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Simple tools for the evaluation of protected areas for the conservation of grasshoppers

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ABSTRACT

Spatial conservation prioritization needs a strong informational background on the conservation value of sites. However, standard diversity indices do not distinguish between less valuable (e.g. invasive species) and highly valuable species (e.g. threatened endemics). Furthermore, park managers often lack the taxonomic capacity to study species-rich insect groups. Therefore, there is a need for indices that consider the conservation value of species and simple indicators for the conservation value of sites. The aim of our study was to develop such indices and test them in a biodiversity hotspot. We studied grasshopper diversity in the UNESCO World Heritage "Cape Floral Region Protected Areas" (South Africa). We used endemism, mobility and rarity to calculate a grasshopper conservation index (GCI) for each species and site and a standardized index (GCIn) to evaluate the mean conservation value of species per site. We analyzed the indicator value (IndVal) of environmental factors for identifying sites of high conservation value or high biodiversity. Unlike plant species richness, we found the highest species richness in the Eastern Cape. The main factors determining grasshopper diversity were vegetation heterogeneity, altitude and cover of bare ground. The abundance of wingless grasshopper species and the ratio of wingless to winged species were suitable indicators of conservation value (regarding the diversity of rare or endemic species) of sites. These factors might function as conservation indicators in other regions as well, as they are generally associated with the occurrence of endemic species. GCI/GCIn are globally applicable tools for the evaluation of grasshopper communities.

1. Introduction

The global loss of biodiversity is one of the major challenges of the Anthropocene. Although invertebrates are the most species-rich taxa, conservation prioritization is often based on vertebrate species such as birds, mammals and amphibians (Ceballos and Ehrlich, 2006), because they are both well-described and easy to identify, and information on their conservation status is available, whereas information on invertebrate species is scarce and many species are still undescribed. Therefore, there is a need for data on invertebrate diversity in protected areas (Hochkirch, 2014). However, as reserve managers and rangers often lack taxonomic capacity to identify insects, there is also a need for simple guidelines on the conservation value of sites. This should be based upon the conservation value of species rather than on simple alpha diversity indices, which may also be driven by invasive or common species.

Protected areas are generally believed to be the most effective tool for sustainable conservation of biodiversity (Watson et al., 2014). Protected areas are particularly necessary in species-rich regions, i.e. biodiversity hotspots (Myers et al., 2000). One biodiversity hotspot is the Cape Floral Region in South Africa (Mittermeier et al., 1998; Mittermeier et al., 2004; Grant and Samways, 2011). Due to its enormous plant diversity and high rate of endemism in a comparatively small area, eight reserves situated in this fynbos biome were inscribed as UNESCO world heritage site ("Cape Floral Region Protected Areas") in 2004 (UNESCO, 2014; see Fig. 1). The Cape region is rich in red-listed plant species (i.e. 1406 species: Raimondo et al. 2009), it maintains many endemic vertebrate species and is also recognized as an Endemic Bird Area (Stattersfield, 1998). However, information on species richness, biogeography, ecology, biology and evolution of most endemic invertebrate taxa is missing. Such data are essential for developing effective conservation strategies and management plans in order to prevent the loss of biodiversity (Olson et al., 2001). The Cape Floral Region is highly threatened due to climate change, invasive species, changed fire regimes and other anthropogenic influences (UNESCO, 2014). The delineation of the UNESCO World Heritage sites is biased towards mountain areas, whereas other parts suffer from a lack of protection, especially lowland areas (Rouget et al., 2003). A total of 90% of

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Fig. 1. Study sites in the UNESCO world heritage site "Cape Floral Region Protected Areas". Dots represent study sites.

these lowland areas have been transformed anthropogenically and they are likely to disappear completely if no suitable extension of the reserves is performed. However, it is worth noting that the world heritage site has recently been extended from eight to now 13 reserves including an important lowland reserve (Agulhas Complex, UNESCO, 2015).

Orthoptera are important herbivores in many open ecosystems (e.g. Sinclair, 1975). They show high levels of endemism (Hochkirch, 1998) and are known to be sensitive to changes in climate and vegetation structure (Weiss et al., 2013). Therefore, they have become an important group for environmental impact assessments in Europe (Henle et al., 1999). Even though many endemic Orthoptera species occur in the Cape region, there is still very little known on their ecology (Matenaar et al., 2014). This is mainly caused by the lack of field guides or other comprehensive taxonomic literature, hampering managers and rangers in collecting data about distributions and ecology of Orthoptera. While information on the occurrence of rare grasshopper species might help to identify sites of particular importance for conservation, this can currently be obtained only by taxonomic experts. Increased taxonomic efforts might be one solution to this problem, but it is also important to identify potential surrogate indicators as a proxy for biodiversity and conservation value (Crous et al., 2013).

The aim of our study was to develop an index for the assessment of conservation value of grasshopper assemblages based upon their endemism, dispersal capacity and rarity as a tool for prioritization of conservation measures. Furthermore, we wanted to test the indicator function of simple environmental parameters for grasshopper species richness and conservation value. Therefore we studied grasshopper diversity on 46 plots in eight reserves of the Cape Floral Region and examined the major factors influencing species richness.

