BIODIVERSITY RISK ASSESSMENT OF SOUTH AFRICA's MUNICIPALITIES

Thesis presented in partial fulfilment of the requirements for the degree of Master of Science at the University of Stellenbosch

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously, in its entirety or in part, submitted it at any university for a degree.

Signature:…………………………......... **Date:……………………………….**

ABSTRACT

South Africa is one of the most biodiverse countries in the world and even with conservation initiatives in place continues to face biodiversity loss. There is a need to prioritise areas for conservation as resources for conservation purposes are limited in South Africa. From prioritisation methods reviewed it was found that prioritisation indices normally use one or a combination of variables that measure stock; and/or variables that measure threat. Rarely did priority indices include all measures of biodiversity stock, pressure, and conservation effort. One example where all three types of variables were included was in the National Biodiversity Risk Assessment Index (NABRAI) that measured biodiversity risk per country. The NABRAI was tested at a municipal scale to see whether it could be implemented to measure biodiversity risk of the municipalities of South Africa. It was found to be problematic and not as useful at the municipal scale and was amended to form the Municipal Biodiversity Risk Assessment Index (MuBRAI). Variables identified were grouped as pressure, stock and response measures and were reviewed and analysed for inclusion in the MuBRAI using non-parametric multivariate statistics. Results indicate that the City of Johannesburg Metro faced the largest pressures; Mtubatuba in KwaZulu-Natal contained the highest biodiversity stock and Witzenberg municipality in the Western Cape the most conservation responses of all 262 municipalities surveyed. Umdoni municipality in KwaZulu-Natal was identified as having the highest biodiversity risk in the country. The index and its components were assessed in order to better understand the drivers of municipal biodiversity risk. This index together with other prioritisation methods could be useful to decision makers in prioritising resources for conservation.

KEYWORDS: Biodiversity Risk Assessment, Municipality, South Africa, Prioritisation, Conservation

UITTREKSEL

Suid-Afrika is een van die mees biodiverse lande in die wêreld, maar selfs met bewarings-inisiatiewe in plek, staar dit steeds die risiko van biodiversiteits-verlies in die gesig. ‘n Behoefte bestaan vir prioritisering van areas vir bewarings-inisiatiewe as gevolg van beperkte hulpbronne. Uit prioritiseringsmetodes wat ondersoek is, is daar gevind dat deur te prioritiseer, indekse gewoonlik een of ‘n kombinasie van die veranderlikes wat toestand en waarde van biodiversiteit meet gebruik; en/of veranderlikes wat druk op biodiversiteit meet gebruik. Dit was ongewoon vir prioriteits-indekse om al drie aspekte van biodiversiteit naamlik toestand, druk en bewarings-inisiatiewe as maatstawwe saam te gebruik. Een voorbeeld waar al drie tipes veranderlikes ingesluit is, was in die National Biodiversity Risk Assessment Index (NABRAI) wat biodiversiteits-risiko per land gemeet het. Die NABRAI is getoets op munisipale vlak om te sien of dit geimplimenteer kon word om die biodiversiteits-risiko van die munisipaliteite van Suid-Afrika te meet. Daar is gevind dat dit nie so geskik is op die munisipale skaal nie en dit is toe aangepas om die Municipal Biodiversity Risk Assessment Index (MuBRAI) te vorm. Gepaste veranderlikes is geïdentifiseer, ondersoek en geanaliseer om in die MuBRAI indeks saamgevat te word deur gebruik te maak van nie-parametriese multivariate statistiek. Veranderlikes is soos volg gegroepeer: die wat druk op biodiversiteit meet (Pressure), die wat toestand en waarde van biodiversiteit meet (Stock) en die wat bewarings-inisiatiewe voorstel (Response). Resultate het gewys dat Johannesburg Metropolitaanse gebied die grootste biodiversiteit druk in die gesig staar; Mtubatuba in KwaZulu-Natal die hoogste biodiversiteit waarde het en dat Witzenberg munisipaliteit in die Wes-Kaap die meeste bewarings-inisiatiewe in plek het van al die 262 munisipaliteite ondersoek. Umdoni munisipaliteit in KwaZulu-Natal is geïdentifiseer met die grootste biodiversiteits risiko in die land. Die indeks en sy komponente is geassesseer om die drywers van munisipale biodiversiteits risiko beter te verstaan en kan, tesame met ander prioritiserings-metodes, waardevol wees vir besluitnemers in die prioritisering van hulpbronne vir bewaring.

