



Systematic underestimation resulting from measurement error in score-based ecological indices

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ABSTRACT

Many ecological indices convert raw estimates of a variable into a score, and combine scores for multiple variables into a total score. Biodiversity valuation indices, for example, convert raw estimates of variables thought to be surrogates for habitat attributes into a quantitative expression of biodiversity value for use in market-based conservation policies. This study evaluated two potential sources of inaccuracy in total scores: quantitative or model uncertainty; and input data uncertainty or measurement error. Simulated scenarios were run to explore the effects of measurement error and bias on hypothetical sites in a grassy woodland, using two indices of biodiversity value commonly used in Australia. Parameterisation of measurement error was informed by published information on empirical measurement error, as well as results of a field trial using 10 independent observers. As expected, larger observer errors led to less precision in valuations, although coefficients of variation in total scores were often smaller than those of the input variables due to compensatory errors. Unexpectedly, unbiased observer errors in the input variables generated biased valuations of biodiversity. This bias was almost always in one direction – the indices underestimated the true biodiversity value of most sites, high-value sites in particular. Underestimation primarily occurred where raw true values were within benchmark scoring categories but observer error caused a majority of observer estimates to fall into lower scoring categories. The size of benchmark scoring intervals and parameter weightings were the two factors that most influenced the degree of bias. Depending on the index used to calculate biodiversity value, the underestimation effect was more significant for sites with intact woody or herbaceous features, due to scoring intervals and weightings of these features. For market-based biodiversity policies, significant implications include increasing the risk of worse than expected outcomes. This research highlights the imperative to minimise observer error hitherto poorly dealt with, to design and construct quantitative ecological indices in ways that do not exacerbate uncertainty, and to explicitly address uncertainty in decision making.

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1. Introduction

Ecological indices attempt to assess ecosystem condition, or an aspect thereof, to provide information relevant to specific management or policy decisions (Cohen et al., 2005; Hyatt, 2001; Niemi and McDonald, 2004). They increasingly underpin market-based policies, providing quantitative valuations of condition for decisions regarding stewardship payments (DSE, 2008; Oliver et al., 2005; Stoneham et al., 2003; USDA FSA, 2006) and offsets (DEC, 2005; DSE, 2006; ten Kate and Inbar, 2008). In many contexts, including market-based uses, inaccuracy in estimates generated

by ecological indices may have wide-reaching financial implications, as well as implications for conservation. For any given management decision there is a range of possible outcomes, including the intended outcome, worse than expected outcomes (risks) and better than expected outcomes (windfalls) (Burgman, 2005). In general, a greater magnitude of inaccuracy in ecological index values leads to a greater chance of an unexpected outcome. Despite this, uncertainty in ecological indices is rarely explicitly considered in condition estimates or in the decisions they inform. Ecological indices can be considered to consist of conceptual, quantitative model and input data components (Gorrod, 2011). Epistemic or linguistic uncertainty (Regan et al., 2002) in any of these components can lead to inaccurate estimates of current condition.

Conceptual uncertainty is difficult to identify and quantify, but the same is not necessarily true of quantitative model and input data uncertainties. Empirical evidence suggests that input data uncertainties, such as measurement error in field estimates of

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vegetation attributes, are commonplace and non-trivial (e.g. Archaux et al., 2006; Gorrod and Keith, 2009; Klimes, 2003; Milberg et al., 2008; Ringvall et al., 2005; Sykes et al., 1983). Measurement error may be random around the true value, or error may be systematically biased to over- or under-estimate as a result of bias in sampling procedures (Regan et al., 2002). Aspects of the quantitative or mathematical structure of ecological indices (model uncertainty, Regan et al., 2002) may serve to minimise or exacerbate input data uncertainties. In the case of score-based ecological indices, in which raw estimates of site features (predictor variables) are converted to a score by standardising against a benchmark value of that feature, scoring thresholds may minimise the effect of measurement error (by allocating the same score to range of values) or exacerbate it (by allocating a different score to similar estimates that fall on either side of a threshold). Chatfield (1995) points out that errors arising from uncertainty in model structure are likely to be far worse than errors resulting from other sources including measurement errors in estimates of model parameters. Conversion of raw estimates of site features into scores is common because benchmarking allows: spatial and temporal comparisons across sites and site types; and combination of multiple predictors into a single index score. Well known examples of benchmarked multi-metric indices include Habitat Suitability Indices (US FWS, 1981) and Indices of Biological Integrity (Karr, 1981).