2. Material & methods

2.1. Study sites

The Cape Floral Region Protected Areas cover eight reserves: Table Mountain National Park, Boland Mountain Complex, Groot Winterhoek Wilderness Area, Cederberg Wilderness Area, Boosmansbos Wilderness Area, Swartberg Nature Reserve, De Hoop Nature Reserve and Baviaanskloof Nature Reserve (Fig. 1). The Boland Mountain Complex consists of four nature reserves: Limietberg, Hottentots Holland and Kogelberg and the water catchment area of Jonkershoek. The CFRPA reserves cover an area of 553,000 ha and contain a buffer zone with approximately. 1,315,000 ha (UNESCO, 2014). Elevations range from sea level in De Hoop to 2077 m in Groot Winterhoek and soil types vary from nutrient poor, acid soils to marine alkaline sands and alluvials. Mountain fynbos is the common vegetation type in the reserves, whereas lowland fynbos is associated with flat areas, being typically found in De Hoop. The threatened vegetation type Renosterveld occurs in patches on nutrient rich soils in Table Mountain NP and Swartberg. Kogelberg features other rare fynbos types, such as western strandveld and seashore vegetation (Mucina and Rutherford, 2006; Grab and Knight, 2015).

In each reserve we selected four to six study sites together with the park managers according to the following criteria: veld age (i.e. time since last fire), accessibility, vegetation type (aiming at a high variety of vegetation types per reserve) and range of elevation (Fig. 1, for details see Table A1 in Supplemental Material). In Boosmansbos only one study site could be studied as the wilderness area is difficult to access. Therefore this reserve was excluded for most statistical analyses.

2.2. Data collection

The 46 study sites were surveyed during three field trips, one in spring (October to December 2012) and two in summer (February to April 2012 and 2013). During each field trip the study sites were inspected by two persons for one hour and all detected grasshoppers were recorded (timed counts; for information on species abundances see Table A2 in Supplemental Material). One observer focused on searching for species in dense bushes and trees, while the other observer focused on more open vegetation. The size of the sites was 1–2 ha and the distance between them was minimally 1 km (a distance, which is usually not crossed by grasshoppers, e.g. Hochkirch and Adorf, 2007). This method has successfully been used in several invertebrate studies before (Pryke and Samways, 2009). It is particularly useful in habitats, which are difficult to sample with other quantitative methods due to their dense and thorny vegetation (Gardiner et al., 2005). Specimens which could not be identified in the field were collected and identified later in the laboratory. At each site, we recorded the abiotic parameters altitude and veld age as well as the biotic parameters bare ground cover, forb cover, shrub cover, tree cover, forb height, shrub height and tree height. Altitude was recorded with a GPS (Garmin GPS Etrex 38) and veld age was determined by maps and, if necessary, updated using information provided by rangers in the field. Cover of rocks, bare ground, forbs, shrubs and trees was estimated (in 5% intervals), whereas for forb height, shrub height and tree height a mean value was calculated from the dominating layer height.

2.3. Statistical analyses

As an index of species richness (alpha diversity), we calculated the Shannon diversity Index and the Evenness for each reserve and each plot (Magurran, 1988) in BiodiversityPro (McAleece et al., 1997). As a measure of species overlap (i.e. beta diversity) between reserves, we calculated the Renkonen similarity index (Renkonen 1938). As we expected a high species turnover due to local endemism, all indices were calculated for both species level and genus level. A strong increase in Re from species to genus level suggests that species turnover is mainly caused by local endemism of similar genera.

As a measure of conservation value, we developed an index emphasizing the occurrence of rare and endemic grasshopper species in the reserves. This grasshopper conservation index (GCI) was used to identify possible micro-hotspots which can support an effective conservation management (Grant and Samways, 2011). The GCI was created in a way to value species with high extinction risk assuming that protected areas should aim at reducing overall species loss (Hochkirch, 2014). The index was calculated from three parameters: "endemism", "dispersal capacity" and "rarity" for each recorded species, all of which are known to be associated with extinction risk. Each parameter was grouped in three classes. "Endemism" was classified with "1″ when occurring also outside of South Africa, "2″ when endemic to South Africa and "3″ when endemic to the Cape region. For "Dispersal capacity", we defined three groups: "1″ fully capable of flight, "2″ wing-dimorphic, "3″ flightless. These categories were chosen because dispersal ability is highly associated with extinction risk in grasshoppers (Reinhardt et al., 2005). Rarity was measured based upon the occurrence of a species in the reserves. A species was considered as rare (=3) when it occurred at ≤five sites, intermediate (=2) at ≤10 sites, and common (=1) at >10 sites. The three parameters were summed for each species and divided by nine (the maximum value) to obtain a value between zero and one. In order to determine the GCI for a study site, the index values of all species occurring on the respective site were summed (GCI). While GCI is determined by both species number and value, we calculated a second index (GCIn) by dividing GCI by the number of species on that site. This standardized GCI (GCIn) is a measure of the mean species value on a given site and is not influenced by the number of species.