SLEUTEL WOORDE: Biodiversiteit Risiko Assessering, Munisipaliteit, Suid Afrika, Priotirisering, Bewaring

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LIST OF ABBREVIATIONS

CSIR	Council for Scientific and Industrial Research
DEAT	Department of Environmental Affairs and Tourism
DMA	District Management Area
DWAF	Department of Water Affairs and Forestry
IUCN	The World Conservation Union
MA	Millennium Ecosystem Assessment
MuBRAI	Municipal Biodiversity Risk Assessment Index
NBI	National Botanical Institute
NABRAI	National Biodiversity Risk Assessment Index
NBSAP	National Biodiversity Strategy and Action Plan
NSBA	National Spatial Biodiversity Assessment
PCA	Principal Component Analysis
PR	Pressure
RE	Response
SANBI	South African National Biodiversity Institute
ST	Stock
UNEP	United Nations Environmental Programme
WCMC	World Conservation Monitoring Centre

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1. INTRODUCTION

1.1. BIOLOGICAL DIVERSITY AND ITS IMPORTANCE

There are three broad viewpoints on how the term biodiversity is perceived. It is used either as a concept, a measurable entity or as a political or social construct (Gaston 1996). As a concept, the Convention on Biological Diversity definition states: "biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (UNEP 1992). Conceptual definitions mainly describe biodiversity as 'the variety of life' (Gaston 1996) and include the components of genes, species, populations, assemblages and ecosystems. Most definitions also acknowledge the three attributes of biodiversity called composition (the identity and variety of the biotic components), structure (physical organization of biodiversity elements) and function (processes of biodiversity) (Noss 1990).

It must be stressed that biodiversity is a multi-dimensional concept which cannot be quantified with a single value (Purvis and Hector 2000), yet the mistake is often made. Species richness, rarity, taxonomic uniqueness, threatened species and indicator taxa are often separately used as ultimate stand alone measures of biodiversity (Prendergast *et al.* 1993; Faith and Walker 1996), when in fact each of them is simply one measure of biodiversity (Gaston 1996). When measuring biodiversity it must be clearly stated that the quantifiable aspects of it serve only as surrogates for biodiversity as a whole.

Biodiversity has also become a popular word in public and political circles where "the term 'Biodiversity' itself is seen to embody concepts not only of the variety of life, but additionally of the importance of that variety, of the crisis represented by its loss, and of the need for conservation action" (Gaston 1996, pp. 5). Here, biodiversity is not just a scientific concept, but is perceived as having direct and indirect value. Biodiversity supports many lives and livelihoods and has direct value through consumptive use by providing products for industry and agriculture such as food, medicine and grazing. Indirect values include tourism, educational, social, aesthetic, intrinsic, spiritual and bequest value for future generations (Convention on Biological Diversity 1992; Grimble and Laidlaw 2002; Gaston and Spicer 1998).

One of the least acknowledged, but most important functions, of biodiversity is that it provides ecosystem services. These include provisioning services (e.g. food, water), regulating services (e.g. climate stability, regulating floods and drought), supporting services (e.g. facilitating carbon sequestration, nutrient cycling, soil formation) and other non-material benefits mentioned such as recreational value (Chapin III *et al.* 2000; MA 2003). Biodiversity is also the basis for evolution and adaptation to changing environments, making it essential for survival of life.

1.2. CONDITION OF BIODIVERSITY

South Africa, due to its size and great range of topography and climates, hosts a variety of habitats resulting in this country's rich biodiversity. Excluding migratory species and alien species, southern Africa has 20 300 vascular plant species, 370 amphibian and reptilian species, 220 freshwater fish species, 80 000 known insect species, 800 avian species and 243 mammalian species that have indigenous breeding populations (Siegfried 1989). Therefore, it is no wonder that South Africa is ranked as one of the most biologically diverse countries in the world (WCMC 1992). It is also one of the twelve most mega diverse countries (Mittermeier *et al.* 1997), which altogether contain approximately two thirds of global biodiversity (WCMC 1992). It is the only country in the world that encompasses an entire floristic kingdom (Younge and Fowkes 2003). South Africa also has three internationally recognised biodiversity hotspots, areas with high species richness, species diversity and endemism, namely the Cape Floristic Region, the Succulent Karoo and Maputaland-Pondoland-Albany Thicket (Myers *et al.* 2000; Mittermeier *et al.* 2005).

