Bothalia 37,1: 79–88 (2007)

Can anthropogenic variables be used as threat proxies for South African plant richness?

M. KEITH†* and M. WARREN*

Keywords: endemic species, human population density, land transformation, setting conservation priorities

ABSTRACT

Human demographic and socio-economic measures (anthropogenic variables) reflect the detrimental impact of humans on plant diversity globally. The Pretoria (PRE) Computerised Information System (PRECIS) of the South African National Biodiversity Institute (SANBI), provided three sets of South African plant richness data, overall (OPR), endemic (EPR), and threatened (TPR), to investigate the relationships between richness and six anthropogenic variables. Spearman's Rank order correlations, Kruskal Wallis Analysis of Variance (ANOVA) and Generalized Linear Models (GLZ) were used. Although all three plant richness measures were correlated with anthropogenic variables, individual anthropogenic variables contributed a small fraction to the explained variation in richness. Differences in spatial and temporal scaling of the datasets, or the response to another causal mechanism, may have contributed to this low explained variation. Because more variation was accounted for in OPR than EPR or TPR, OPR is a more suitable surrogate measure of plant biodiversity when investigating the anthropogenic variables used here. Average human density (HD), infrastructure (degree of urbanization and road cover) (LRU) and percentage land area transformed and degraded (LTD) were identified as useful surrogates of human impacts on OPR. LTD may be a more inclusive human impact measure when conducting analyses of human impacts using OPR. LTD includes the effects of urban expansion, road networks and other land transformation impacts, such as agriculture.

INTRODUCTION

Human actions threaten biological diversity at a global scale. The sources of threat include taxon-specific threats such as exploitation, introduced taxa and various forms of ecosystem degradation, including land transformation and pollution (World Resources Institute 2000). Strong evidence indicates correlations between rates of habitat and species disappearance with human demography patterns, such as population density and population growth, and human activities (James 1994; Ceballos & Ehrlich 2002; Harcourt & Parks 2003; Luck *et al.* 2003). As a result, conservation planners have been urged to integrate biological, socio-economic and human demographic data in their assessments to effectively determine real world conservation priorities (Cincotta *et al.* 2000; Brooks & Thompson 2001).

Human demographic and socio-economic data are often current and easily available (Harcourt & Parks 2003), and may constitute useful surrogate measures of the proximate threats to certain life forms and taxa. A number of human-related variables are correlated with plant richness measures around the world, both at regional and global scales. These include human demographic parameters (e.g. population density, human population growth rate change, poverty and affluence, urbanization), land transformation, land fragmentation and fuel wood consumption (Macdonald 1991; Kerr & Currie 1995; Cincotta *et al.* 2000; Ceballos & Ehrlich 2002; Liu *et al.* 2003).

Of these parameters, human population density has been considered a reasonably good indicator of threat of the risk of species extinction (Thompson & Jones 1999; Harcourt & Parks 2003). Plant population declines are mostly concentrated in areas with either high human densities or high human impact, such as agriculture (Burgess *et al.* 2002; Ceballos & Ehrlich 2002; Araújo 2003). In turn, rapid and continuing population growth, and the associated human impact on the environment, is ever increasing (Cincotta *et al.* 2000; World Resources Institute 2000; Liu *et al.* 2003), necessitating urgent investigation into the relationship between plant richness and human population increase.

Sub-Saharan countries have some of the highest population growth rates in the world (United Nations Development Programme 2001). This, tied with high human population densities, clearly translates into considerable landscape transformation (James 1994; McKinney 2001). Most of Africa's dense human settlements, intensive agricultural activities and habitat fragmentation are concentrated in areas of high animal and plant endemism (Balmford *et al.* 2001; Harcourt *et al.* 2001; Burgess *et al.* 2002; Chown *et al.* 2003).

A strong association between population growth and environmental degradation exists that is mediated, in part, through income. For example, it has been demonstrated that as human populations grow, agricultural productivity declines, and this in turn raises rural poverty (Ukpolo 1994). Poverty stricken people are forced to rely heavily on surrounding resources for survival, placing increased pressure on vegetation and plant and animal species in the region (Lucas & Synge 1981; James 1994). Struggling populations in rural areas may then move to the cities (Ukpolo 1994; World Resources Institute 2000) resulting in, for example, urban sprawl that generally involves complete transformation of relatively large areas (Macdonald 1991; Cincotta *et al.* 2000; Liu *et al.* 2003).

On the other end of the income scale, higher per capita income may also lead to environmental degradation (Naidoo & Adamowicz 2001). Areas with a high Gross National Product (GNP) correspond to areas with a high

† Former address: Threatened Species Programme, South African National Biodiversity Institute, Private Bag X101, 0002 Pretoria.
* Department of Zoology and Entomology, University of Pretoria, 0002 Pretoria. mkeith.za@gmail.com
MS. received: 2005-04-01.

proportion of threatened plants in various countries (Kerr & Currie 1995; Naidoo & Adamowicz 2001). High GNP usually fuels excessive land conversion and resource exploitation, increasing the number of threatened plant and vertebrate taxa (Naidoo & Adamowicz 2001). In many cases, this association between humans and environmental degradation, and humans and species threat, is mutually reinforced by additional anthropogenic measures such as household dynamics, urbanization, technology and political instability (World Resources Institute 2000; Liu *et al.* 2003). In this sense, the combined forces of human population pressure apply tremendous stress to ecological systems in Africa and other underdeveloped areas (Ukpolo 1994).

Environmental degradation extends beyond the effects of human population growth. Land use and land-cover changes are important elements of the larger problem of global environmental change. Land use impact and the loss of species can often be directly related to the percentage area under urbanization, transformation or fragmentation (Wood *et al.* 1994; Pfab & Victor 2002). Theobald (2003) found that areas with more than 15% infrastructure development coverage could be deemed highly fragmented and thus impacting negatively on biodiversity, resulting in species loss (Santos *et al.* 2002; Tscharntke *et al.* 2002). Correspondingly, roads have been claimed to have a disproportionate effect on biotic diversity (Macdonald 1991; Reyers 2004). Reyers *et al.* (2001) illustrated that road construction and maintenance significantly altered surrounding natural habitat and landscapes. In addition, other forms of landscape transformation and degradation such as areas utilized for agriculture and plantations may lower species richness. Although the effect of high human population density on species richness may be observable through increased road infrastructure and urban expansion, agriculturally degraded or transformed landscapes are likely to occur in lower human density areas, confounding the relationship between land transformation and human population density. As a result, land-cover changes may also impact species richness patterns.

Identifying and managing threatening processes, threatened areas and taxa at risk of extinction at national scales, in essence, requires interpreting the impacts of human activities on biodiversity at smaller spatial extents (Brooks & Thompson 2001; Gärdenfors *et al.* 2001; Chown *et al.* 2003; Liu *et al.* 2003). Incorporating human demographic and socio-economic variables into conservation priority setting procedures will allow more informed conservation decisions to be made (Hannah *et al.* 1994; Sisk *et al.* 1994). An understanding of the relationships between these variables and plant richness at national scales is essential to determining the suitability of such data as surrogate measures to assist in understanding the proximate and ultimate threats to plant taxa (Kerr & Currie 1995; Brooks & Thompson 2001). However, ascertaining the relationships between biodiversity and human impacts are not as straightforward as originally believed. The effects of, and threat posed by, human demographic and socio-economic activities on taxon richness at national scale remain unclear because of the complexity and multiplicity of human activities, as mentioned above.