As park managers often lack taxonomic knowledge of insects, it is important to identify potential surrogate parameters that might indicate a high conservation value. We therefore calculated the Indicator value (IndVal) according to Dufrene and Legendre (1997) and used a permutation test (1000 permutations) in R to test these for significances (Dorman and Kühn, 2009). We were particularly interested in parameters indicating overall species richness (Species number, Shannon index, Evenness) and conservation value (GCIn, GCI). For each analysis, we grouped the sites according to the respective values of these measures in a higher (target) subgroup (1/3) and lower subgroup (2/3). The lower threshold for assignment to the high-value group was 0.902 for Shannon, 0.850 for Evenness, 0.611 for GCIn, 7 for GCI and 13 for the number of species. For these response variables, we calculated the IndVal of the abundance of each genus (assuming that genera are easier to identify in the field and might still indicate a high conservation value) and the environmental factors. Additionally, we calculated the total abundance of winged and wingless species for each study site as well as the ratio of these abundances to test for a possible indication value.

For calculating the indicator value, we used the following formula (see Dufrene and Legendre, 1997):

$$\mathrm{IndVal_{ij}} = A_{ij}\ \mathrm{X}\ B_{ij}\ \mathrm{X}\ 100$$

$$A_{ij} = \mathrm{Nindividuals_{ij}}/\mathrm{Nindividuals_{j}}$$

$$B_{ij} = \mathrm{Nsites_{ij}}/\mathrm{Nsites_{j}}$$

A_{ij} is the mean abundance (or frequency) of an explanatory variable i (in our case either genus or environmental factor) on sites within (target) subgroup j divided by the sum of the mean frequency in this subgroup and the lower value subgroup. B_{ij} is mean presence of the explanatory variable on the sites of the target subgroup.

Linear mixed models and generalized linear mixed models were constructed to test for significant correlations of environmental factors (rockiness, bare ground cover, tree cover, shrub cover, forb cover, tree height, shrub height, forb height, altitude and veld age) with the biotic indices (Shannon, Evenness, GCI, GCIn and number of species). Before calculating the LMMs/GLMMs hierarchical partitioning was used to determine the relative importance of each fixed effect variable for each response variable. For this purpose the hier.part package and gtools package was used (Walsh and Mac Nally, 2013; Warnes et al., 2015). The LMMs/GLMMs were calculated in R 3.0.3 using the lme4 package (Bates et al., 2014) and glmer function. The variables "reserve" and "period" (collection period) were included as random factors while the environmental variables represented the fixed effects and the biotic indices the response variables. For GLMMs Laplace approximation was chosen for likelihood estimations as only two random effects were taken into account (Bolker et al., 2009). Most response variables showed a Gaussian distribution except for "number of species", which required Poisson distribution. Afterwards, Likelihood ratio tests were performed in R (lrtest, Zeileis and Hothorn, 2002) to test whether the random factors had significant effects on the models. Fixed effects were tested with a Post hoc Tukey test (R package multcomp, Hothorn et al., 2015). In order to compare the species communities in a multidimensional context, a detrended correspondence analysis (DCA) was performed to test for correlations between species data and environmental factors. DCA was performed in R 3.0.3 (R Core Team, 2014) using the vegan package (Oksanen et al., 2008). An environmental fitting test with 1000 permutations was performed afterwards to test for significant correlations of environmental factors to the DCA functions.

3. Results

3.1. Grasshopper diversity

In total 86 species and 52 genera were recorded in the eight reserves. For both species and genera the mean Shannon index per site was highest at Baviaanskloof and lowest for species at Boosmansbos and lowest for genera at Table Mountain (Table 1). Shannon indices on genus level approximately followed the same pattern as on species level and reached between 92.3% (Table Mountain) and 100% (Swartberg) of the Shannon indices on species level. For both species and genera the mean Evenness per site was highest in Swartberg (0.84) and lowest in Boosmansbos (0.73).

Species overlap (Renkonen indices) between reserves ranged between 10.4% (Baviaanskloof/Swartberg) and 91.4% (Boosmansbos/Boland Area; Table 2). The Boland Area had the highest mean species overlap with other reserves (70% ± 3.28% SE), ranging from 31.0% (to Baviaanskloof) to 91.4% (Boosmansbos; Fig. 2). The lowest mean species overlap was detected for the most eastern reserve Baviaanskloof

Table 1
Alpha-diversity (Mean Shannon index, Mean Evenness and total species number) for each reserve based upon species data and genera; mean and standard error for GCIn and GCI for species.

	Species					Genera		
Reserve	Shannon	Evenness	Total	GCIn	GCI	Shannon	Evenness	Total
Baviaanskloof	0.93 (±0.02)	0.81 (±0.03)	41	0.53 (±0.01)	7.78 (±0.65)	0.90 (±0.02)	0.81 (±0.03)	33
Boland Area	0.84 (±0.02)	0.74 (±0.02)	44	0.58 (±0.02)	6.65 (±0.32)	0.78 (±0.02)	0.78 (±0.02)	29
Boosmansbos	0.76	0.73	11	0.58	6.33	0.73	0.73	10
Cederberg	0.84 (±0.09)	0.81 (±0.07)	29	0.62 (±0.03)	6.76 (±0.38)	0.82 (±0.09)	0.80 (±0.07)	22
De Hoop	0.87 (±0.05)	0.81 (±0.05)	30	0.56 (±0.02)	6.82 (±0.61)	0.82 (±0.06)	0.81 (±0.05)	21
Groot Winterhoek	0.88 (±0.04)	0.81 (±0.02)	30	0.55 (±0.03)	6.64 (±0.55)	0.83 (±0.04)	0.81 (±0.02)	22
Swartberg	0.78 (±0.02)	0.84 (±0.03)	20	0.63 (±0.03)	5.42 (±0.56)	0.78 (±0.04)	0.84 (±0.03)	20
Table Mountain	0.78 (±0.08)	0.75 (±0.06)	22	0.54 (±0.04)	5.83 (±0.71)	0.72 (±0.06)	0.74 (±0.06)	19