South Africa has a moderate population size with an above average human population growth rate of 2.2% per year (calculated from 1996 and 2001 demographic data by Van Rensburg *et al.* (2004)) in relation to the world average of 1.3% per year, and developing countries' growth rate of 1.6% per year (Cincotta *et al.* 2000). Human population density and growth rate (change in population density) are important drivers of biodiversity loss and degradation (Holdren and Ehrlich 1947; Thompson and Jones 1999; Cincotta *et al.* 2000; UCS 2000; Veech 2003; Liu *et al.* 2003).

They can result in over-exploitation of natural resources (Hoffman *et al.* 1999), habitat degradation, natural habitat conversion to agriculture and urban areas (Sala *et al.* 2000; Ricketts and Imhoff 2003) and habitat fragmentation (Sponsel 2001) which all threaten species' population viability (Van Rensburg *et al.* 2004). Human activities also contribute severely to the introduction of alien invasive species (Hoffman *et al.* 1999; Pimm *et al.* 1995), pollution (Sponsel 2001) and recently also to climate changes (IPCC 2001). In addition high levels of poverty and a large disparity between rich and poor, all place pressure on biodiversity.

Extinction is a natural process, but is currently occurring at a rapid rate due to human impacts (Chapin III *et al.* 1998; Chapin III *et al.* 2000). The current global rate of extinction is 100 to 1000 times higher than it was before man existed, and it is still rising (Pimm *et al.* 1995). With 1406 Red Data Book plant species, South Africa has the highest known concentration of threatened plant taxa in the world, of which 98% are endemic (Cowling and Hilton-Taylor 1994). The IUCN Red Data lists for birds, mammals, reptiles and amphibians and freshwater fish have to be updated regularly due to increasing threatened species and improvement of information on these species in South Africa (Friedman and Daly 2004).

The seven major biomes that cover South Africa are Fynbos, Forest, Thicket, Grassland, Savanna and Karoo (Low and Rebelo 1996) and are all under anthropogenic pressure. Fynbos occurs mostly in the Western Cape and covers about 6 percent of South Africa (70 000km^2). Its floristic and invertebrate diversity is particularly high (Hilton-Taylor and Le Roux 1989), but is unfortunately under high pressure from urbanisation, industrialisation and agriculture (Rouget *et al.* 2003a). Less than 10% of the original extent of natural Renosterveld, which is part of the Fynbos biome, remains (Von Hase *et al.* 2003). These patches are highly fragmented mainly due to agriculture (Kemper *et al.* 1999). South-coast Renosterveld, once rich in geophyte endemics, is now severely impacted by cereal crop fields and planted pastures (Hilton-Taylor and Le Roux 1989, Von Hase *et al.* 2003). Due to frequent disturbances of Coastal Fynbos associated with wetter areas, it is also severely threatened especially by rapid invasion of alien vegetation species. Limestone Fynbos is highly specialised and contains many threatened species, which are not only threatened by the rampant spread of alien vegetation, but also threatened by commercial flower pickers (Hilton-Taylor and Le Roux 1989).

The Karoo is subdivided into the Nama-Karoo and Succulent Karoo regions. The Succulent Karoo hotspot (Myers *et al.* 2000) is a truly unique landscape with high species diversity with many geophytes and annual plants. It is well-known for the plant families *Mesembryanthemaceae* and *Crassulaceae*. The biggest threats that the Karoo systems face are overgrazing, mining, invasive alien plants, succulent plant collectors and some urbanization threats (Hilton-Taylor and Le Roux 1989).

Forests, mostly found around the southern and eastern coast of South Africa, offer direct and indirect services and goods to people including timber, furniture, fuel, medicines, recreation and hunting sites. Threats to forest ecosystems are destruction of habitat through over-exploitation, forest clearing for agriculture and forestry, subsistence utilization and burning practices for grazing (Geldenhuys and MacDevette 1989; WWF 2001).

The Grassland biome is the second largest biome in South Africa (Low and Rebelo 1996) and has exceptionally high biodiversity value with high levels of endemism (Le Roux 2002). High numbers of threatened and rare species occur within this biome for which very little scientific information is currently available. The Grassland biome was identified as critically endangered by the WWF in 1998 (Olsen and Dinnerstein 1998).

