An easy-to-use index of ecological integrity for prioritizing freshwater sites and for assessing habitat quality

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Abstract
Prioritizing and assessing the condition of sites for conservation action requires robust and ergonomic methodological tools. We focus here on prioritizing freshwater sites using two promising biodiversity indices, the Dragonfly Biotic Index (DBI) and Average Taxonomic Distinctness (AvTD). The AvTD had no significant association with either species richness or endemism. In contrast, the DBI was highly significantly associated with species richness and endemism, although the strengths of the associations were weak. These associations are related to how the sub-indices in the DBI are weighted, and how species are distributed geographically. Additionally, the DBI was found to be very useful for site selection based on its ability to measure ecological integrity, combined with level of threat, at multiple spatial scales. The AvTD was found to be useful principally for regional use. As the DBI is a low-cost, easy-to-use method, it has the additional use as a method for assessing habitat quality and recovery in restoration programs. The DBI operates at the species level, and is therefore highly sensitive to habitat condition and has great potential for environmental assessment and monitoring freshwater biodiversity and quality. Practical, worked examples of river restoration are given here. In view of the ease and versatility by which the DBI can be employed, we recommend its testing and possible integration into freshwater management and conservation schemes elsewhere in the world.

Keywords:
Conservation, Prioritization, Assessment, Freshwater, Catchments, Odonata, Taxonomic distinctness, Dragonfly Biotic Index .

Introduction

Site prioritization for conservation action, such as the setting aside of reserves and delineation of hotspots, is usually based on biodiversity measures such as species richness, abundance, complementarity, taxonomic and functional diversity, diversity at different scales (i.e. α, β, and γ), and indices that combine some of the above measures (Magurran *2004*). The most commonly used diversity measure in ecology is species richness (Jennings et al. *2008*; Fleishman et al. *2006*; Magurran *2004*). However, there are five problems with diversity measures based on species counts alone (Warwick and Clarke *2001*; Fleishman et al. *2006*): Firstly, species richness is heavily dependent on sampling effort, and is therefore highly sensitive to sample size and non-comparable across studies involving unknown or differing degrees of sampling effort. Secondly, species richness does not directly reflect phylogenetic diversity. Thirdly, although observed species richness measures can be compared across sites, which are strictly controlled by sampling design, the values of species richness cannot be compared against an absolute standard. Fourthly, the response of species richness to environmental degradation is not monotonic. Indeed, Wilkinson (*1999*) notes that under

moderate levels of disturbance, species richness may increase. Fifthly, species richness will differ markedly with different habitat types.

An additional problem with species richness is that the measure is scale-dependent (Jennings et al. *2008*). Some studies of higher taxa found that areas of high endemism do not correspond with those of high species richness at regional (Prendergast et al. *1993*) nor at global scales (Orme et al. *2005*). However, other studies, using different resolutions, at the regional (Graham and Hijmans *2006*) and global (Lamoreux et al. *2006*) scale did find a correlation. Given two assemblages with identical numbers of species and equivalent patterns of species abundance, but differing in the diversity of taxa to which they belong, the most taxonomically varied assemblage will be the more diverse (Clarke and Warwick *2001*).

In response to these findings, Average Taxonomic Distinctness (AvTD) has been proposed as a biodiversity measure (Warwick and Clarke *1995*; Clarke and Warwick *1998*, *2001*). It calculates the average taxonomic distance between any two species chosen at random from a sample. In contrast to other diversity measures, AvTD can be used in situations where sampling is uncontrolled, unknown or unequal, and where data are nominal, i.e. species are present or absent. Indeed, use of simple species lists has the advantage of ensuring that no one species can dominate contributions to the index (Clarke and Warwick *1998*, *2001*). Measures of taxonomic diversity can be used in conjunction with species richness and rarity scores in the context of conservation (Virolainen et al. *1998*). Already, taxonomic distance has gained impetus in environmental assessment (Heino et al. *2007*; Ellingsen et al. *2005*; Mouillot et al. *2005*; Clarke and Warwick *1998*).

The Dragonfly Biotic Index (DBI) is also a biodiversity measure, but based on a blend of expert knowledge of the focal species and quantitative assessment (Simaika and Samways *2008a*). The DBI is based on the widely recognized potential of Odonata as indicator species (Chovanec *2000*), although to date the index has been used only for measuring habitat recovery (Samways and Taylor *2004*). This is an extension of the fact that odonates can be used as indicators of freshwater health (Oertli *2008*), ecological integrity (Smith et al. *2007*; Chovanec and Waringer *2001*), and global climate change (Ott *2008*).

We investigate here the value and use of the AvTD and DBI: (1) for measuring ecological integrity (i.e.: species composition of habitats), (2) for prioritizing sites for protection, and, (3) discuss the use of the DBI in freshwater quality assessments such as for restoration.