(20.5% ± 1.20% SE), ranging from 10.4% (to Swartberg) to 32.4% (De Hoop; Fig. 2).

Renkonen indices on genus level differed substantially from the species level analysis (Table 2, Fig. 2), varying between 17.9% (Baviaanskloof/Boosmansbos) and 96.5% (Boosmansbos/Boland Area). Average genus overlap was highest for Groot Winterhoek (81.7% ± 6.36% SE), ranging from 49.9% (to Baviaanskloof) to 96.2% (De Hoop). The lowest overlap in genera was still found for Baviaanskloof (36.4% ± 4.64% SE), varying between 17.9% (to Boosmansbos) and 50.7% (Boland Area).

3.2. Detrended correspondence analysis

The eigenvalue of the first detrended correspondence axis was 0.566 (37% of the total eigenvalue) and for the second axis 0.372 (24%). Species assemblages within single reserves were highly variable, whereas the assemblages between reserves showed a strong overlap, except for Baviaanskloof and Swartberg. The environmental fitting revealed a significant correlation between the DCA functions and the factors “tree cover” ($p = 0.003$) “veld age” ($p = 0.014$), “tree height” ($p = 0.024$), all of which correlated positively with the first two DCA axes. Significant correlations were also found for “forb cover” ($p = 0.045$), which correlated negatively with the first and second DCA axes, and for “altitude” ($p = 0.025$) which correlated negatively with the second, but positively with the first axis. The species assemblage of Baviaanskloof strongly correlated with tree height, while the species assemblage of Swartberg correlated positively with altitude (Fig. 3).

3.3. Grasshopper conservation index (GCI/GCIn)

GCIn reached the highest value at a site at Cederberg (0.72), followed by a plot on the mountain crest of Swartberg (0.70). The lowest value was calculated for a study site in Kogelberg (0.43; Table 3). The highest mean GCIn was found in Swartberg 0.63 (±0.03; Table 1). GCI scored the highest value on a study site at Baviaanskloof (9.56) and lowest on a site at Table Mountain (4.11). The highest mean GCI was found at Baviaanskloof (7.78 ± 0.65). Species with the highest possible GCI value (1) were *Devylderia bothai* Dirsh, 1956, all species of the genus *Euloryma* Spearman, 2013 (except for *Euloryma vittipennis*) and *Gymnidium turbinatum* Karsch, 1896. Species with the lowest possible value (3) were *Eyprepocnemis calceata* (Serville, 1838), *Heteropternis pudica* (Serville, 1838) and *Vitticatantops humeralis* (Thunberg, 1915).

3.4. Indicator value

The highest indicator values for the Shannon index (species level) were found for the environmental factors bare ground cover, veld age and altitude (but none of them significant; Table 4). High Evenness was indicated by altitude, bare ground cover (significant) and the abundance ratio of wingless to winged species. The latter ratio also performed well for high GCIn, followed by altitude and the abundance of *Thericlesiella meridionalis* (Sjöstedt, 1923). High GCI was best indicated by the abundance of *Euloryma*, wingless species and *Devylderia*. The three best indicators for GCI and GCIn were all significant (see Fig. A1 in Supplemental Material). A high species number was best indicated by a high abundance of winged specimens, shrub height and abundance of the genus *Acrotylus*, but none significant.

The LMMs/GLMMs provided no significant effects of the random factor “reserve”, while “period” had significant effects on GCI and GCIn ($\chi^2 = 3.85$, $p < 0.05$; $\chi^2 = 15.9$, $p < 0.001$). Rockiness influenced Evenness (Species: $t = 7.35$, $p = 0.008$; Genera: $t = 2.62$, $p = 0.018$) as well as GCIn ($t = 2.97$, $p = 0.008$) positively. Altitude influenced both Evenness (Species: $t = 2.71$, $p = 0.014$; Genera: $t = 2.76$, $p = 0.011$) and GCIn ($t = 3.56$, $p = 0.002$) positively.

4. Discussion

4.1. Evaluation of conservation value of grasshopper communities

Prioritization of conservation action needs guidance by scientific data. It is therefore important to develop objective measures for the evaluation of communities based upon clearly defined criteria (Hockey and Branch, 1997; Smith and Theberge, 1986). Diversity parameters such as the Shannon Index are often criticized for being too imprecise and ambiguous as they are influenced by the number of species as well as their frequency distributions (Grant and Samways, 2011). While Evenness is a better measure to describe frequency distributions, it is independent of species number and might thus be high even for species-poor communities. Furthermore, these indices treat all species equally, which means that the occurrence of widespread or even

Table 2
Beta diversity (Renkonen indices) for grasshopper species (lower left part) and genera (upper right part).