The biome is also a very important economic region. More than 60 percent of this biome has already been transformed (Fairbanks *et al.* 2000). Transformation is mostly due to growing monocultures, afforestation, mining, degradation from overgrazing, invasive vegetation, collecting medicinal plants and fragmentation (Neke and Du Plessis 2000). According to the 1996 National Land Cover database (Fairbanks and Thompson 1996), 6.6% of the biome has been degraded, but the true extent is probably higher. Reasons for this are firstly, because it is difficult to detect grassland degradation from satellite imagery used by Fairbanks and Thompson (1996), and secondly, the image was taken ten years ago and land use changes would have taken place since then. It is therefore clear that the grassland is a productive landscape that urgently needs more conservation attention. Conservation efforts in the grassland biome are regarded as extremely poor as only 1.6% of the biome is formally protected (Low and Rebelo 1996; Neke and Du Plessis 2000).

The Thicket biome has only recently been classified as a separate biome and is adequately described as intermediate between the Forest and Savanna biomes (Low and Rebelo 1996). The two main Thicket vegetation types are called Dune Thicket and Mainland Thicket. The biome is species rich with approximately twenty percent of its plant species endemic to the biome. These include endemic succulents like *Mesembryanthemeceae, Euphorbiaceae* and *Crassulaceae* as well as a number of bulb groups (Vlok and Euston-Brown 2002).

Currently it is obvious that biodiversity pattern and process of the Thicket biome are not adequately conserved as only 7% of this biome is protected in formal protected areas (Lombard *et al.* 2003). This percentage excludes the additional sections recently added to the Addo Elephant National Park to form the Greater Addo Elephant National Park. The Park has been undergoing expansion since 2000. It is envisaged to expand the park to 240 000 ha, adding a further 120 000 ha of marine protected area to the park making it the fourth largest national park in South Africa.

Transformation and degradation of the thicket biome are mainly caused by urban development, especially along the coast, and the construction of rural settlements, crop cultivation and herbivory of livestock, earlier kaoline mining, commercial plantations and invasive alien vegetation species (Lloyd et al 2002). The severities of these impacts differ between the various thicket vegetation types. The Mesic Thicket is particularly threatened by cultivation and the coastal dune system by excessive hot fires. Harvesting of medicinal plant species for medicine and hardwood species for wood-fuel also add to the pressures exerted on the Thicket biome. Mainland Montane Solid Thicket has the highest proportion of pristine thicket remaining (Lloyd *et al.* 2002).

The Savanna biome is the largest biome in South Africa and makes up one third of the country (Low and Rebelo 1996). A grass ground layer and a distinct upper layer of woody plants typify Savanna. Tourism and big game hunting are some of the main economic activities of the area. Environmental concerns with Savannas include unsound fire management, crop cultivation, overgrazing by livesock and poaching. Because of the hot and moist climate, and diseases associated with these areas, urbanisation is not seen as a threat to biodiversity. While the Savanna biome is well protected within large reserves like Kruger and Kalahari Gemsbok National Parks, there is concern that individual Savanna vegetation types are not adequately conserved (Hoffman *et al.* 1999).

1.3. CONSERVATON EFFORTS AND THE NEED FOR PRIORITISATION

Increasing pressures on the natural environment by the human population make conservation areas crucial for the persistence of biological diversity (Wilson *et al.* 2005). To maintain biodiversity, organisms ideally should be managed in their natural state within their existing ranges in areas managed for conservation. A conservation area is defined by Wilson (2005, pp. 99) as "any area of land or sea managed for the persistence of biodiversity and natural processes *in situ*, through constraints on incompatible land uses". An effective conservation area should thus represent biodiversity at all levels of organisation, ensure persistence of species by maintaining viable populations, and act as buffers against possible threats, especially anthropogenic threats (Margules and Pressey 2000).

Not all conservation areas in South Africa reflect these characteristics. In the past, conservation areas were not chosen explicitly for their ecological importance (Rebelo and Siegfried 1992), but rather by public sentiment and for political gain (DeNormandie and Edwards in review). Because reserves have been chosen on an *ad hoc* (Rebelo 1997), rather than a scientific basis, they usually have low commercial value and low primary productivity and accessibility (Pressey *et al.* 1993, Rouget *et al.* 2003b, Wilson *et al.* 2005). They thus do not always sustain biodiversity to the fullest. A good example of this is the established reserves for the protection of the Cape Floristic Region of South Africa, which do not explicitly or specifically protect the species of the region any better than randomly chosen areas in the vicinity would have (Pressey *et al.* 1993). South Africa has limited conservation efforts in place on a national scale apart from its protected areas. The country has a network of almost 582 national parks and nature reserves which only formally protect 5.85% of its land surface (Reyers *et al.* 2001). This percentage is far below the suggested 10% by IUCN standards (WCMC 1996).