Methods

Background on the Dragonfly Biotic Index

As in the case of the AvTD, the DBI relies on species presence/absence data. The DBI is comprised of three sub-indices: a species relative geographic distribution, threat status based on IUCN Categories and Criteria (IUCN *2001*), and species sensitivity to habitat disturbance (Table 1) (Simaika and Samways *2008a*). Each sub-value ranges from 0 to 3. The sum of the sub-values for any one species is the standard DBI score, which can range from 0 to 9. The standard DBI for all known South African odonate species is given in Samways (*2008*).

Table 1
The sub-indices of the Dragonfly Biotic Index (DBI) range from 0 to 3

Score	Sub-indices		
	Distribution	**Threat**	**Sensitivity**
0	Very common throughout South Africa and southern Africa	LC; GS	Not sensitive; little affected by habitat disturbance and may even benefit from habitat change due to alien plants; may thrive in artificial waterbodies
1	Localized across a wide area in South Africa, and localized or common in southern Africa; or very common in 1–3 provinces and localized or common in southern Africa	NT; GS or VU; NS	Low sensitivity to habitat change from alien plants; may occur commonly in artificial waterbodies
2	National endemic confined to 3 or more provinces; or widespread in southern Africa but marignal and very rare in South Africa	VU; GS or CR; NS or EN; NS	Medium sensitivity to habitat disturbance such as from alien plants and bank disturbance; may have been recorded in artificial waterbodies
3	Endemic or near-endemic and confined to only 1 or 2 Provinces	CR; GS or EN; GS	Extremely sensitive to habitat change from alien plants; only occurs in undisturbed natural habitat

It is based on the three sub-indices relating to geographical distribution, level of threat, and sensitivity to habitat change, with particular reference to invasive alien riparian trees. The DBI is the sum of the scores for the three sub-indices, and ranges from 0 to 9. A common, widespread, not-threatened and highly tolerant (of disturbance) species would score 0 (0 + 0 + 0), while a highly range-restricted, threatened and sensitive species would score 9 (3 + 3 + 3)
Abbreviations: IUCN species threat status (IUCN *2001*): LC least concern, NT near threatened, VU vulnerable, CE critically endangered, EN endangered, GS global status, and NS national status (Table modified from Simaika and Samways *2008a*)

To arrive at a DBI score per site, we divided the total of all the standard DBIs by the total number of species. The range of values for the DBI per site will therefore fall between 0 and 9.

Database development

Biogeographic information from South Africa (including Lesotho and Swaziland) was used here. This area is unique in that such information is not only available to potential users worldwide, via the internet (SANBI *2008*), but that many taxa, including the Odonata, are well sampled. A spatial-relational database was constructed from records of adult dragonfly and damselfly collections and sightings. The database consists of a merger between Samways' database of collections and sightings (from 1988 to present) and a database of Pinhey's (*1984*, *1985*) records. Additional records came from insect collections housed at the Iziko Museum (Cape Town), Albany Museum (Grahamstown), Northern Flagship Institution (Pretoria), National Museum (Bloemfontein) and National Insect Collection (Pretoria). Museum visits included verification of old records and identification of new specimens accessioned since 1984. Additional records came from new collection effort, with special emphasis on endemic species sampling, during the field seasons from 2005 to 2008 in the western and eastern Cape. These new records extend the known geographical range of the endemic Red Listed Ecchlorolestes peringueyi and E. nylephtha (Simaika and Samways *2008b*), and discoveries of the two new species Syncordulia legator and S. serendipator (Dijkstra et al. *2007*). From the resultant database, species distribution maps were constructed using both ArcView GIS 3.2a and ArcGIS 9.2

(Environmental Survey Research Institute *1999*, *2006*). The quaternary catchments map of South Africa was used for distribution mapping (SANBI *2008*).

Statistical analysis

To ensure that equal sampling effort was compared, and that statistical analyses could be done using the presence/absence data from the compiled South African Odonata database, a minimum of ten species per catchment was admitted for analysis (Bob Clarke, Primer-E, pers. comm. 2008). This decision was made after comparison of analyses with a minimum of three and then five species. Analysis with lower species numbers (a minimum of three and five species) confirmed that a minimum sampling effort of ten species is required for meaningful analysis.

To allow for easy comparison of AvTD and the DBI, quaternary catchments were grouped into larger primary catchment areas, called zones (Fig. 1). A count of sampled quaternary catchments in each primary catchment zone is presented in Table 2. These primary catchment zones are equivalent to the existing river regions used by Schulze et al. (*2006*) and earlier by Midgley et al. (*1994*), and their convention was not altered here. Primary areas that were under-represented were clustered into larger zones, where possible. Clustering was not an arbitrary process, but made by a careful, repeated elimination process in Primer 5 (Clarke and Warwick *2001*). First, species occurrence in each quaternary catchment was averaged by the primary catchment, using the AVERAGE function in Primer 5. The averages were then standardized and square-root transformed in a Bray–Curtis similarity matrix. Using the similarity matrix, a CLUSTER dendrogram, clustered by group average, was produced (Fig. 2). Average taxonomic distinctness was calculated using PRIMER 5. Analysis of variance (ANOVA) was run both on AvTD and DBI data using SPSS 13 (SPSS Inc. *2004*). The Kolmogorov–Smirnov test of normality and Levene test for homogeneity of variances were employed using SPSS 13.0 The tests determined the non-normality and un-equal variance of the index data. Therefore, the Brown–Forsythe test was used as an alternative to analysis of variance. Tamhane post hoc test was used to determine which zones differed significantly in biodiversity. To determine whether the biodiversity indices are correlated, a Spearman Rank correlation was used in SPSS 13, as the data were non-normally distributed. Recovery scores for examples used in the application of the DBI, were calculated by dividing the value before restoration by the value after restoration, and expressing this as a percentage. This was done using species richness, giving the Species Recovery Score (SRS), and the DBI, giving the Dragonfly Reovery Score.

