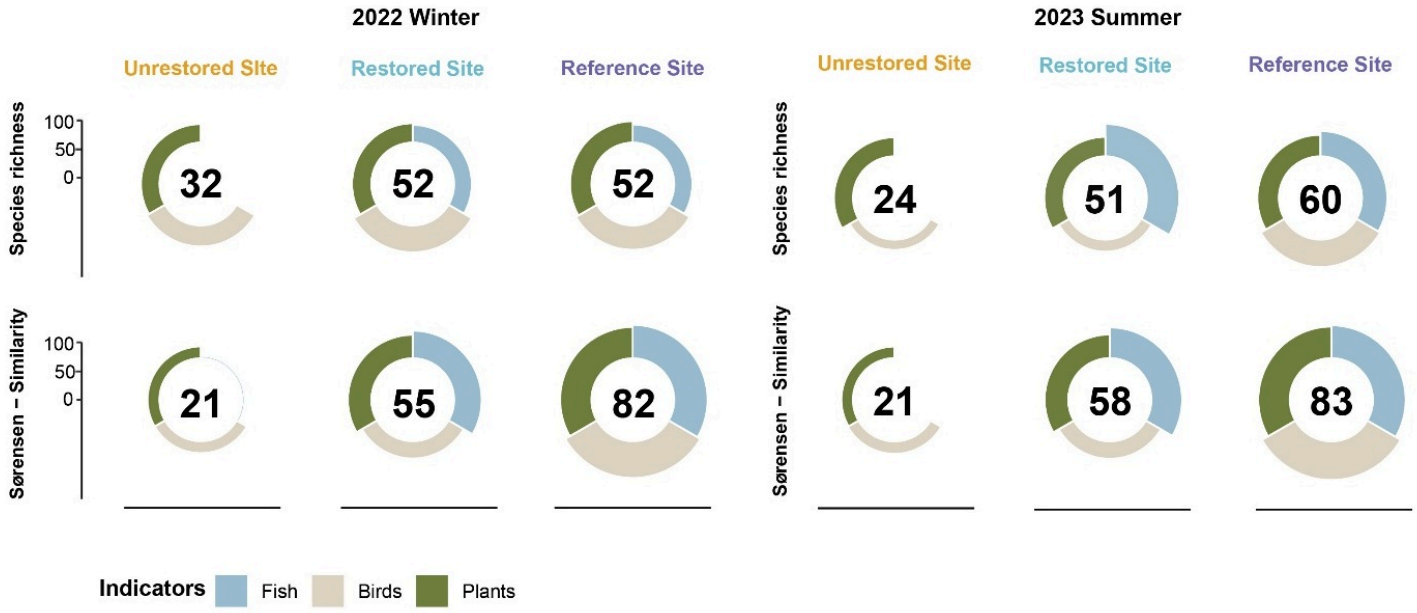


Figure 4

A multi-diversity index summarising the biodiversity values reported for Species Richness and Sørensen Similarity for each wetland location and sampling event. The central value is the averaged biodiversity score across all three ecological communities. Larger sectors of the polar plot denote greater biodiversity values recorded for each ecological community

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- BiodiversitymetricchoiceaffectsthecredibilitycomparabilityandfinancialviabilityofcoastalrestorationSupps.docx