Other conservation initiatives in place are bioregional programmes. These are "generic" responses that initiate conservation in bioregions without having a physical presence or value (DEA&DP 2003). These biome-wide biodiversity initiatives coordinate projects regarding biodiversity conservation and the sustainable use thereof. They also promote economic development, community involvement and poverty alleviation through the establishment of partnerships between governmental and non-governmental organisations, civil society and the private sector (Driver *et al.* 2005). Three programmes already being implemented are the Cape Action Plan for the People and the Environment (CAPE), Succulent Karoo Ecosystem Plan (SKEP) and the Subtropical Thicket Ecosystem Plan (STEP). These initiatives has proven to be very successful in their conservation efforts and attracted national and international funding to kick-start many important conservation and research projects within their biomes (Cowling *et al.* 2003; Driver *et al.* 2003). Because of their successes similar bioregional programmes are being planned for the Wild Coast and the Grassland biome (NBSAP 2005).

Since 1994 (post-apartheid), environmental issues have received significant attention in new national legislation of South Africa. Important pieces of legislation such as the National Environmental Management Act (Act No. 107 of 1998) and the National Environmental Management: Biodiversity Act (Act No. 10 of 2004) were formulated. South Africa is also signatory to various international conventions such as the Convention on Biological Diversity and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). But even with all these mentioned national conservation efforts in place, South Africa is still experiencing biodiversity loss (Wynberg 2002). Contributing factors include the lack of implementation of new policies and laws, the lack of communication between scientists and policy makers and lack of properly documented biodiversity loss data (Convention on Biological Diversity 1992). Efforts which include better land use practises, increased environmental education and awareness and better implementation of sustainable development paradigms are especially poorly implemented in South Africa. There is a great need to expand and implement alternative conservation measures in addition to creating more reserves in South Africa. Because reserves are in direct competition with more destructive land uses like agriculture and mining and are costly to maintain (Pressey *et al.* 1993), more attention will have to be given to alternative conservation efforts in the future. Socio-economic drivers of biodiversity loss, such as unsustainable consumption, should also figure into conservation responses (Convention on Biological Diversity 1992).

Ideally, biodiversity and its components should be managed within natural boundaries, but instead management follows political boundaries in South Africa. It is therefore often difficult to protect specific biodiversity areas in real need of protection because they often overlap with political boundaries, this complicates the logistics of conservation and the management thereof (Rodrigues and Gaston 2002). Currently in South Africa, apart from formally protected areas and non-governmental conservation efforts, each municipality in South Africa has to manage its "own" biodiversity. Although not ideal, at least some unit for managing the environment has been set. This notion is strengthened by the Constitution and the National Environmental Management Act (NEMA) (Act No. 107 of 1998) which both contain important clauses relevant to the environment which obligate all spheres of government, including municipalities, to manage biodiversity sustainably. Environmental legislation also determines the norms and standards for provincial and municipal environmental conservation plans. A National Spatial Development Perspective (NSDP) (The Presidency 2003) which guides investments in infrastructure and development spending is also in place (Driver *et al.* 2005). This includes the new process of Integrated Development Planning (IDP) for local municipalities, which forces municipalities to conduct environmentally conscious planning by producing Spatial Development Frameworks (SDF) which promote sustainable development. Within this framework the municipal level is seen as an important planning and implementation scale for politicians and decision makers to work with, in terms of biodiversity. As a result of all this legislation and the responsibility of municipalities, it would be very useful to evaluate the biodiversity state of South Africa at the local government scale to assist better decision making.

1.4. PRIORITISING CONSERVATION EFFORTS

The prioritisation of conservation efforts is not new. Scoring systems have been developed since the 1980s to provide a rational basis for prioritising certain areas for conservation purposes (Wilson *et al.* 2005). Indices or scoring systems do have weaknesses, but the summarised information they provide on the condition of biodiversity is helpful for conservationists and decision makers alike. Scoring systems often differ in approach and variables used, but their common aim is to rate areas according to a certain conservation value.