Results

The AvTD described per primary catchment zone is visualized in Fig. 3. High AvTD scores have a widespread distribution, running along the Great Escarpment of South Africa, starting with the coastal belt in the Cape, high in endemism, from the west to the east Coast

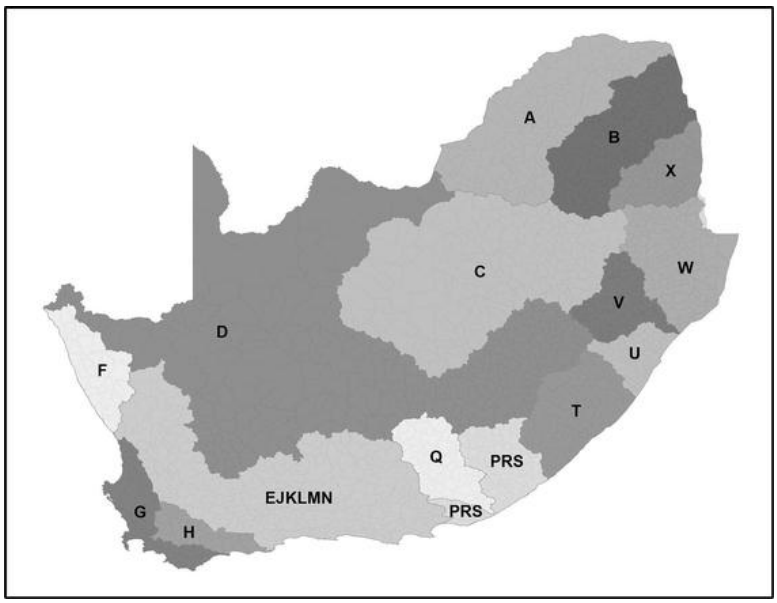

Fig. 1
Primary catchment zones of South Africa. Highlighted quaternary catchments (strong gray outlines) were used in the study comparing the biodiversity indices. The Buffels and Fish river systems (F and Q) were not included in the analyses, due to insufficient sampling effort in the areas. Abbreviations are as follows: A (Limpopo); B (Olifants); C (Vaal); D (Orange); EJKLMN: E (Olifants), J (Gourits), K (Keurboom/Storm/Krom), L (Gamtoos), M (Swartkops), N (Sundays); G (Berg/Bot/Potberg), H (Breede); PRS: P (Bushmans), R (Keiskamma), S (Kei); T (Mzimvubu); U (Mkomazi); V (Tugela); W (Mfolozi/Pongola); and, X (Komati/Crocodile)

Table 2
Count of sampled quaternary catchments in each primary catchment zone

Zone	**Primary catchment**	**Polygon count**
A	Limpopo	34
B	Olifants	23
C	Vaal	7
D	Orange	4
EJKLMN	Olifants/Gourits/Keurboom/Storms/Krom/Gamtoos/Swartkops/Sundays	15
G	Berg/Bot/Potberg	11
H	Breede	11
PRS	Bushmans/Fish/Keiskamma/Kei	9
T	Mzimvubu	8
U	Mkomazi	18
V	Tugela	16
W	Mfolozi/Pongola	31
X	Komati/Crocodile	26
Total		213