The impacts of human activities on biodiversity may also vary between richness measures (Van Rensburg *et al.* 2002). For example, human impacts may be greater, and therefore more apparent, for threatened and endemic plant taxa than for total species richness. Higher taxon richness has been successfully used as a biodiversity surrogate in prioritizing areas of conservation importance at both national and continental scales (Fjeldså 1997; Balmford *et al.* 2001; Harcourt & Parks 2003; Rouget *et al.* 2004). But conservation strategies based solely on overall plant richness are often of limited use (Jetz & Rahbek 2002). The large proportion of endemic taxa in southern Africa has been attributed to the diverse ecological conditions, as well as the product of high speciation within a large number of endemic genera (Cowling & Hilton-Taylor 1994). It is essential to include an analysis of threatened and range restricted taxa when classifying areas of conservation priority (Rouget *et al.* 2004).

In South Africa, the Western Cape has been favoured by human settlement for the past 350 years, leading to substantial land transformation through agricultural and urban development, and alien plant encroachment (Deacon 1992; Rebelo 1992a; Richardson *et al.* 1996). Subsequently, much of the remainder of southern Africa has also undergone extensive land transformation over the past 100 years (Macdonald 1991; Van Rensburg *et al.* 2004). People have been attracted to the interior where mineral and fossil fuel resources abound (Deacon 1992). This has resulted in a multi-faceted combination of human demands and inherent threats across the southern African landscape (Reyers *et al.* 2001; Neke & Du Plessis 2004).

Previous work investigating human impacts in South Africa has focused on the relationships of taxon (or species) richness and human variables for South Africa's birds and, recently, frogs (Van Rensburg *et al.* 2002; Chown *et al.* 2003; Van Rensburg *et al.* 2004; Evans *et al.* 2006). Their results show that avian species richness and human density were positively correlated, apparently as both responded positively to increasing levels of primary productivity (Van Rensburg *et al.* 2002; Chown *et al.* 2003; Van Rensburg *et al.* 2004). Here, we investigate the relationships between three plant richness measures that include all endemic and threatened South African plant taxa and six human demographic and socio-economic variables, to better understand potential and realistic anthropogenic threats to South African plants.

METHODS

Plant distributions of all South African taxa were extracted from the Pretoria National Herbarium (PRE) Computerised Information System (PRECIS) for 1 936 quarter degree squares (QDS) of South Africa. Richness maps were collated for three sets of plant groups. First, overall plant richness (OPR) was collated for South Africa at QDS level. Secondly, a list of 'endemic' taxa believed to occur only in South Africa, were extracted from the PRECIS database as well as Germishuizen *et al.* (2006) to produce a richness map for South African endemic taxa. Finally, a measure of threatened plant richness per QDS was calculated based on a list of threatened taxa, which was extracted from the Threatened Species Programme's database of December 2003 (Threatened Species Programme unpublished data). This list of threatened species as used here (preliminary 2003 Red List of South African plants) is currently in the process of being re-assessed according to the IUCN (2001) Red List Categories & Criteria, by the Threatened Species Programme of the South African National Biodiversity Institute (SANBI). On release, this SANBI Red List will supersede the current 2003 list used. All taxa listed either by Hilton-Taylor (1996) as Endangered (E), or Vulnerable (V) or by IUCN (2001) categories Critically Endangered (CR), Endangered (EN) or Vulnerable (VU), were classified as Threatened.

Taxon richness counts across South Africa's QDSs were square root-transformed following Rebelo & Tansley (1993). Endemic and threatened taxon richness per QDS were also square root-transformed and corrected for total plant richness by dividing by total plant richness in that QDS (following Rebelo & Tansley 1993) yielding standardized endemic plant richness (EPR) and standardized threatened plant richness (TPR) at a QDS scale across South Africa.

South African anthropogenic data

Six human and socio-economic variables (anthropogenic variables from here on) were extracted from various data sources at a national scale in South Africa. These include: 1, human population density, 2; human population growth rate change; 3, a poverty index; 4, an affluence measure; 5, infrastructure; and 6, the degree of land transformation and degradation. Human population density, human population change, poverty, and affluence data were derived from magisterial district data (Central Statistical Service 1995, 1998), whereas all land-cover and transformation data were collated from the National Land-Cover (NLC) database (Fairbanks & Thompson 1996; Fairbanks *et al.* 2000). To standardize the scale of this data with the plant distributional data, data were converted to a spatial scale at the QDS level (25×25 km^2) using ESRI ArcView GIS 3.2.

The 1996 South African population census data (Central Statistical Service 1998) were used to estimate the weighted average population density per QDS (human density—HD). Human density was denoted as the average number of people/km^2 within each QDS. The average percentage increase or decrease of human population per QDS (human growth rate change—HC) over the period 1996 to 2001 (Central Statistical Service 1998; Rouget *et al.* 2004) was used as a direct proxy for the impact of human population growth on the environment.

A poverty index (economic poverty—EP) was estimated as the proportion of people per municipality earning less than R200 per month (Central Statistical Service 1998). The United Nations Development Programme South Africa (2003) report indicated that people earning less than R354 per month could be regarded as earning below the poverty line. The census data uses broad categories of which 'less than R200/month' together with the 'no income' category are regarded as earning below the poverty level. This allowed the computation of a weighted average of the proportion of people per QDS earning less than R200/month.

A measure of economic affluence (EA) defined as the weighted average Gross Geographic Product (GGP) per capita income per QDS, was based on GGP obtained for all South African magisterial districts (Central Statistical Service 1995). GGP represents 'the remuneration received by the production factors—land, labour capital and entrepreneurship for their participation in production within a defined area' (Central Statistical Service 1995). The Central Statistical Service (1995) provides 1994 estimates of GGP and remuneration of employees by magisterial district in South African Rand (R). Fine-scale spatial Gross National Product (GNP) data for South Africa were not available, forcing the use of GGP data, which represents the finest-scale data available for South Africa and was incorporated in the current analysis rather than GNP data used by other authors (Kerr & Currie 1995; Naidoo & Adamowicz 2001).

To obtain a measure to investigate the effects of urbanization and related development (e.g. industry) on plant richness in South Africa, infrastructure coverage (in the form of the percentage of a QDS covered by road and urbanized areas) was estimated (land-cover, roads and urban, LRU). Infrastructure data were extracted from the NLC database (Fairbanks & Thompson 1996). The extent of the urban area was extracted from all types of 'urban/built-up land' land-cover type (= land-cover type 24–30; Fairbanks & Thompson 1996) in the NLC database. A buffered road network for South Africa was obtained from Reyers *et al.* (2001) representing various buffered road types in South Africa.