Various indices that measure biodiversity risk at a global scale have been developed through the years. Of the indices that were reviewed, the variables used to prioritise areas for conservation effort can be grouped into the three broad categories of pressure, stock and response (Reyers *et al.* 1998). Apart from including variables from these categories, McNeely (1996) also highlighted the importance of including economic value in biodiversity risk assessments, but since this information is not readily available it is not often incorporated into risk indices.

Pressure variables measure threats to biodiversity; anything that might deplete stocks, such as increased human population density, landscape transformation, degradation and habitat fragmentation. Stock variables give some indication of biological richness, endemism and extent of pristine habitat, the genes, species and ecosystems of an area. Response variables measure effort put into biodiversity conservation and the sustainable use of natural resources. Rarely have all three types of variables been used in a single index, but one example of such an index is the global biodiversity prioritising method, the National Biodiversity Risk Assessment Index (NABRAI) (Reyers *et al.* 1998; Reyers and James 1999). This index ranked countries according to the biodiversity risk experienced. Pressure variables used in this index were threatened species richness, human population density and high disturbance intensity (Reyers *et al.* 1998). Stock variables used were species density, percentage endemic species, and a measure of low disturbance intensity. Responses per country were measured with conservation budget, amount of protected land, genetic resource collections, reference collections and biodiversity conventions (Reyers *et al.* 1998).

Although preferred, prioritisation methods do not have to include variables representing pressure, stock and response to be successful. The Megadiversity plan (Mittermeier 1988) used species richness and endemism to identify priority conservation areas. The World Conservation Monitoring Centre (1994) developed a National Biodiversity Index that ranked each country according to its total species richness. The Biodiversity Hotspot method (Myers 1988, Myers 1990) considered both stock and pressure variables to identify the top 25 biodiversity hot spots in the world. Sisk *et al.* (1994) used biodiversity stock and pressure variables to identify critical areas of concern. Dinnerstein and Wikramanayake (1993) used remaining habitats together with protection status to set conservation priorities. The International Council for Bird Preservation (1992) concentrated on the endemism of bird species using pressure, stock and response variables. A small scale assessment of biodiversity of the Cape Floristic Region of South Africa used cultivation, urbanization and alien invasive vegetation (Rouget *et al.* 2003a) to prioritise conservation efforts.

It was found that many prioritisation methods used population density (Reyers *et al.* 1998; Cincotta *et al.* 2000; Veech 2003) and rate of population change (Cincotta *et al.* 2000; Veech 2003) as pressure indicators. Yet, using only population density change as a biodiversity risk indicator could obscure spatial distributions of growth and other trends in the data (Cincotta *et al.* 2000). For example: a small increase in a dense population would add more people to the area than a large increase would in a sparsely populated area. A similar problem exists with population density as an indicator as it often masks trends in population distribution within certain areas (Cincotta *et al.* 2000). People cannot survive just on resources in their immediate environment, especially in an urban situation. Their ecological footprints (impact) are thus often far reaching (Cilliers *et al.* 2004). In the Succulent Karoo population density also does not accurately describe the pressures on biodiversity. This arid area on the western coast of South Africa, has a very low human population density, but has heavy grazing and over harvesting of its unique flora (Cincotta *et al.* 2000). A trend like this thus cannot be sufficiently represented by population density alone.

Population density and population density change could also mask the impacts of affluence or poverty (Cincotta *et al.* 2000). South Africa is a middle income country with high poverty levels and great affluence discrepancies through income inequality (Statistics South Africa 2000). Different studies have shown that for developing countries both extremes, the very wealthy and the very poor, heavily impact biodiversity (Athanasiou 1996; World Bank 2002). Wealthy people impact on the environment through their extensive ecological footprints (Lenzen and Murray 2003). They consume greater amounts of resources like energy and water and they exploit land for personal gain through commercial farming and industries (Athanasiou 1996). Due to lack of resources poor people mostly impact on the environment through their struggle for survival by overexploitation of already fragile natural resources for food, medicinal plants, wood, building materials and overgrazing and cultivating on marginal land (World Bank 2002; Steiner 2004). Therefore indicators of poverty and affluence would be useful measures of biodiversity pressure in addition to the already mentioned demographic variables.