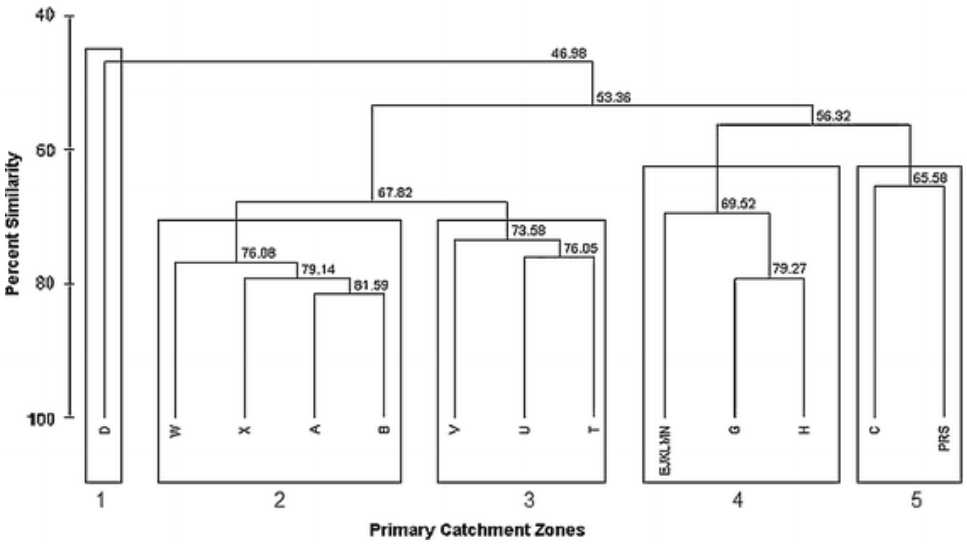

Fig. 2
Cluster graph of the primary catchment zones. Percent similarities are given for each junction. Abbreviations for catchment zones are as follows: A (Limpopo), B (Olifants), C (Vaal), D (Orange), EJKLMN (Olifants/Gourits/Keurboom/Storm/Krom/Gamtoos/Swartkops/Sundays), G (Berg/Bot/Potberg), H (Breede), PRS (Bushmans/Keiskamma/Kei), T (Mzimvubu), U (Mkomazi), V (Tugela), W, (Mfolozi/Pongola) and X (Komati/Crocodile)

(G, H, EJKLMN and PRS), and further inland into the Highveld (V) and KwaZulu-Natal (W, X) northwards, to the species rich lowveld region of Mpumalanga (A, B).

The analysis of variance (ANOVA) test revealed that there are significant differences between zones ($F = 5.14$, $df = 12$, $P < 0.01$). The Tamhane post hoc test determined which catchment zones were responsible for these differences. Catchment zone A differs significantly from EJKLMN ($P < 0.01$), G ($P < 0.00$), H ($P < 0.00$), PRS ($P < 0.00$) and V ($P < 0.00$); zone B from H ($P < 0.04$) and PRS ($P < 0.00$); zones EJKLMN and G from zone A; zone H from zones A, B, and W ($P < 0.01$); zone PRS from zone A, B, W ($P < 0.00$) and X ($P < 0.00$); zone V from A; zone; zone W from H and PRS; and, zone X from zone PRS. Zones C, D, T and U did not differ significantly from any other zone.

Comparison of Figs. 3 and 4 reveals that the means of the zones, while significantly different, are overall high. Thus, there are many catchments with high AvTD scores.

Dragonfly Biotic Index

Visualization of the DBI scores for South African odonate assemblages is presented in Fig. 5. A very small proportion of catchments have a high DBI score. These are all restricted in the Cape region, in primary zones G and H in the south-west, and EJKLMN in the south-east Cape. Most of the medium–high DBI scores are distributed south of the Great Escarpment, from the south-west Cape (G and H), along the south east coastal belt (PRS, U, W). Inland medium scores are also found in zone EJKLMN in the Cape; D in the Karoo; T in the Transkei; V in KwaZulu-Natal, and X, B and A in Mpumalanga.

The analysis of variance (ANOVA) test revealed that there are significant differences between the means of the DBIs of the primary zones ($F = 8.937$, $df = 12$, $P < 0.01$) (Fig. 6). The Tamhane post hoc test determined which means of the primary catchment zone were responsible for the observed differences. The mean DBIs of primary catchment zone A, B, C,

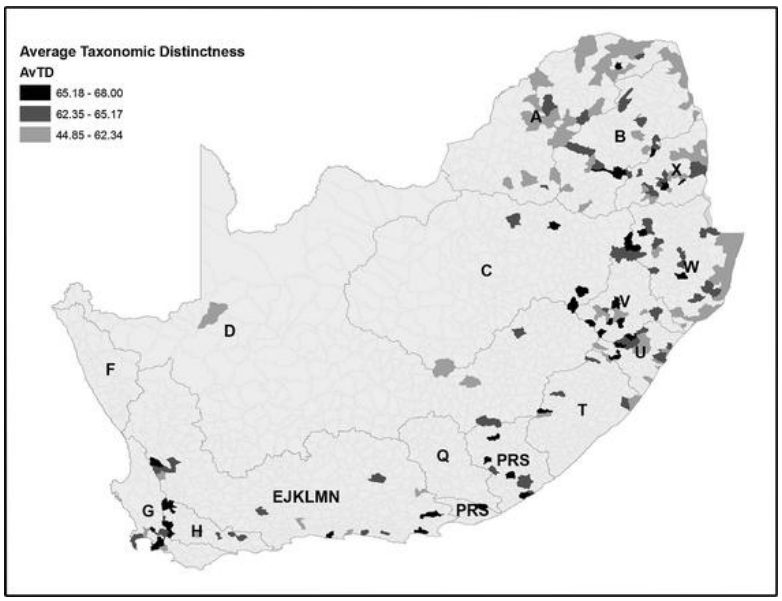

Fig. 3
Average Taxonomic Distinctness (AvTD) of assemblages of South African Odonata per quaternary catchment. Light gray catchments indicate low AvTD value, dark gray catchments medium value, and black catchments high value

H, V, and W are significantly different from at least one other catchment zone. Catchment zone A differs significantly from zone H ($P < 0.02$) and W ($P < 0.01$); zone B differs significantly from zone H ($P < 0.04$); zone C also differs significantly from zone H ($P < 0.03$); zone H differs significantly from zones A, B, C and V); zone V is significantly different from zone H ($P < 0.04$); and zone W is significantly different from zone A ($P < 0.01$).
Comparison of Figs. 5 and 6 confirms that the highest DBI means are in catchment zones G, H, EJKLMN and PRS. In zone EJKLMN, primary catchments K and M are most responsible for the high means. The mean of PRS is high overall.