The extent of land transformation (land-cover, transformed and degraded (LTD) was obtained from the NLC database, by calculating and summing the percentage of each land-cover class in each QDS, based on the six transformed land-cover classes identified by Fairbanks & Thompson (1996) and Fairbanks *et al.* (2000). These classes were based on seasonally standardized Landsat TM satellite imagery captured primarily during 1994–1995 and included anthropogenic effects such as forest plantations, artificial water bodies, urban/built-up areas, cultivated lands, degraded land as well as mines/quarries. LTD may be a more inclusive human impact measure than HD or LRU alone (when available), as it includes the effects of human population density on urban expansion, road networks and the effects of other forms of land transformation that occur in lower human density areas but that may significantly affect species richness (e.g. agricultural, industrial and other land transformations, such as plantations).

The values of the weighted average anthropogenic variables calculated for each QDS across South Africa (Table 1) conform reasonably well to human statistics presented by the Development Bank of South Africa (DBSA) (2000). This suggests that the rescaled (to weighted average values for each QDS across South Africa) human demographic variables used here do not noticeably differ from the provincial scale data issued by DBSA.

TABLE 1.—No. approximate total plant taxa, no. endemic and threatened plant taxa for South Africa and for the nine respective provinces. All national and provincial taxa counts are approximate counts (rounded off) obtained from PRECIS (see Germishuizen *et al.* 2006 for up to date counts)

Area	Plant taxa	Endemic taxa in area	Endemic taxa to area	Threatened taxa in area	Threatened and endemic in area	HD	HC	EP	EA	LRU	LTD
Eastern Cape	7 000	2 800	750	259	234	33.51	5.5	68.7	R 406 × 10^6	6.61	21.2
Free State	2 900	320	25	36	24	26.98	7.68	67.7	R 625 × 10^6	7.78	28.7
Gauteng	2 700	220	20	39	19	301.7	19.88	51.8	R 6 558 × 10^6	18.70	41.6
KwaZulu-Natal	6 400	1 350	400	198	151	83.95	12.49	71.6	R 1 126 × 10^6	6.14	34.3
Limpopo	4 500	480	130	101	58	40.89	13.53	56.8	R 891 × 10^6	4.79	24.1
Mpumalanga	5 000	640	250	108	62	43.97	18.23	57.2	R 483 × 10^6	7.12	29.3
North-West	2 500	180	10	29	13	32.86	6.57	69.6	R 1 083 × 10^6	5.84	29.1
Northern Cape	5 100	1 900	650	337	282	2.97	–6.15	57.5	R 307 × 10^6	3.77	2.6
Western Cape	11 800	7 900	5 550	1 093	1 060	24.07	12.46	49.9	R 1 287 × 10^6	5.79	23.4
South Africa	22 800	11 200	11 200	1 880	1 464	33.76	6.57	61.1	R 1 099 × 10^6	6.13	20.4

Endemic taxa in area: approximate no. South African endemic taxa occurring in particular region.
Endemic taxa to area: approximation of taxa endemic to area, reported to occur only in area.
Threatened and endemic taxa: no. threatened taxa [Critically Endangered (CR), Endangered (EN), Vulnerable (VU) (IUCN 2001), Endangered (E), and Vulnerable (V) pre-1994 criteria] based on preliminary 2003 Red List (Threatened Species Programme 2003 unpubl. data).
Information on average anthropogenic variables for each of areas calculated for all provincial quarter-degree squares (QDS), with abbreviations as follows: HD, human density (people/km^2); HC, human growth rate change (% increase/decrease of people); EP, economic poverty (proportion of people earning < R200/month); EA, economic affluence [Rands (GGP) per capita × 10^6]; LRU, land use roads and urbanization (% area under urban or road); LTD, land-cover transformed and degraded (% area transformed or degraded).

Statistical analysis

All three measures of richness (OPR, EPR and TPR) and the six anthropogenic variables (HD, HC, EP, EA, LRU, LTD) were log-transformed for statistical analyses. Kruskal Wallis Analysis of Variance (ANOVA) by Ranks and Spearman's *R* Rank order correlations (Zar 1996) were used to test for statistical differences and correlations, respectively, between measures.

Generalized Linear Models (GLZ; McCullagh & Nelder 1989) were used to assess the relationship between OPR and EPR, and between OPR and TPR, as well as between each of the three measures of plant richness and each anthropogenic variable independently. Anthropogenic variables were not included simultaneously in the analysis because of high correlations between some variables (which may lead to collinearity in the model), the substantial differences in the manner in which the variables were measured and subsequently rescaled, and because we wanted to examine the contribution of each variable to explained deviance in each richness variable independently, to assess its potential as a surrogate measure of anthropogenic impact. Because the measures of plant richness were in the form of counts, a Poisson distribution with a logarithmic link function was used in the GLZs (Maggini *et al.* 2002). A goodness-of-fit test (a deviance statistic), which yields the proportion of deviance explained (similar to an R^2 value) by the variable in the GLZ (McCullagh & Nelder 1989) was used to determine which anthropogenic variable contributed the most to explained deviance in the richness variable used. All statistical analyses were based on analytical subroutines in STATISTICA version 6.1 (StatSoft 2001).

RESULTS

Based on the 2003 data extracted from the PRECIS data set, ± 11 200 of the 22 000 recognized South African plant taxa are endemic to South Africa. The preliminary 2003 Red List regarded about 1 900 taxa as threatened with extinction (Threatened). The Western Cape and Eastern Cape proved to have the highest number of plant taxa, endemic as well as threatened (Table 1; Figure 1), mainly in the Cape Floristic Region.

Considering the anthropogenic measures, Gauteng displayed the highest human variables except for economic poverty (EP) and economic affluence (EA—GGP/capita). KwaZulu-Natal, was highlighted as the province with the highest proportion of poverty (EP), and Northern Cape highlighted with the highest average GGP/capita (EA), mainly the result of lower human population density and large GGP contributors (mining and quarrying, data not shown) in the province (Table 1). Excluding 'per capita' from the GGP measure, Gauteng Province was the largest contributor to South Africa's economy.

Human densities (HD) and high human growth rate change (HC) were evident mostly in the large metropolitan areas such as City of Cape Town, eThekwini Municipality (city of Durban) and municipalities in Gauteng Province (Figure 2A, B). EP in turn was higher in areas in the North-West, Eastern Cape and northeastern KwaZulu-Natal. EA (affluence/capita) was high in areas with low human density, e.g. Northern Cape (Figure 2C, D). Gauteng Province yielded QDSs with the highest levels of urbanization and road coverage, with Western Cape, Eastern Cape (Transkei), North-West and Free State yielding areas of high transformation and/or degradation (Figure 2E, F).