Degradation and transformation are both pressure measures commonly found in most risk indices (Rouget *et al.* 2003a). They provide information on the physical condition of an area resulting from social, economic, and political reasons rather than biophysical reasons (Geach and Peart 1998). The most degraded areas within South Africa occur along the steeply sloping eastern escarpment in the former Transkei, Ciskei and KwaZulu-Natal (Hoffman *et al.* 1999). Parts of the Limpopo Province, Northwest Province and Nothern Cape are also severely degraded (Hofmann *et al.* 1998). All ecosystems have been modified or transformed in some way through human activities like overstocking, cultivation, afforestation and urbanization. Overgrazing is seen as the largest threat in Maputuland, Pondoland and the Succulent Karoo (Cowling and Hilton-Taylor 1994). Transformation and degradation also drive the extinction rate of many species and ecosystems. Threatened species (Master 1999; Flather *et al.* 1998) and ecosystems (Beissinger *et al.* 1996) often act as a pressure measure of biodiversity. It would thus be valuable to include such indicators discussed in the proposed biodiversity risk assessment index for South Africa to provide a more holistic analysis of the human related pressures on biodiversity.

Measures of stock in the literature commonly include species richness (Myers 1990), endemism and rarity (Balmford and Long 1994) as surrogates to describe biodiversity (Reyers *et al.* 1998). Although they are reasonably accurate it must always be kept in mind that they are only measuring certain aspects of biodiversity and cannot truly reflect overall complexity of biodiversity. The same applies for this study; measures of stock used in this study represent only specific aspects of biodiversity.

1.5. RATIONALE

Biodiversity has received a lot of attention during the last decade with many studies focussing on increased rates of biodiversity loss (Cincotta *et al.* 2000; Myers *et al.* 2000; Pimm and Raven 2000). South Africa experiences moderate, but increased pressure on its biodiversity, especially anthropogenic pressure. There are limited responses in place for preserving biodiversity and implementation remains a problem. Lack of money and appropriately trained staff are the main contributors to poor implementation and coordination of conservation efforts (Wynberg 2002) and is also true for the municipal scale. There is a great need to target conservation efforts to areas where it is most needed. As South African environmental policies obligate all spheres of government to manage, research and conserve biodiversity and promote its sustainable use, the municipal level provides an appropriate scale of analysis. Target or priority municipalities for conservation effort should therefore have high biodiversity value, be exposed to high levels of threats and have few responses in place. The National Spatial Biodiversity Assessment (Driver *et al.* 2005) has started the process of identifying large priority areas for biodiversity conservation in South Africa, but has not scaled down its findings to managerial units such as municipalities. It uses measures of stock and only some measures of pressure and response. Socio-economic factors are not included, even though recently the effects thereof on biodiversity are being realised (MA 2005).

From all the different indices and prioritisation methods reviewed, it was decided to test, and if necessary, amend the NABRAI (Reyers *et al.* 1998; Reyers and James 1999) prioritisation method to create an index for South Africa that could assist in prioritising resource allocation at the municipal scale. The NABRAI was selected because it is simplistic, flexible and easy to understand by both the implementer and interpreter. Another strong point and appeal to the index is that it uses measures of pressures, stocks as well as responses to assess biodiversity risk.

It was realised that even if it was possible to apply the NABRAI on a sub-national scale, not all the variables that are available at the national level will be available on the sub-national level, therefore alternative variables will have to be identified. This resulted in a thorough review of what variables for each category of pressure, stock and response are commonly used in such indices and which of those variables are available for South Africa on a municipal scale.

Recently information on species richness, endemism and red data book species, as well as information on the formally protected areas of South Africa, became available (Driver *et al.* 2005). Therefore this information, together with other biophysical and socio-economic datasets available for the country could be utilised and applied in biodiversity conservation planning for South Africa.

1.6. AIMS AND OBJECTIVES

The two main objectives of this project were firstly to explore the use of relevant, robust variables to represent the pressures, stocks and responses of biodiversity and secondly to construct an index that will assess biodiversity risk for each municipality of South Africa.

The first part of the study was the most time consuming as the appropriate variables had to be identified. The following had to be undertaken:

- Compiling of spatial information from different sources that could possibly represent aspects of biodiversity risk at the municipal scale of South Africa (both biophysical and socio-economic variables);
- Reviewing information for appropriateness to be included in a model of biodiversity risk;

- To be able to review information, perform literature reviews and where necessary interview experts;
- Identify gaps in the datasets;
- Identify and evaluate trends and relationships between variables;
- Using statistical analyses, select the most appropriate variables to represent the different aspects of biodiversity risk; and
- Categorise the selected variables into pressure, stock and response variables, where pressure variables also represent anthropogenic threats; a quality not often included in other indices.