Comparison of AvTD to DBI

Two-tailed Spearman's rank correlation found a weak but highly significant positive correlation between AvTD and DBI ($r_s = 0.400$, $n = 213$, $P < 0.01$). The AvTD showed no association with either species richness ($r_s = -0.091$, $n = 213$, $P < 0.188$) or endemism ($r_s = 0.151$, $n = 50$, $P < 0.294$). The DBI was found to be highly significantly correlated with species richness ($r_s = 0.209$, $n = 213$, $P < 0.01$) and with endemism ($r_s = 0.448$, $n = 50$, $P < 0.01$), yet the association of the DBI with species richness is very weak, and weak for endemism. High DBI scores are localized in the Cape region (zones G and H). High AvTD scores have a wider distribution particularly catchments in zones G, H and PRS, and include zone V in the north-east region, poor in endemics (Figs. 3–6). High scoring AvTD catchments are also within the species rich zones, A, B and X. Catchments in zones A, B and X score either low or medium DBI.

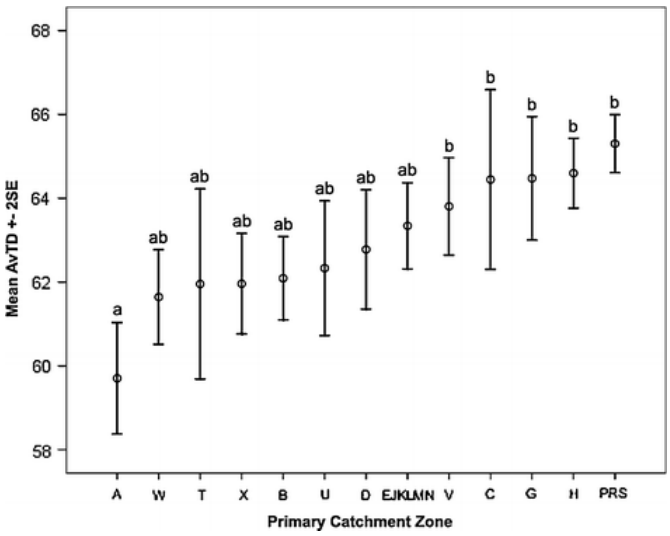

Fig. 4
Mean Average Taxonomic Distinctness (AvTD) per primary catchment zone. An analysis of variance (ANOVA) determined that zones are significantly different (F = 5.14, df = 12, P = 0.0001). Catchment zones fall into three groups: a (zone A); ab (zones B, D, EJKLMN, T, U, W and X); b (zones C, G, H, PRS, and V). Error bars represent standard error (SE) ± 2

Practical application of the Dragonfly Biotic Index

Table 3 shows ten examples where dragonfly assemblage composition was recorded before and after restoration, achieved through removal of invasive alien trees which were shading out the naturally sunny habitats. The species are recorded as a percentage ratio (the SRS) of the number of species after restoration compared with the number prior to restoration. The recovery is also given in terms of the percentage ratio (the Dragonfly Recovery Score, DRS) of the total DBI after, compared with, prior to restoration. In all cases, both the SRS and the DRS are above 100%, illustrating an increase in both number of species and in total DBI following restoration. Figure 7 shows the SRSs and the DRSs for the ten sites overlaid on a map of levels of endemism. The very high DRS values are associated with high levels of endemism, illustrating the great effectiveness of the remediation on the irreplaceable, endemic fauna. As level of endemism decreases while species richness increases, reaching the highest species richness but lowest endemism at site J, the DBI decreases in proportion to the SRS. The DBI thus has strong conservation value in that it emphasizes the threatened, narrow-range and sensitive species, and their recovery when restoration is undertaken.

Discussion

A practical index for prioritizing sites or for assessing success of conservation action must be easy to use and provide reliable, repeatable results (McGeoch *2007*). Ideally, it should also operate at the species, rather than higher, taxonomic level, so as to be sensitive to the various subtle characteristics of, and changes in, the habitats (Smith et al. *2007*).