Relationships between species richness measures

Overall plant richness (OPR), endemic plant richness (EPR) and threatened plant richness (TPR) were all significantly different from one another across South Africa (Kruskal Wallis $H_{3,\ 7752}$ = 4070; $P < 0.001$). Nonetheless,

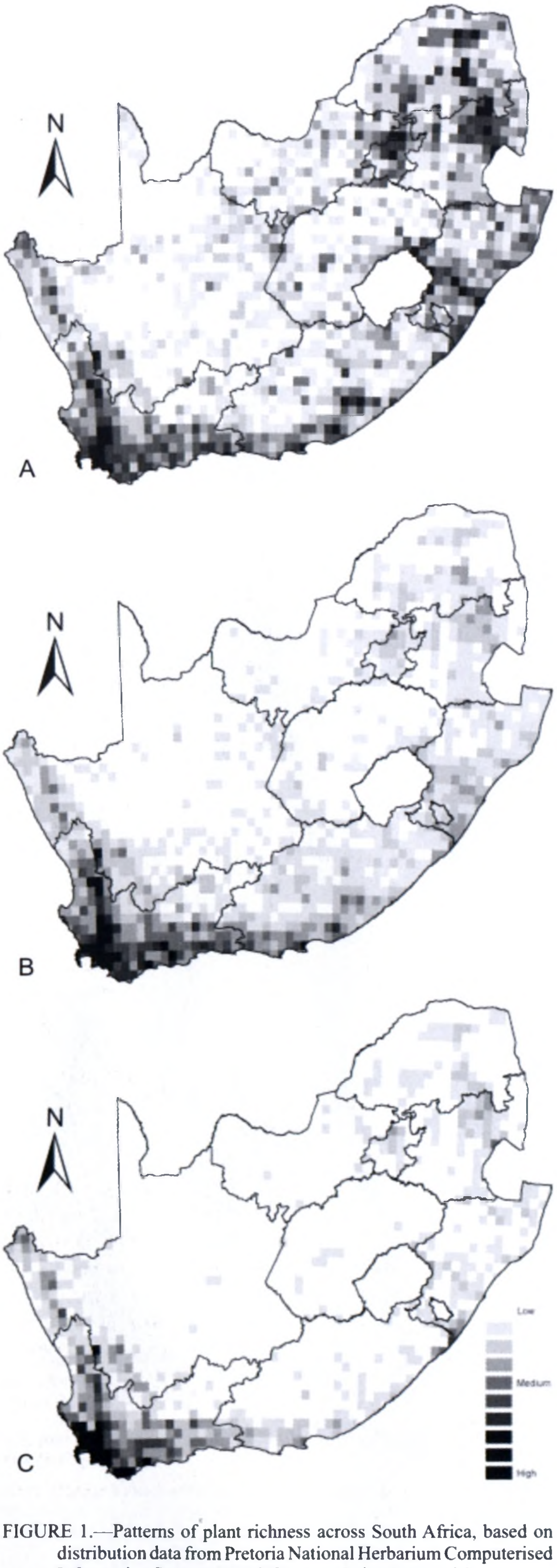

FIGURE 1.—Patterns of plant richness across South Africa, based on distribution data from Pretoria National Herbarium Computerised Information System (PRECIS) presented at quarter-degree square (QDS, 25 × 25 km). A, overall plant richness (OPR); B, endemic plant richness (EPR); C, threatened plant richness (TPR). Darker shades represent higher plant richness for each QDS. Threatened plant richness was based on the preliminary 2003 Red List of South African plants. Note: this map should not be used for provincial conservation purposes until our results are verified by the updated Red List (shortly to be released by SANBI).

EPR was strongly significantly correlated with OPR (Spearman $R = 0.807$; $n = 1936$; $P < 0.05$), with EPR (dependant variable) contributing to 63% (Pearson $X^2 = 3468.52$; d.f. = 1935; $P < 0.001$) of the total deviance in OPR. OPR and TPR were also strongly correlated, but not as strongly as the relationship between OPR and EPR (Spearman $R = 0.679$; $n = 1936$; $P < 0.05$), with the regression model explaining 61% (Pearson $X^2 = 724.76$; d.f. = 1935; $P < 0.01$) of the total deviance. The strong correlation and percentage deviance explained for overall plant richness with both EPR and TPR indicates, not surprisingly, that endemic and threatened South African taxa are relatively strongly dependent on total taxon richness. Despite this strong link between richness measures, ± 40% of the variation in overall plant richness remains unaccounted for when including either endemic or threatened taxa. We felt it prudent to investigate the relationships between each plant richness variable and the six anthropogenic variables, given that the richness measures varied significantly from one another across QDSs and because human impacts on endemic and threatened taxa may differ from overall plant richness.

Relationships between human demographic and socio-economic variables

The anthropogenic variables were all strongly significantly different from one another (Kruskal Wallis $H_{5, 11601} = 7307.40$; $P < 0.001$). All variables were positively correlated with one another except for the measure of affluence (EA—GGP/capita), which was negatively correlated with all anthropogenic variables calculated within the current study (Table 2). The poverty index (EP) and human growth rate change (HC) were the only two variables that were not significantly correlated with each other. Human density (HD) was strongly positively correlated with all variables, except EA (Table 2), suggesting that this variable may be the single, most inclusive anthropogenic variable to include in investigations of human impacts on flora. Human density was particularly strongly correlated with both land transformation (LTD) and roads and urbanization (LRU).

The effects of anthropogenic variables on species richness measures

Statistical analysis indicated varying relationships between OPR and the six anthropogenic variables. Plant richness (OPR) was positively correlated with human density (HD), human population growth rate change (HC), land-cover roads and urban (LRU) and land-cover transformed and degraded (LTD). Economic poverty (EP) and economic affluence (EA) were negatively correlated with plant richness, indicating that the effect of these variables on OPR was inverse to the effect of the remaining anthropogenic variables (Table 3). Although HD and LTD were strongly correlated (Table 2), LTD was able to contribute 2% more than HD to explained deviance in OPR (Table 3). No single anthropogenic variable accounted for more than 10.10% deviance explained in OPR (Table 3). Therefore, the observed effect of individual anthropogenic variables on OPR was small, but significant.