	Table Mt.	Boland	G. Winterhoek	Cederberg	B'bos	De Hoop	Swartberg	B'kloof
Table Mt.		72.03	56.29	51.09	35.54	47.77	37.98	30.79
Boland Area	64.44		96.15	91.44	96.49	87.99	75.78	50.68
Groot Winterhoek	48.51	91.04		76.47	38.27	50.4	50.16	34.49
Cederberg	37.61	79.06	66.04		38.33	52.1	52.19	39.08
Boosmansbos	18.02	91.42	34.76	29.56		44.53	57.72	17.94
De Hoop	39.37	80.68	43.24	28.37	21.37		41.97	48.61
Swartberg	26.05	52.4	27.54	28.77	28.84	32.31		18.01
Baviaanskloof	19.67	30.95	16.8	17.27	16.1	32.41	10.39	

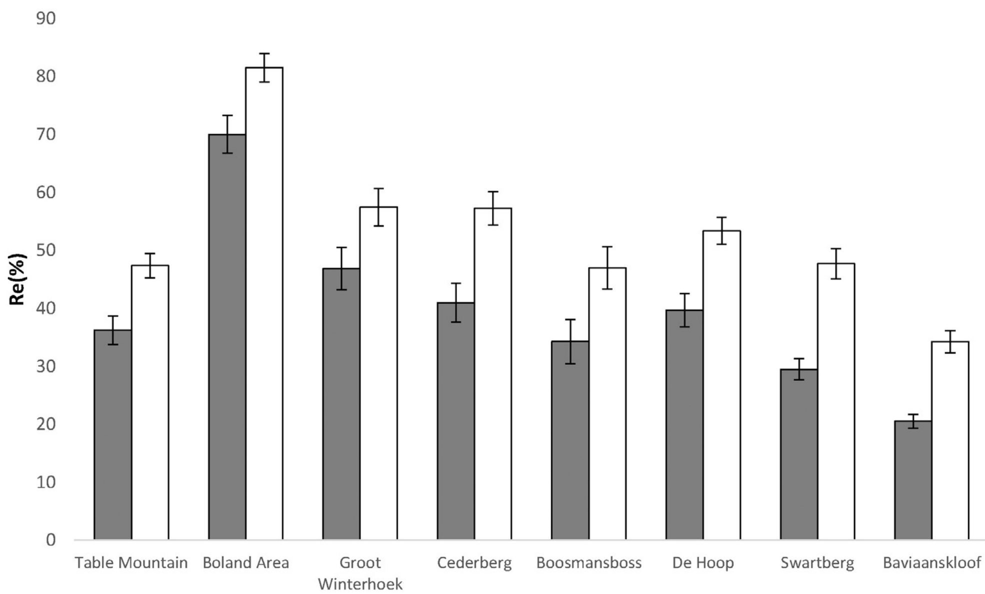

Fig. 2. Mean Renkonen index for each reserve (i.e. species overlap with other reserves; gray bars: species, white bars: genera, error bars: SE).

invasive species might increase these values (McKinney, 2008). Thus, it is not recommended to use solely these indices to assess the value of sites or to identify priority sites for conservation. If the major aim of a protected area is to preserve biodiversity, it is far more important to focus conservation action on rare and threatened species. The evaluation thus must consider information on the conservation status of species, such as the IUCN Red List status (Hochkirch et al., 2013). However, for most invertebrates, red list assessments have not yet been conducted (Gerlach et al., 2014). This is also true for most of the South African grasshoppers.

GCIn is similar to the dragonfly biotic index (DBI), which has been developed to evaluate Odonata communities (Simaika and Samways, 2009). The DBI uses the total of three subvalues (distribution, red list status and species sensitivity to habitat disturbance) and the total for

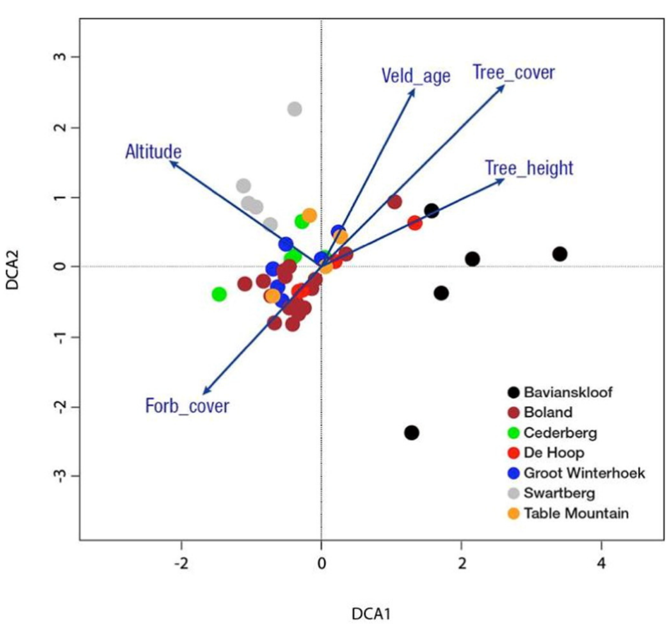

Fig. 3. Plot of the first two axes of a Detrended Correspondence Analysis (DCA) on species composition, explaining 61.4% of the total variance. Dots represent the different study sites, colored according to the reserve. Arrows show correlations of environmental factors with the DCA from an environmental fitting analysis (Significance Tree cover $p = 0.003$, Tree height $p = 0.024$, Forb cover $p = 0.045$, Altitude $p = 0.025$, Veld age $p = 0.014$).