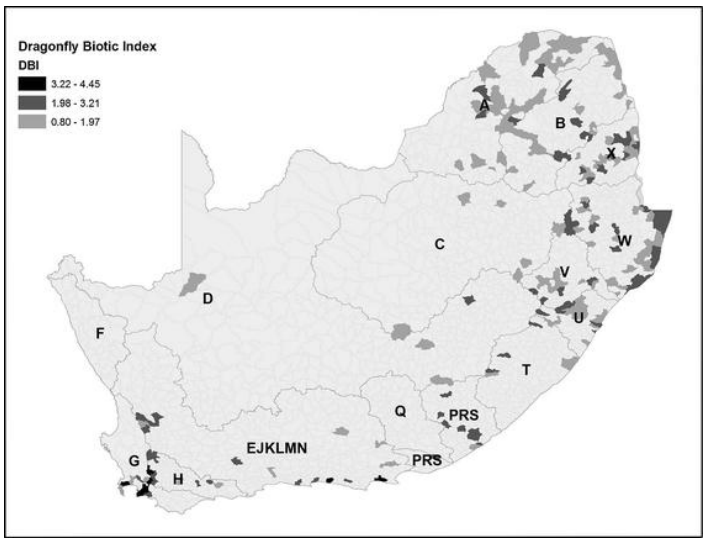

Fig. 5
Dragonfly Biotic Index scores of assemblages of assemblages of South African Odonata per quaternary catchment. Light gray catchments indicate low DBI value, dark gray catchments medium value, and black catchments high value

Many biodiversity measurements have fallen short of the ideal because they have consisted of simple counts of the numbers of species (species richness), an observation voiced by many (Jennings *2008*; Price et al. *1999*). Researchers have thus suggested that aggregate biodiversity levels are more important in identifying priority sites (Dinerstein and Wikramanayake *1993*; Pressey et al. *1993*), or alternatively, a measure of the species' identities (Jennings et al. *2008*; Clarke and Warwick *2001*). Therefore, it was appropriate here to test the validity of two biodiversity indices for prioritizing freshwater sites: the DBI and the AvTD.

Comparison of biodiversity indices

There was a weak but significant relationship between the AvTD and the DBI. Both indices are based on presence/absence records. Yet, these indices are very different, in that the first is based solely on weighted taxonomic relatedness (Clarke and Warwick *2001*), while the latter is based on weighted geographic distribution, conservation status and sensitivity to disturbance (Simaika and Samways *2008a*).

The DBI is based on a mixture of objective science and expert opinion, and gives more weight to geographically restricted, Red Listed and disturbance-sensitive species, than to any other species. Its main thrust lies in identifying species of global conservation concern. In other words, the DBI gives priority to rare and endemic Red Listed species. In South Africa, these occur, as do many other taxa, mainly in the south-west Cape and eastern Cape, regions characterized by endemic Corduliidae and Synlestidae (Figs. 5, 6). The remaining areas, particularly the north-east, are dominated by a species rich Afro-tropical element.

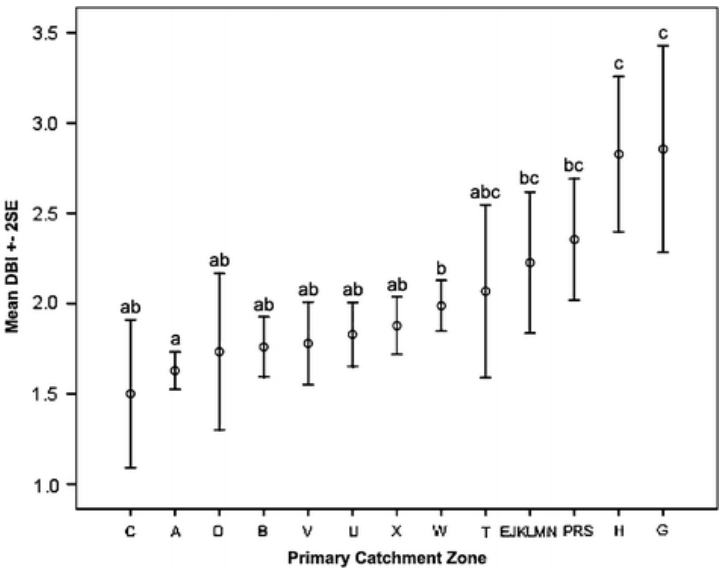

Fig. 6
Error plot of mean Dragonfly Biotic Index (DBI) per primary catchment zone. An analysis of variance (ANOVA) determined significant differences DBI means of between catchments (F = 8.937, df = 12, P = 0.0001). Primary catchment zones fall into six larger groups, a (zone A); ab (zones B, C, D, U, V, X); abc (zone T); b (zone W); bc (zones EJKLMN, PRS); and c (zones G, H). Error bars represent standard error (SE) ± 2

In contrast to the DBI, the AvTD is sensitive to the taxonomic relatedness of species. It is based on the intuitive principle that an assemblage of distantly related species is more diverse than an assemblage of closely related species (Warwick and Clarke *2001*). In each assemblage, the AvTD tracks this principle throughout the country from the south-west to the north-east. High AvTD values were found to have a widespread distribution, along the Great Escarpment of South Africa, starting with the coastal belt in the Cape, high in endemism, from the west to the east coast, and farther inland into the Highveld and KwaZulu-Natal northwards, to the species rich lowveld region of Mpumalanga.