Any uncertainty in raw estimates or scores for individual predictor metrics may be exacerbated in the total score via weighting and/or combination of predictors. For example, error in the total index score may be exacerbated where the most heavily weighted predictor is prone to measurement error and has narrow scoring intervals, and even moreso if the predictor is combined via multiplication with other predictors. Further, where multiple predictors are correlated or overlap (e.g. canopy cover and litter), uncertainties may be effectively double-counted, and therefore inaccuracy or bias in the total score may be greater when these predictors are combined. Despite this, the contribution of measurement error and quantitative aspects of ecological indices to inaccuracy in condition estimates is not routinely evaluated, nor are the implications for effectiveness of monetary investments (Australian National Audit Office, 2007) and conservation outcomes considered.

This study examines the contribution of quantitative aspects of ecological indices to inaccurate estimates of condition, in particular whether they may minimise or exacerbate the expression of data inaccuracies due to observer error in field assessments. Simulations informed by empirical data were run using two multi-metric score-based indices of biodiversity value that are commonly used to inform government investment and offsetting decisions in Australia.

2. Methods

2.1. Vegetation condition indices and protocols

In Australia, vegetation condition indices underpin biodiversity offsetting and incentive funding decisions. BioMetric (DECC, 2008a; Gibbons et al., 2005, 2008, 2009) and Habitat Hectares (DSE, 2004; Parkes et al., 2003) are the vegetation condition indices employed in New South Wales and Victoria, respectively. BioMetric intends to represent the value of native vegetation for terrestrial biodiversity (Gibbons et al., 2005); Habitat Hectares intends to represent the capacity of a site to provide habitat for the range of indigenous plant and animal species that may reasonably be expected to use a site (Parkes et al., 2003). The indices contain similar sets of vegetation attributes as predictor variables (Tables 1 and 2) and both are score-based, with each vegetation attribute scored relative to a benchmark that represents a long-undisturbed patch of the same vegetation type (Gibbons et al., 2005; Parkes et al., 2003). The total BioMetric score is calculated by combining the individual attribute scores to yield a score out of 100 (Eq. 1; DNR, 2007). The Habitat Hectares total score is the sum of site attribute scores with a maximum score of 75 (Eq. 2; DSE, 2004) plus landscape context scores with a maximum of 25. The landscape context components of the indices were not addressed in this study, and the Habitat Hectares site attribute scores were standardised to a maximum value of 100.

$$BM = \frac{\sum_{v=a}^j (s_v \cdot w_v) + 5((s_a \cdot s_g) + (s_b \cdot s_i) + (s_h \cdot s_j) + (s_c \cdot s_k))}{480} \times 100 \quad (1)$$

where BM is total BioMetric score, s_v is the score of attributes a–j: (a) native plant species richness; (b) native overstorey cover; (c) native mid-storey cover; (d) native ground cover grasses; (e) native ground cover shrubs; (f) native ground cover other; (g) cover of weeds; (h) number of hollow bearing trees; (i) proportion of overstorey species regenerating; (j) total length of logs; s_k is the average of s_d , s_e and s_f , and w_v is the weight of attributes a–j as shown in Table 1. Selected pairs of attributes are combined as products to reflect ecological relationships (S. Briggs, pers. comm., 2007), with the implication that they are not directly substitutable. The denominator, 480, is the maximum possible score for a community in which values for all 10 attributes fall within the benchmark.

$$\text{Habitat Hectares} = \sum_{i=1}^7 (s_i \cdot w_i) \quad (2)$$

Table 1

BioMetric component attributes and weights (from DECC, 2008a), benchmarks (which score 3) and scores for Cumberland Plain Woodland vegetation community (from DEC, 2006 and DECC, 2008b).

Attribute	Weight	Score			
		3	2	1	0
(a) Native plant species richness	25	>29	15–28	1–14	0
(b) Native overstorey cover	10	19–24%	9.5–18.9 24.1–36	2–9.4 36.1–48	0–1.9 >48
(c) Native mid-storey cover	10	20–30%	10–19.9 30.1–45	2.1–9.9 45.1–60	0–2 >60
(d) Native ground cover (grasses)	2.5	23–31%	11.5–22.9 31–46.5	2.4–11.4 46.4–62	0–2.3 >62
(e) Native ground cover (shrubs)	2.5	0–5%	5–7.5	7.5–10	>10
(f) Native ground cover (other)	2.5	12–20%	6–11.9 20.1–30	1.3–5.9 30.1–40	0–1.2 >40
(g) Cover of weeds	5	0–5%	5–33	33–66	>66
(h) Number of hollow bearing trees	20	≥ 1 tree	n/a	n/a	0 trees
(i) Proportion of overstorey species regenerating	12.5	1	0.5–0.99	0–0.49	n/a
(j) Total length of logs (m of logs ≥ 10 cm diameter)	10	≥ 5 m	2.5–4.99	0.51–2.49	0–0.5

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