all species is divided by species number. As red list status and information on ecological sensitivity are not available for South African Orthoptera, we used three factors that are important in red list assessments: distribution, rarity and mobility. Contrary to the DBI (which is scaled from 0 to 9), we divided the values by the maximum value of nine to achieve a more intuitive scale from 0 to 1. Furthermore, we used both GCIn and GCI, as the latter provides a measure of overall conservation value in terms of number and value of the species present on a given site, whereas GCIn is a measure of the mean conservation value of species on the site. The occurrence of common and wide-spread species is generally down-weighted for both measures. Thus, the indices help to identify sites with species in need of protection, but they still require comprehensive species inventories. If a larger number of sites is surveyed over time and in other regions, it will be possible to create a more comprehensive overview of potential values for GCIn and GCI values and to determine high priority areas within a protection area network. It is probably not useful to calculate universal thresholds from a biodiversity hotspot as the Cape Floral Region. We thus recommend a comparison of GCIn and GCI values with other regions. In our study, the upper tertile of GCIn was 0.63 and for GCI 7.56.

It must be considered that our indices are purely based on extinction risk of species, without any differentiation between other aspects that might be applied to evaluate species, such as the function as key stone species or high functional or genetic diversity. Our major intention behind the indices was to highlight species, for which the region has a special responsibility (i.e. endemism) and which have a high extinction risk (i.e. low mobility, rarity).

4.2. Simple indicators of conservation value

As managers and rangers often have insufficient taxonomic knowledge concerning invertebrates, we aimed to identify simple bioindicators which can be used by non-taxonomists and still provide a reliable assessment of the conservation value of sites. Obviously, the performance of bioindicators differed among target indices, but a couple of parameters generally performed well throughout. The cover of bare ground had the highest indicator value for the Shannon index (even though not significant) and was the only significant indicator for Evenness. Altitude was a significant indicator for the GCIn, and had also high values for Shannon index and Evenness (but for both not significant). Sites at higher altitude and the availability of patches with bare ground thus seem to be suitable abiotic indicators of grasshopper

Table 3
GCIn, GCI, total species number, Shannon index and Evenness in the eight reserves of the UNESCO World Heritage site "Cape Floral Region Protected Areas".

Reserve	Plot	GCIn	GCI	#Species	Shannon	Evenness
Baviaanskloof	BK_80	0.50	9.56	19	0.994	0.778
	BK_81	0.51	9.11	18	0.917	0.73
	BK_82	0.53	6.33	12	0.875	0.811
	BK_83	0.58	7.00	12	0.946	0.877
	BK_84	0.53	6.89	13	0.942	0.846
Boosmansbos	BB_85	0.58	6.33	11	0.76	0.73
Cederberg	CB_59	0.59	5.89	10	0.86	0.86
	CB_60	0.66	6.56	10	0.574	0.574
	CB_61	0.61	6.11	10	0.737	0.737
	CB_62	0.72	7.89	11	1.009	0.968
	CB_63	0.52	7.33	14	1.033	0.901
De Hoop	DH_73	0.53	7.89	15	0.792	0.673
	DH_74	0.56	7.33	13	1.05	0.942
	DH_75	0.53	4.78	9	0.776	0.813
	DH_76	0.61	6.11	10	0.873	0.873
	DH_78	0.57	8.00	14	0.877	0.765
Groot Winterhoek	GW_47	0.48	6.78	14	0.996	0.869
	GW_65	0.59	6.44	11	0.807	0.775
	GW_66	0.59	7.67	13	0.916	0.822
	GW_77	0.47	4.67	10	0.812	0.812
	GW_95	0.64	7.67	12	0.846	0.784
Hottentots-Holland (Boland)	HT_28	0.57	7.44	13	0.897	0.805
	HT_53	0.60	9.56	16	1.02	0.847
	HT_54	0.56	6.11	11	0.736	0.707
Jonkershoek (Boland)	JH_33	0.64	6.44	10	0.798	0.798
	JH_33a	0.56	5.00	9	0.811	0.85
	JH_67	0.63	7.56	12	0.84	0.778
Kogelberg (Boland)	KB_21	0.52	5.22	10	0.72	0.72
	KB_30	0.57	6.22	11	0.911	0.875
	KB_49	0.64	7.67	12	0.902	0.835
	KB_50	0.65	5.89	9	0.771	0.808
	KB_51	0.43	5.56	13	0.861	0.773
	KB_99	0.56	7.89	14	0.821	0.716
Limietberg (Boland)	LB_34	0.68	8.11	12	0.944	0.875
	LB_55	0.48	5.78	12	0.671	0.622
	LB_56	0.63	6.89	11	0.93	0.893
	LB_57	0.57	5.11	9	0.779	0.817
Swartberg	SB_68	0.61	6.11	10	0.882	0.882
	SB_69	0.65	3.89	6	0.659	0.847
	SB_70	0.70	4.22	6	0.697	0.896
	SB_71	0.63	6.33	10	0.871	0.871
	SB_72	0.55	6.56	12	0.769	0.713
Table Mountain	TM_86b	0.63	7.56	12	0.938	0.869
	TM_87	0.50	6.00	12	0.874	0.81
	TM_88	0.46	4.11	9	0.587	0.615
	TM_89	0.57	5.67	10	0.722	0.722