This is where there appears to be the greatest difference between the AvTD and DBI. There are far fewer endemics in the north-east, and the DBI reflects this quite clearly. The DBI was found to be highly significantly associated with species richness, although the strength of the association was very weak or non-existent. The DBI was more strongly correlated with endemism than with species richness, although also a weak correlation. The AvTD in contrast was not found to have any significant association with either species richness or endemism.

The reason the DBI may be very weakly, although highly significantly, associated with species richness, is that it is intrinsically dependent on how the sub-indices in the DBI are weighted, and distributed. For example, a species assemblage of only ten highly sensitive and threatened Cape endemic odonates at a site in the Cape floristic region may score an average (i.e. score per site) DBI of seven, while at a site in the species rich region of KwaZulu-Natal, an assemblage of 25 widespread Afro-tropical species may only score an average DBI of two.

Table 3
Changes in dragonfly species richness and Dragonfly Biotic Index (DBI) values following removal of invasive alien riparian trees

Site	Before		After		Species recovery	Dragonfly recovery	Co-ordinates	Reference
	S	Total DBI	S	Total DBI	Score (%)	Score (%)		
A	5	8	11	48	220	600	33º59'S, 18º24'E	Simaika and Samways (*2008*)
B	7	23	16	85	229	370	33º35'S, 19º08'E	Simaika and Samways (*2008*)
C	7	19	15	72	214	379	33º57'S, 19º12'E	Simaika and Samways (*2008*)
D	11	37	18	46	164	124	33º25'S, 19º17'E	Samways and Grant (*2006b*)
E	8	22	18	51	225	232	33º24'S, 19º17'E	Samways and Grant (*2006b*)
F	5	7	11	15	220	214	33º50'S, 22º26'E	Samways and Grant (*2006b*)
G	4	9	8	22	200	244	33º49'S, 23º50'E	Samways and Grant (*2006b*)
H	5	11	11	36	220	327	32º36'S, 27º25'E	Samways and Grant (*2006b*)
I	7	10	9	21	129	210	24º53'S, 30º45'E	Samways and Grant (*2006b*)
J	13	22	20	25	154	114	22º50'S, 30º36'E	Magoba and Samways (*2009*)

This recovery is expressed as a change in both percentage of species richness (Species Recovery Score) and in percentage DBI (Dragonfly Recovery Score). Scores are based on raw data on dragonfly species changes over time in published works

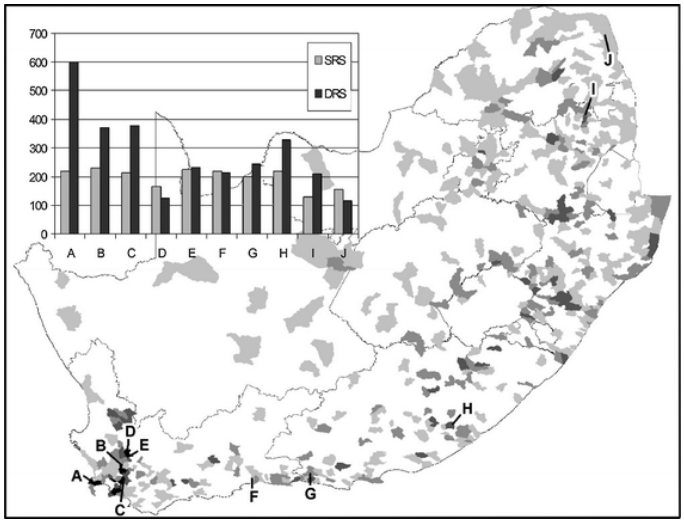

Fig. 7
Percent recovery of dragonfly fauna at sites (A–J) following removal of alien invasive riparian trees, expressed as percent Species Recovery Score (SRS) and Dragonfly Recovery Score (DRS). Source data for sites A–J are given in Table 3. The recovery scores are overlaid on a map of South Africa, showing the number of national endemic dragonfly species across South Africa, at the quaternary catchment scale. Light gray catchments show low levels of endemism, black ones high levels of endemism

In terms of global prioritization of habitat conservation, the DBI is more readily applied than the AvTD. Conservation organizations would be interested in the results of the DBI, as the index identifies priority sites for conservation action of highly threatened and sensitive species. The AvTD can also be used to identify areas of conservation concern, but more readily at a national level. For example, different provinces of South Africa may want to conserve their own hotspots of biodiversity, in a regional context, that takes species representativeness into account.

Use of the Dragonfly Biotic Index for environmental monitoring

The use of the DBI and AvTD has been suggested for environmental monitoring (Simaika and Samways *2008a*; Warwick and Clarke *1995*). The AvTD has already been applied to tracking habitat disturbance (e.g. Clarke and Warwick *1998*; Mouillot *2005*), while the DBI has been employed for assessing the success of stream restoration through removal of invasive alien trees, a key threat to various aquatic organisms (Samways and Taylor *2004*).