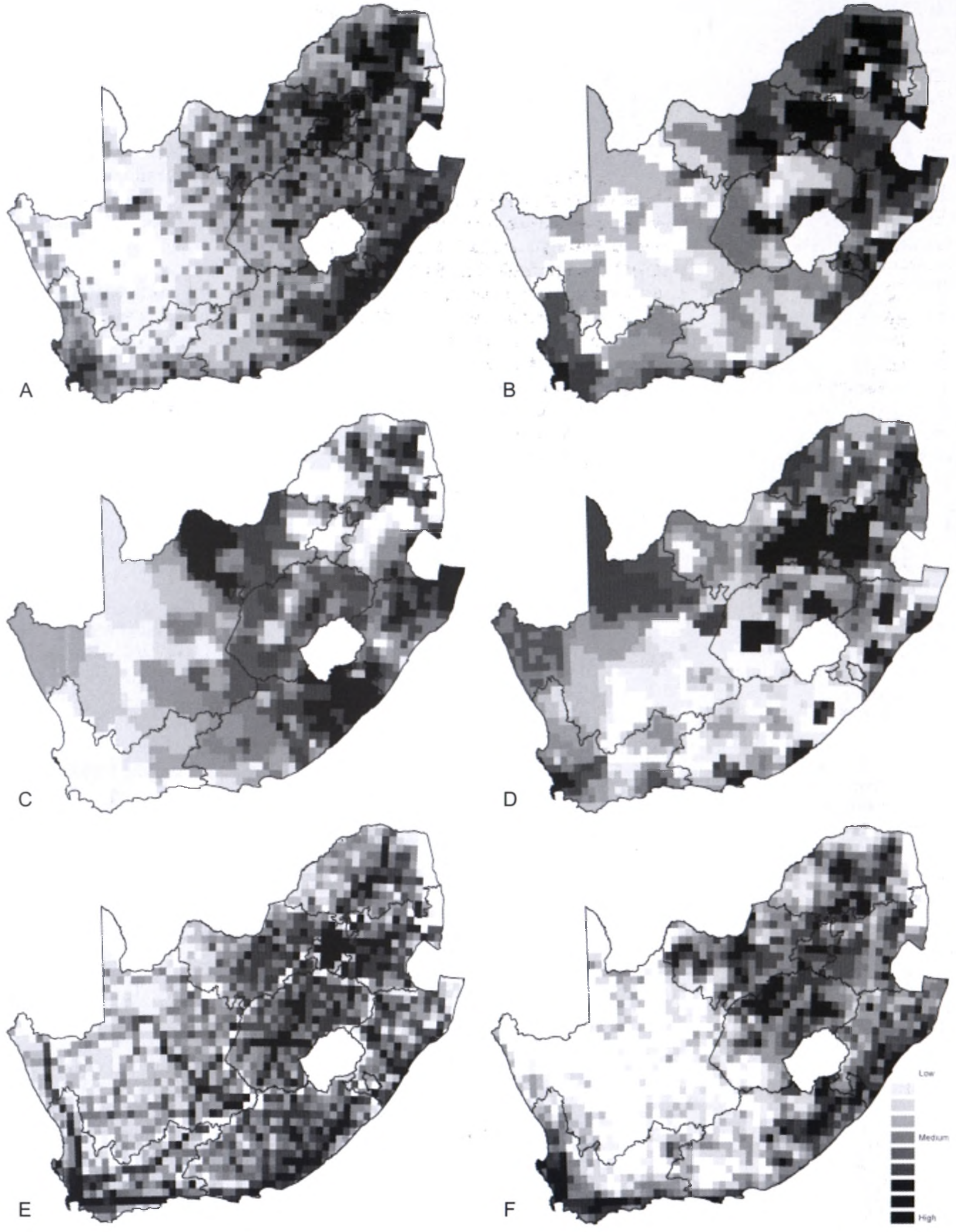

FIGURE 2.—Spatial representation per QDS across South Africa. A, human population density (HD); B, human growth rate change (HC); C, economic poverty (EP); D, measure of economic affluence (EA) denoted as the weighted average GGP/capita (EA); E, infrastructure of land-cover road and urban areas (LRU); and F, degree of land-cover transformed and degraded (LTD). Darker shades represent higher impacts.

Endemic plant richness (EPR) and the anthropogenic variables were all weakly correlated with one another (Table 3). Only the poverty (EP) variable, which was weakly negatively correlated with EPR, explained a significant proportion of the deviance (10.50%) in EPR (Table 3). Other than EP, the anthropogenic variables used here do not appear to contribute sufficiently to understanding the effects of human impacts on endemic plant species.

Threatened plant richness (TPR) and the human variables were all weakly significantly correlated (Table 3).

TABLE 2.—Spearman Rank order correlation (*R*-values) for the six anthropogenic measures

	HD	HC	EP	EA	LRU
HD	**1.00**				
HC	**0.54**	**1.00**			
EP	**0.34**	0.003 ns	**1.00**		
EA	**–0.86**	**–0.37**	**–0.48**	**1.00**	
LRU	**0.57**	**0.26**	**0.10**	**–0.49**	**1.00**
LTD	**0.73**	**0.54**	**0.25**	**–0.59**	**0.42**

Values in bold: statistical significance of $P < 0.05$; ns, not significantly correlated; HD, human density; HC, human growth rate change; EP, economic poverty; EA, economic affluence; LRU, percentage land-cover under roads and/or urban; LTD, percentage land-cover transformed and degraded.

Poverty (EP) and economic affluence (EA) were again negatively correlated with the plant richness variable (TPR). Only these variables contributed significantly to explained deviance in TPR, although the contribution was minimal (Table 3).

DISCUSSION

Strong evidence links rates of habitat and species loss with human demographic patterns (Cincotta *et al.* 2000; Ceballos & Ehrlich 2002; Luck *et al.* 2003). Given South Africa's low economic growth during the past decade (2.7%), increased population size (2.2% per annum) and increasing demand on urbanized areas (DBSA 2000; Statistics South Africa 2002; Chown *et al.* 2003), anthropogenic effects on species should be readily apparent. None of the anthropogenic variables measured here contributed more than 10% towards explaining variation in any of the three species richness measures used. Nonetheless, the contribution of single, anthropogenic variables on overall species richness was both significant and observable. It is important to remember that anthropogenic variables entered in combination, may contribute substantially more than individual variables. This analysis is, however, beyond the scope of the current paper.

Various studies have found a significant, albeit weak, relationship between human population size, human population growth, poverty, per capita income, urbanization and species per country (Ehrlich & Holden 1971; Kerr & Currie 1995; Cincotta *et al.* 2000). Balmford *et al.* (2001) reported a marked congruence of high species richness and human population density across the African continent. Chown *et al.* (2003) state that a strong significant relationship exists between South African birds and human population density ($R^2 = 0.67$) at a quarter-degree scale that is driven, in part, by available energy (Evans *et al.* 2006). Moreover, strong evidence supports remarkably strong correlations between plant richness and potential evapotranspiration, annual precipitation, as well as geographic variation in plant taxonomic richness (Rutherford & Westfall 1986; Currie & Paquin 1987; O'Brien *et al.* 1998, 2000; Van Rensburg *et al.* 2002). Yet none of the human predictors under consideration here had any such strong relationship with any of the richness variables, even though weak significant correlation was present.

The discrepancy between temporal scales of the data may have contributed to the weak relationships that were detected between richness and anthropogenic variables in this study. The time scale of the plant richness distribution data range from specimens collected in the early 1700s until the present time. Most collections occurred in and prior to 1970 with only 7% of all the specimen collections occurring since 1990 (PRECIS unpublished data). Furthermore, plant distribution data are rarely representative and accurate, and in most cases old and out of date (Rebelo 1992a, b; Freitag & Van Jaarsveld 1997; Maddock & Du Plessis 1999; Maddock & Samways 2000; Rouget *et al.* 2004). Conversely, the human and socio-economic variable data used in the current study generally date from 1994 to present.