alpha diversity. These parameters may easily be applied by reserve managers to identify priority conservation areas at a relatively coarse scale. In fact, the high performance of altitude suggests that the bias of the initial UNESCO sites to high altitudes might even have helped to preserve sites with high grasshopper diversity. Our results fit well to those of Crous et al. (2014), who recently showed that rockiness together with altitude effects grasshopper diversity positively. However, it is likely that at higher altitudes than in our study sites species diversity and endemism decrease again as the overall shape of the relationship between species diversity and altitude is likely to be hump-shaped rather than linear. Rockiness correlated positively with both Shannon index and GCIn, but bare ground performed better as an indicator for general diversity measures. The importance of patches of bare ground for Orthoptera has been shown for many other grasshopper species (Gröning et al., 2007; Poniatowski and Fartmann, 2008). Altitude also performed well for GCIn, but GCI, GCIn and species number were generally stronger predicted by biotic parameters. The best IndVal (75.59) was achieved by the abundance ratio of wingless to winged species (GCIn), which also performed relatively well for Shannon Index, Evenness and GCI. The highest IndVals for GCI were obtained for the abundance of the genus *Euloryma*, wingless species in general and the genus *Devylderia*. However, it must be considered that species from these genera generally had high GCI values as they have a low mobility and small range size. Nevertheless, they may serve well as bioindicators as the identification of these genera is easy compared to the identification of complete grasshopper communities. By contrast, the number of species was mainly indicated by the abundance of winged species, shrub height and the abundance of the genus *Acrotylus*, a widespread generalist genus, which is usually associated with patches of bare ground. However, none of these parameters was significant. Our findings regarding the parameters rockiness and altitude were also supported by the results of the LMMs/GLMMs.

For the specific evaluation of sites within reserves, indicators of GCI and GCIn will be particularly useful as they highlight sites of importance for grasshopper conservation. Obtaining data on the abundance of winged and wingless grasshopper species is relatively easy and will help to identify such sites by using the abundance of wingless species as a proxy for GCI, the abundance of winged species as a proxy of species number and the ratio of these abundances (wingless/winged) as a proxy of GCIn. For using these indicators, rangers would not even require taxonomic skills, except for distinguishing grasshopper nymphs from wingless adults. Nevertheless, it will probably be also desirable for reserve managers to obtain full species inventories and identify priority species for conservation (Hochkirch, 2014). Therefore, the wingless/winged ratio will just serve as a tool for rapid assessment of conservation value of sites.

4.3. Grasshopper diversity in the cape region

Our results show that the Cape region maintains species-rich insect communities, confirming the findings of Procheş and Cowling (2006). In total, we found 86 grasshopper species (i.e. Acridomorpha) with a maximum of 44 species found in a single reserve complex (Boland area) and 41 species found in a single reserve (Baviaanskloof). Our survey was probably not comprehensive (three surveys on ca. five plots), which makes it difficult to compare to other studies using other methods. Species diversity in single reserves is comparable to mountain blocks of a tropical biodiversity hotspot, the Eastern Arc Mountains (East Usambara Mts: 42 species, Uluguru Mts: 31 species; Hochkirch, 1998). While the complete species number is comparable to the Mediterranean hotspots in Europe (e.g. Greece: 117 Acridomorpha recorded over decades). Our results show that vegetation structure has a significant impact on grasshopper assemblages, confirming previous findings (Tews et al., 2004; Joubert and Samways, 2014; Bazelet and Samways, 2011). Grasshoppers are rarely specialized in food (Chapman, 1990), but some species in the Cape region depend on the presence of certain plant families (e.g. *Betiscoides* on Restionaceae, (Matenaar et al., 2014). Baviaanskloof has an outstanding diversity of grasshoppers and is

Table 4
The five highest indicator values (IndVal) for factors indicating Shannon Index (Species), Evenness (Species), GCIn, GCI and number of species (*: significant; wl/w: ratio wingless/winged).