Application of the DBI to tracking habitat recovery, from alien riparian plant invasion, is termed here the DRS, which is the total DBI after restoration compared with the value before restoration. The results (Table 3; Fig. 7) are clear, with restoration resulting an increase in both species richness (the SRS) and the total DBI (DRS) at all the sites. However, the added value of the DBI over species richness is that it weights those species which are geographically restricted, threatened and sensitive. The outcome in practical terms is that the restoration activities were highly beneficial not just to the common, widespread generalists but noticeably also to the irreplaceable, narrow-range endemics. Thus, the DBI is a very effective method for monitoring river remediation, especially for those species of conservation concern.

In terms of practicality, the individual DBIs for all species, with a description and other essential species information is given in Samways (*2008*). This information is therefore readily available to managers without them having to undertake any individual species assessments. This ‘canned’

information is simply ready to plug into the total DBI calculations (and the DRS), which makes it easy to use. The DBI has the added advantage that species can be easily and rapidly identified, and habitats scored while in the field. Thus for local rapid environmental impact assessments and habitat monitoring schemes, the DBI is a low-cost, easy-to-use alternative. We therefore recommend the use and integration of the DBI into management and conservation schemes.

Previous work has shown a strong correlation between adult dragonfly scores and macroinvertebrate scores (Smith et al. *2007*). This suggests that the DBI, as a measure of ecological integrity, could be used alongside macroinvertebrate scores (Dickens and Graham *2002*) for freshwater health assessments. However, the exact relationship between the DBI and macroinvertebrate scores requires further, detailed exploration.

Despite the obvious and very positive advantages of the indices presented here, it must be mentioned that all the various elements of biodiversity cannot be encapsulated within a single index (Warwick and Clarke *1995*; Price et al. *1999*). Furthermore, species presence–absence data, whether using taxonomic distinctness or a combined index based on geographic distribution, threat and sensitivity, are not the only facets of diversity. The distribution of individuals among species (evenness), for example, is another very important element (Price et al. *1999*) and the particular abundances of species may be important for maintaining significant functions and services (Luck et al. *2003*). Finally, study of a single taxon, including odonates, should not be taken simply at face value to represent overall biodiversity (Price et al. *1999*; Oertli *2008*), a situation easily remedied by concordance studies with other taxa.

Practicality and general applicability of the Dragonfly Biotic Index

The DBI requires a good record of dragonfly species in an area under investigation (e.g. 100 m stretch of stream, subsection of marshland or portion of catchment). As found elsewhere, five site visits with slow walking of the banks is usually sufficient (Schmidt *1985*). It is at times necessary to supplement this activity with searches of dense vegetation for crepuscular species (for example Gynacantha and Zyxomma species). The only equipment required is an aerial net for confirmation of species identity, and a 10X + 20X hand lens for close examination of diagnostic characters (e.g. genitalia). A good field guide of the local odonate fauna, its habitat tolerance, geographical distribution and some indication of level of threat is also necessary. When more knowledge becomes available, this can be built into a field guide, as has been done for South African dragonflies (Samways *2008*). Thus the method initially will have some challenges where the dragonfly fauna is poorly known. However, it is not out of the question to establish some preliminary values for individual species DBIs, refining them as more information becomes available. Also, there needs to be some knowledge of the flight periods to ensure all species are accounted for (Samways and Grant *2006a*, *b*).

Employing the DBI will inevitably bring upon itself the criticism that adults may not represent the larvae, and larvae should also be used in the index. This can be countered on various points. Firstly, a comparable sample of larvae requires far more sampling effort, because sampling in water is awkward and larvae can be very cryptic and live in inaccessible places (Niba and Samways *2006a*). Secondly, if a good sample is obtained, only final-instar larvae can be identified to species level. Thirdly, in many countries, including South Africa, a large proportion of dragonfly larvae remain yet to be described, and their identification requires more effort than that of adults. Fourth, adults typically mate and oviposit only in suitable freshwater habitats, thus residency of most species collected in mating habitat can be assumed. Should there still be skeptics, one could argue that the only true record of residency is not the larvae but the exuviae, left behind after emergence (Ott et al.

2007). This is the only true demonstration that the habitat in question is suitable to odonates in both the aquatic and aerial parts of the life cycle.

The total DBI records the 'core resident species' (Niba and Samways *2006b*). Some vagrant species will of course also be recorded, particularly when more intensive searches over longer periods of time are done. The occasional, additional records, however, tend not to affect the total DBI to any great extent. Thus, the overall score of the DBI is the contribution by core resident species.

While we have presented the results here for one country, the concept of the DBI could be easily adapted elsewhere. However, this depends on the number of species in the odonate fauna, its breadth of geographic distribution, Red List status and sensitivity to disturbance. Where more or alternate information is available, the index could be expanded to include sub-indices such as habitat tolerance and relative abundance. The limit to the DBI is that odonates may not be good surrogate species for other taxa, owing to lack of concordance (Prendergast et al. *1993*), although they have potential use as umbrellas for wetland plant species (Bried et al. *2007*). Nevertheless, the easy use of the DBI and the sensitivity of the index mean that it is a useful tool towards conservation action.

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