Other than time scale differences in data collection, another major factor influencing statistical results and analysis could be the different spatial scales of the biotic and anthropogenic databases. Most of the anthropogenic data were measured at magisterial district scale and consequently were transformed by up- or down-scaling to QDS scale and converted to weighted averages. A QDS is often too large to reflect finer-scale topographical and vegetation differences and will most likely not reflect many of the finer interactions between human predictors and plant richness measures (Rebelo & Tansley 1993; Van Rensburg *et al.* 2004). However, this effect

TABLE 3.—Spearman Rank (*R* values) and *P* value, as well as Generalized Linear Model with Poisson error distribution and Log Link function (McCullagh & Nelder 1989) parameters for relationships between overall plant richness (OPR), endemic plant richness (EPR) and threatened plant richness (TPR) with each anthropogenic variable

	OPR Spearman *R* value	OPR Explained Deviance	*OPR Pearson* χ^2	EPR Spearman *R* value	EPR Explained Deviance	*EPR Pearson* χ^2	TPR Spearman *R* value	TPR Explained Deviance	*TPR Pearson* χ^2
HD	0.488**	6.67**	770999.68	0.040**	0.28 ns	525.64	0.145**	0.00 ns	5507.44
HC	0.421**	10.10**	733711.85	–0.063**	0.26 ns	525.66	0.195**	0.28 ns	5501.54
EP	–0.071**	3.40**	795575.84	–0.175**	10.50**	423.59	–0.217**	7.27*	5494.70
EA	–0.399**	0.93**	9814042.08	–0.120**	0.26 ns	526.04	–0.112**	0.05***	5438.64
LRU	0.264**	9.69**	743557.77	0.128**	0.31 ns	526.78	0.062**	0.00 ns	5537.99
LTD	0.343**	8.17**	746962.96	0.038ns	0.57 ns	522.37	0.142**	0.34 ns	5586.00

HD, human density; HC, human growth rate change; EP, economic poverty; EA, economic affluence; LRU, percentage land-cover under roads and/or urban; LTD, percentage land-cover transformed and degraded.
Statistical significance: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; ns, not statistically significant.

is unlikely to be substantial as the summarized statistics for each province, using the data rescaled to QDS (see Table 1), are remarkably similar to the results of the Development Bank of South Africa issued at provincial scale (DBSA 2000). Notwithstanding these temporal and spatial scaling issues, all the databases are still useful to investigate the presence of broader spatial scale relationships and trends, albeit if finer scale interactions may be weakened.

Finally, other more important causal mechanisms may dominate plant richness patterns, e.g. climatic variables, topographic variables and β–diversity (Bailey *et al.* 2002). Indeed, Evans *et al.* (2006) suggest that available energy may be driving the observed patterns in bird species richness and human population change.

Even though conservationists are urged to include human variables when setting conservation priorities, human population variables are imperfect indicators of risk to biodiversity (Thompson & Jones 1999; Cincotta *et al.* 2000). Indeed, the results of this study show that the strength of the relationships between human variables were weak, albeit significant, and the strength of the relationship did not improve when endemic or threatened taxa were used in the analyses instead of overall plant species richness (OPR).

Thompson & Jones (1999) found that human population density accounted for almost 35% of the variability in rare and threatened plant loss in a study conducted in Britain. Our study shows that human population density did explain a significant proportion of the variation in OPR but that its contribution to explained variation in endemic (EPR) or threatened (TPR) plant species richness was not significant. Therefore, although there is a strong link between the three richness measures used here, OPR appears to be the most suited richness surrogate when using the anthropogenic variables included in this study. Nonetheless, it remains important to consider how human impacts may affect endemic and threatened plant richness patterns. This study shows that the only suitable anthropogenic variable to use for EPR and TPR is economic poverty. This was the only anthropogenic measure to show a significant relationship with these richness measures. In addition, TPR data used here are based on preliminary 2003 data, which will be superseded by the Red List due in 2007 (Threatened Species Programme, SANBI). This will allow for more up-to-date richness data, as well as updated threat data and subsequent threat analysis. The results from the present study should be verified when the updated SANBI Red List becomes available.

Although clear evidence for different measures of human impact affecting plant extinction have been highlighted, it is difficult to assign a risk value to the impacts of these measures (Kerr & Currie 1995; Czech & Krausman 1997; Chertow 2001; Ceballos & Ehrlich 2002). Anthropogenic activities form a complex web of threats that is influenced by various socio-economic and political factors, e.g. national policies, economic conditions and a host of other factors varying among nations (Macdonald 1991; Kerr & Currie 1995; DBSA 2000; McKinney 2001; O'Neill *et al.* 2001; Liu *et al.* 2003). Testing certain human threat predictors (as used in the current study) should not be taken to mean that other anthropogenic variables are insignificant, as many additional human predictors are also extremely important at local scales (Macdonald 1991; Rouget *et al.* 2004).

For the current study, human population density (HD), land-cover that is transformed and degraded (LTD) and land-cover roads and urban areas (LRU), appear to be useful measures of anthropogenic impacts on OPR. The pooled strength of the relationship between these variables and OPR may not increase as HD is strongly correlated with LTD and LRU. LTD is, however, a more inclusive human impact measure than HD or LRU when conducting analyses of human impacts using OPR. The analyses show that slightly more variation in OPR is explained by this variable than for HD. Also, the effects of large human populations on urban expansion and road networks are included in HD and LRU. However, other forms of land transformation that occur in lower human density areas that may significantly affect species richness, such as, areas under agricultural or industrial use or plantations, are not included in HD and LRU. These impacts are included in LTD. Plant population decreases are concentrated in areas with high human densities or high human impact, such as agricultural areas (Burgess *et al.* 2002; Ceballos & Ehrlich 2002; Araújo 2003), also suggesting that the use of LTD may yield more information on human impacts than HD and LRU alone. It has been shown that human density is clearly a proximate threat, whereas agriculture, urbanization, land transformation, and roads are ultimate threats (Thompson & Jones 1999). Further analysis is required to ascertain whether other human measures are proximate or ultimate threats.

The differing anthropogenic threats should be assessed individually for each province prior to any risk assessment. Plant richness and endemism are not evenly distributed across South Africa, and most of these endemic taxa are confined to the predominantly winter rainfall Fynbos and Succulent Karoo Biomes (Cowling & Hilton-Taylor 1994; Figure 1A, B). Also, as shown here, anthropogenic variables vary substantially between provinces. For example, Gauteng is an important economic region in terms of business and industrial development, mining and agriculture, and is undergoing rapid expansion of urban areas, constituting the most serious threat to plant populations in this province (Phab & Victor 2002).

It is self-evident of the conservation movement today, that conservation targets are set by incorporating a wide variety of suitable data, ranging from taxa/species information, land types and habitat types (Pressey *et al.* 2003; Rouget *et al.* 2004). Using anthropogenic variables to improve conservation priority, setting procedures for plants is somewhat confounded by the low correlation between anthropogenic and richness variables found in the current study. Studies that do use anthropogenic variables as threat predictors for taxa should not be taken up haphazardly (Cincotta *et al.* 2000). To further assist in identifying South African plant taxa threatened by human activity, additional research is clearly required. Analysis of different human and socio-economic variables may well yield substantially different results. Undertaking a more detailed study on the effects of climate, water energy dynamics, and topography on various species richness measures (not only woody tree and shrub richness; see O'Brien *et al.* 1998), could perhaps provide insight into processes driving species distribution, and subsequently assist in identifying threats to these species. Furthermore, it would perhaps be more relevant to investigate human threats and its impact on broader units (e.g. vegetation type, habitat units) for which the QDS data is adequately suited. The analysis performed here provides insight into the relationships (or lack thereof) between human and socio-economic variables as used in the current study, and provides conservation planners with a better understanding of potential anthropogenic variables that could be regarded as threat proxies for plant taxa.