Shannon		Evenness		GCIn		GCI		#Species	
Bare ground	53.57	Altitude	60.20	wl/w*	75.59	*Euloryma**	65.09	winged	60.86
Veld age	51.13	Bare ground*	59.03	Altitude*	63.53	wingless*	58.90	Shrub height	54.08
Altitude	49.50	wl/w	57.91	*T. meridionalis**	63.07	*Devylderia**	57.58	*Acrotylus*	53.57
Forb height	47.10	Forb height	52.13	*Betiscoides**	61.66	wl/w	55.51	Shrub cover	52.97
wl/w	46.82	Veld age	51.45	wingless*	60.94	Veld age	53.87	Veld age	52.40

distinct from all other nature reserves in the Cape Floral Region. This is probably caused by the fact that Baviaanskloof is situated at the border of five biomes and therefore covers many different habitat types (Procheş and Cowling, 2006). Interestingly, plant diversity in the Cape region decreases eastwards (Cowling et al., 2009), which is contrary to our findings. The strong differentiation of species assemblages (and even genera) of Baviaanskloof compared to the others is probably also influenced by the availability of a higher number of vegetation types. Climate might also contribute to the high diversity in Baviaanskloof. In general, the Eastern Cape has a rather high average rainfall throughout the year (van Wilgen, 2013). A permanent water supply could support a variety of grasshopper species. Pfadt (1982) showed that high rainfall positively affects grasshopper abundance. Furthermore, summer droughts as well as fire events occur less often in the Eastern Cape (van Wilgen, 2013).

Beta diversity was strongly in line with the geographic pattern of the reserves. In most cases, the Renkonen indices were highest among adjacent reserves, suggesting that riverine corridors or mountain stepping stones play a role in shaping these communities. Reserves in the Boland Area had the highest beta diversity, caused by the central situation of these reserves, while the easternmost reserve (Baviaanskloof) and westernmost reserves (Table Mountain) had the strongest differentiation in grasshopper communities. However, it also needs to be considered that the Boland Area is divided into four reserves, so that the total number of study sites (and total number of species) was higher compared to the other reserves.

Cederberg is a hotspot for grasshopper diversity. Even though species abundances were rather low, GCIn indicates that the area maintains a high variety of specialists. We found a couple of specialists including some, which are likely to represent unique species (*Basutacris* spec., *Uvarovidium* spec., *Frontifissia spec*., *Euloryma* spec.). Most of them were found in dry areas with heterogenic vegetation. Areas near rivers or streams showed moderate grasshopper diversity but high abundances, mainly of generalists. Similar patterns have been found in other habitats dominated by grasses (Joern, 2005). The high GCIn values for study sites at Cederberg and Swartberg indicate that sites with a high variety but low abundance of grasshoppers are important for conservation.

4.4. Threats to grasshopper diversity in the Cape region

The unique fynbos biome is threatened by increasing wildfire frequencies, invasions of non-native plants and urbanization near Cape Town and other large cities (Rouget et al., 2003). Even though wildfires occur naturally in the fynbos and are important for the vegetation, the intervals between them has increased as a consequence of human intrusions and climate change. This has already led to a decrease in plant diversity in some reserves. The increasing frequencies of wildfires also threaten the most species-rich sites in Baviaanskloof. Severe wildfires in August 2012 and January 2013 caused a decline of the fynbos area by 70–80% in this reserve. The area is now increasingly often entered by buffalos that change the vegetation dramatically and hamper vegetation recovery (DM *pers. Obs.*). It is thus crucial to manage the buffalo population efficiently and develop useful fire control strategies in Baviaanskloof.

Sites with low GCI values were often affected by disturbance or rural influences, e.g. waste pollution and trails next to the official paths. This emphasizes the importance of buffer zones (Jongman, 1995). The Boland Area suffers from a lack of buffer zones as the boundaries of the reserves themselves are closely connected to rural or urban areas. Buffer zones can be of great importance for grasshopper conservation, even if they do not necessarily preserve specialized or endemic species (Grant and Samways, 2011; Kati et al., 2004). The core zone of a reserve is usually the most important zone for conservation (Joubert and Samways, 2014). However, we also found some sites with high conservation values in the buffer zone of Kogelberg (e.g. sites KB49 and KB50).

The importance of climate change on biodiversity in the Cape region is still little understood, but recent models for birds suggest dramatic species loss (Huntley and Barnard, 2012). In particular changes in the rainfall pattern are expected (Christensen et al., 2007), which can directly affect grasshopper survival as the eggs of most species require specific soil moisture (Ingrisch, 1983), or indirectly via changes in the vegetation. A high rate of habitat loss is expected at Cederberg if temperature rise continues (Midgley et al., 2002). Therefore, the potential effects of climate change on endemic insects of the Cape region needs further attention and research. The presented indicators and indices might contribute to an easier and effective assessment of the conservation status and its trends.

5. Conclusions

We here propose two general indices to evaluate grasshopper communities (GCI/GCIn). These indices can easily be transferred to any region as they are based upon universal criteria (range size, mobility, rarity). We also propose some general indicators for grasshopper diversity and conservation value, which do not require specific taxonomic knowledge and only minimal examination of specimens. They are probably also applicable to other open-land habitats. The importance of bare ground has been shown for many grasshopper species and for other regions (Gröning et al., 2007; Poniatowski and Fartmann, 2008). Mountain regions usually maintain a higher number of endemic grasshopper species (Çiplak, 2003), suggesting that altitude is indeed a suitable proxy for estimating the conservation value of sites with low to moderate altitude. Furthermore, wingless grasshopper species are often highly threatened (Reinhardt et al., 2005) and endemic to smaller areas. Many rainforest endemics are for example wingless (Hochkirch, 1998), suggesting that the abundance of wingless species and the ratio wingless/winged species might be suitable to other regions as well.

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