ACKNOWLEDGEMENTS

This work would not have been possible without the assistance of the Royal Norwegian Embassy (NORAD), via the Department of Environment Affairs and Tourism (DEAT). We would like to thank Statistics South Africa for data and the South African National Biodiversity Institute for use of data from the National Herbarium (PRE) Computerised Information System (PRECIS). H. Snyman, J. Victor, W. Foden and D. Pillay are thanked for their assistance with data acquisition and review of the manuscript. We thank the reviewers for comments on the earlier version of the manuscript.

REFERENCES

ARAÚJO, M.B. 2003. The coincidence of people and biodiversity in Europe. *Global Ecology and Biogeography* 12: 5–12.

BAILEY, S.-A., HAINES-YOUNG, R.H. & WATKINS, C. 2002. Species presence in fragmented landscapes: modelling of species requirements at the national level. *Biological Conservation* 108: 307–316.

BALMFORD, A., MOORE, J.L., BROOKS, T., BURGESS, N., HANSEN, L.A., WILLIAMS, P. & RAHBEK, C. 2001. Conservation conflicts across Africa. *Science* 291: 2626.

BROOKS, T. & THOMPSON, H.S. 2001. Current bird conservation issues in Africa. *AUK* 118: 575–582.

BURGESS, N.D., RAHBEK, C., LARSEN, F.W., WILLIAMS, P. & BALMFORD, A. 2002. How much of the vertebrate diversity of sub-Saharan Africa is catered for by recent conservation proposals? *Biological Conservation* 107: 327–339.

CEBALLOS, G. & EHRLICH, P.R. 2002. Mammal population losses and the extinction crisis. *Science* 296: 904–907.

CENTRAL STATISTICAL SERVICE. 1995. *Gross geographic product 1994*. Statistical release P0401. Central Statistical Service, Pretoria.

CENTRAL STATISTICAL SERVICE. 1998. *The people of South Africa. Population census, 1996*. Report No. 1: 03–01–11. Central Statistical Survey, Pretoria.

CHERTOW, M.R. 2001. The IPAT equations and its variants. Changing views of technology and environmental impact. *Journal of Applied Ecology* 4: 13–29.

CHOWN, S.L., VAN RENSBURG, B.J., GASTON, K.J., RODRIQUEZ, A.S.L. & VAN JAARSVELD, A.S. 2003. Energy, species richness, and human population size: conservation implications at a national scale. *Ecological Applications* 13: 1233–1241.

CINCOTTA, R.P., WISNEWSKI, J. & ENGELMAN, R. 2000. Human population in the biodiversity hotspots. *Nature* 404: 990–992.

COWLING, R.M. & HILTON-TAYLOR, C. 1994. Patterns of plant diversity and endemism in southern Africa: an overview. In B.J. Huntley, Botanical diversity in southern Africa. *Strelitzia* 1:31–52. National Botanical Institute, Pretoria.

CURRIE, D.J. & PAQUIN, V. 1987. Large-scale biogeographical patterns of species richness of trees. *Nature* 329: 326, 327.

CZECH, B. & KRAUSMAN, P.R. 1997. Distribution and causation of species endangerment in the United States. *Science* 277: 1116, 1117.

DEACON, H.J. 1992. *Human settlement*. In R.M. Cowling, *The ecology of fynbos. Nutrients, fire and diversity*. Oxford University Press, Oxford.

DEVELOPMENT BANK OF SOUTH AFRICA (DBSA). 2000. *South Africa: interprovincial comparative report*. Development Bank of South Africa, Halfway House, South Africa.

EHRLICH, P.R. & HOLDREN, J.P. 1971. Impact of population growth. *Science* 171: 1212–1217.

EVANS, K.L., VAN RENSBURG, B.J., GASTON, K.J. & CHOWN, S.L. 2006. People, species richness and human population growth. *Global Ecology and Biogeography* 15: 625–636.

FAIRBANKS, D.H.K. & THOMPSON, M.W. 1996. Assessing land-cover map accuracy for the South African land-cover database. *South African Journal of Science* 96: 34–42.

FAIRBANKS, D.H.K., THOMPSON, M.W., VINK, D.E., NEWBY, T.S., VAN DEN BERG, H.M. & EVERARD, D.A. 2000. The South African land-cover characteristics database: a synopsis of the landscape. *South African Journal of Science* 96: 69–82.

FJELDSÅ, J. 1997. The relevance of systematics in choosing priority areas for global conservation. *Environmental Conservation* 27: 67–75.

FREITAG, S. & VAN JAARSVELD, A.S. 1997. Relative occupancy, endemism, taxonomic distinctiveness and vulnerability: prioritizing regional conservation actions. *Biodiversity and Conservation* 6: 211–232.

GÄRDENFORS, U., HILTON-TAYLOR, C., MACE, G.M. & RODRÍGUEZ, J.P. 2001. The application of IUCN Red List criteria at regional levels. *Conservation Biology* 15: 1206–1212.

GERMISHUIZEN, G., MEYER, N.L., STEENKAMP, Y. & KEITH, M. (eds). 2006. *A checklist of South African plants*. Southern African Botanical Diversity Network Report No. 41. SABONET, Pretoria.

HANNAH, L., LOHSE, D., HUTCHINSON, C., CARR, J.H. & LANKERANI, A. 1994. A preliminary inventory of human disturbance of world ecosystems. *Ambio* 23: 246–250.

HARCOURT, A.H. & PARKS, S.A. 2003. Threatened primates experience high human densities: adding an index of threat to the IUCN Red List criteria. *Biological Conservation* 109: 137–149.

HARCOURT, A.H., PARKS, S.A. & WOODROFFE, R. 2001. Human density as an influence on species/area relationships: double jeopardy for small African reserves? *Biodiversity and Conservation* 10: 1011–1026.

HILTON-TAYLOR, C. 1996. Red Data List of southern African plants. *Strelitzia* 4. National Botanical Institute, Pretoria.

IUCN. 2001. *IUCN Red List Categories and Criteria: Version 3.1*. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK.

JAMES, V.U. 1994. Introduction: the significance of economic and environmental impact studies in African development. In V.U. James, *Environmental and economic dilemmas of developing countries: Africa in the twenty-first century*. Praeger, Westport, USA.

JETZ, W. & RAHBEK, C. 2002. Geographic range size and determinants of avian species richness. *Science* 297: 1548–1551.

KERR, J.T. & CURRIE, D.J. 1995. Effects of human activity on global extinction risk. *Conservation Biology* 9: 1528–1538.

LIU, J., DAILY, G.C., EHRLICH, P.R. & LUCK, G.W. 2003. Effects of household dynamics on resource consumption and biodiversity. *Nature* 421: 530–533.

LUCAS, G. & SYNGE, H. 1981. The assessment of conservation of threatened plants around the world. In H. Synge, *The biological aspects of rare plant conservation*. Wiley, London.

LUCK, G.W., RICKETTS, T.H., DAILY, G.C. & IMHOFF, M. 2003. Alleviating spatial conflict between people and biodiversity. *Proceedings of the National Academy of Sciences* 101: 182–186.

MACDONALD, I.A.W. 1991. Man's role in changing the face of southern Africa. In B.J. Huntley, *Biotic diversity in southern Africa: concepts and conservation*. Oxford University Press, Cape Town.

MADDOCK, A.H. & DU PLESSIS, M.A. 1999. Can species data only be appropriately used to conserve biodiversity. *Biodiversity and Conservation* 8: 603–615.

MADDOCK, A.H. & SAMWAYS, M.J. 2000. Planning biodiversity conservation based on the knowledge of biologists. *Biodiversity and Conservation* 9: 1153–1169.

MAGGINI, R., GUISAN, A. & CHERIX, D. 2002. A stratified approach for modelling the distribution of a threatened ant species in the Swiss National Park. *Biodiversity and Conservation* 11: 2117–2141.

MCCULLAGH, P. & NELDER, J.A. 1989. *Generalized Linear Models.* Chapman & Hall, London.

MCKINNEY, M.L. 2001. Role of human population size in raising bird and mammal threat among nations. *Animal Conservation* 4: 45–57.

NAIDOO, R. & ADAMOWICZ, W.L. 2001. Effects of economic prosperity on numbers of threatened species. *Conservation Biology* 15: 1021–1029.

NEKE, K.S. & DU PLESSIS, M.A. 2004. The threat of transformation: quantifying the vulnerability of grasslands in South Africa. *Conservation Biology* 18: 466–477.

O'BRIEN, E.M., FIELD, R. & WHITTAKER, R.J. 2000. Climatic gradients in woody plant (tree and shrub) diversity: water energy dynamics, residual variation, and topography. *Oikos* 89: 588–600.

O'BRIEN, E.M., WHITTAKER, R.J. & FIELD, R. 1998. Climate and woody plant diversity in southern Africa: relationships at species, genus and family levels. *Ecography* 21: 495–509.

O'NEILL, B.C., BALK, D., BRICKMAN, M. & EZRA, M. 2001. A guide to global population projections. *Demographic Research* 4: 204–288. www.demographic–research.org

PFAB, M.F. & VICTOR, J.E. 2002. Threatened plants of Gauteng, South Africa. *South African Journal of Botany* 68: 370–375.

PRESSEY, R.L., COWLING, R.M. & ROUGET, M. 2003. Formulating conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa. *Biological Conservation* 112: 99–127.

REBELO, A.G. 1992a. Preservation of biotic diversity. In R.M. Cowling, *The ecology of fynbos. Nutrients, fire and diversity.* Oxford University Press, Oxford.

REBELO, A.G. 1992b. Red data book species in the Cape floristic region: threats, priorities and target species. *Transactions of Royal Society of South Africa* 48: 55–86.

REBELO, A.G. & TANSLEY, S.A. 1993. Using rare plant species to identify priority conservation areas in the Cape Floristic Region: the need to standardize for total species richness. *South African Journal of Science* 89: 156–161.

REYERS, B. 2004. Incorporating anthropogenic threats into evaluations of regional biodiversity of conservation areas in the Limpopo Province, South Africa. *Biological Conservation* 118: 521–531.

REYERS, B., FAIRBANKS, D.H.K. & VAN JAARSVELD, A.S. 2001. Priority areas for the conservation of South African vegetation: a coarse-filter approach. *Diversity and Distributions* 7: 79–95.

RICHARDSON, D.M., VAN WILGEN, B.W., HIGGINS, S.I., TRINDER-SMITH, T.H., COWLING, R.M. & MCKELL, D.H. 1996. Current and future threats to plant biodiversity on the Cape Peninsula, South Africa. *Biodiversity and Conservation* 5: 607–647.

ROUGET, M., REYERS, B., JONAS, Z., DESMET, P., DRIVER, A., MAZE, K., EGOH, B. & COWLING, R.M. 2004. *South African National Spatial Biodiversity Assessment 2004: technical report, vol. 1: terrestrial component.* South African National Biodiversity Institute, Pretoria.

RUTHERFORD, M.C. & WESTFALL, R.H. 1986. Biomes of southern Africa—an objective categorization. *Memoirs of the Botanical Survey of South Africa* No. 54: 1–98.

SANTOS, T., TELLERÍA, J.L. & CARBONELL, R. 2002. Bird conservation in fragmented Mediterranean forests of Spain: effects of geographical location, habitat and landscape degradation. *Biological Conservation* 105: 113–125.

SISK, T.D., LAUNER, A.E., SWITSKY, K.R. & EHRLICH, P.R. 1994. Identifying extinction threats; global analyses of the distribution of biodiversity and the expansion of the human enterprise. *Bioscience* 44: 592–604.

STATISTICS SOUTH AFRICA. 2002. *Gross domestic product per region. Annual estimates 1995–2001.* Discussion paper. Statistics South Africa, Pretoria.

STATSOFT, INC. 2001. *STATISTICA* (data analysis software system), version 6.1. www.statsoft.com.

THEOBALD, D.M. 2003. Targeting conservation action through assessment of protection and ex-urban threats. *Conservation Biology* 17: 1624–1637.

THOMPSON, K. & JONES, A. 1999. Human population density and prediction of local plant extinction in Britain. *Conservation Biology* 13: 185–189.

TSCHARNTKE, T., STEFAN-DEWENTER, I., KRUESS, A. & THIES, C. 2002. Characteristics of insect populations on habitat fragments: a mini review. *Ecological Research* 17: 229–239.

UKPOLO, V. 1994. The link between poverty and environmental degradation on sub-Saharan Africa. In V.U. James, *Environmental and economic dilemmas of developing countries: Africa in the twenty-first century.* Praeger, Westport, USA.

UNITED NATIONS DEVELOPMENT PROGRAMME. 2001. *Human development report 2001. Making new technologies work for human development.* Oxford University Press, Oxford.

UNITED NATIONS DEVELOPMENT PROGRAMME SOUTH AFRICA. 2003. *South Africa human development report 2003. The challenge of sustainable development in South Africa: unlocking people's creativity.* Oxford University Press, Cape Town.

VAN RENSBURG, B.J., CHOWN, S.L. & GASTON, K.J. 2002. Species richness, environmental correlates, and spatial scale: a test using South African birds. *The American Naturalist* 159: 566–577.

VAN RENSBURG, B.J., KOLEFF, P., GASTON, K.J. & CHOWN, S.L. 2004. Spatial congruence of ecological transition at the regional scale in South Africa. *Journal of Biogeography* 31: 843–854.

WOOD, J., LOW, A.B., DONALDSON, J.S. & REBELO, A.G. 1994. Threats to plant diversity through urbanization and habitat fragmentation in the Cape Metropolitan Area, South Africa. In B.J. Huntley, Botanical diversity in southern Africa. *Srtelitzia* 1. National Botanical Institute, Pretoria.

WORLD RESOURCES INSTITUTE. 2000. *World resources 2000–2001: people and ecosystems: the fraying web of life.* World Resources Institute, Washington, D.C., USA.

ZAR, J.H. 1996. *Biostatistical analysis. Upper Saddle River.* Prentice-Hall, New Jersey.