In the second part of the study the aim was to construct a biodiversity risk assessment index for South Africa's municipalities using the variables identified in the first part of the study. The following steps had to be undertaken:

- Explore different indices and prioritisation methods, at national and sub-national scales, to identify a technique that can be implemented at the South African municipal scale to assess biodiversity risk;
- If such an index does not exist, amend an existing one to make it applicable at the municipal scale, in this case the National Biodiversity Risk Assessment Index (NABRAI) (Reyers et al. 1998; Reyers and James 1999);
- Develop a surface from where municipal biodiversity risk of South Africa can be assessed;
- Identify priority municipalities that are under the highest biodiversity risk; in other words, those that contain high numbers of stock, are under large pressures and have little or no conservation responses in place.

The outcome of this biodiversity risk assessment would be to evaluate whether this index would successfully represent biodiversity risk at the local level and whether it would be useful in assisting other prioritising methods to identify areas at high risk of imminent biodiversity loss.

2. MATERIALS AND METHODS

2.1. STUDY AREA

South Africa’s human population lives on a total surface area of some 1 220 000km^2. During the 2001 Census the population was recorded as 44.8 million people (Statistics South Africa 2004a) and currently the population is estimated at approximately 46.6 million (Statistics South Africa 2004b). The country is divided in a complex geographic structure consisting of different paths of hierarchical levels (Figure 1).

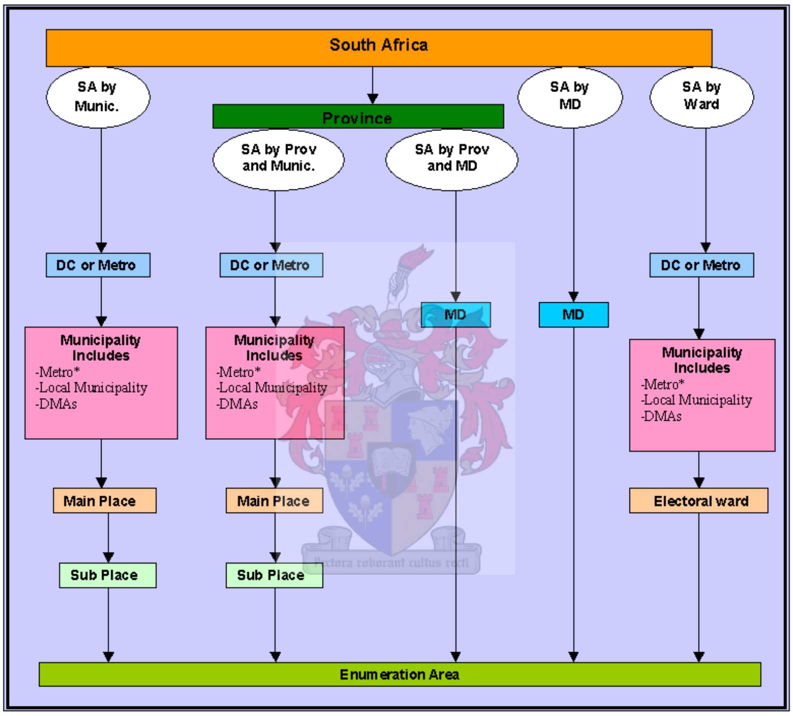

Figure 1. A flow diagram of the official hierarchical structure of South Africa (Statistics South Africa 2001).

The seven basic hierarchical geographic levels of South Africa are Level 1 South Africa; Level 2 Province; Level 3 Metropolitan Area (Category A) or District Council (Category C); Level 4 Local Municipality (Category B) or District Management Area (DMA); Level 5 Main Place; Level 6 Sub-place; and Level 7 Enumeration Area (EA).

Not all of these hierarchical levels are as familiar as the provincial level; Metropolitan Areas are areas with high human population density, intense movement of people, goods and services, and contain various business districts and industrial areas.

The six Metropolitan Areas identified for South Africa are City of Cape Town, Durban (Ethekwini), East Rand (Ekurhuleni), City of Johannesburg, Port Elizabeth (Nelson Mandela Metropolitan Area) and Pretoria (City of Tshwane). District Management Areas (DMAs) include areas such as desert and semi-arid areas, formally protected and other conservation areas, and special economic areas. Main place refers to a small-area geographic entity at a local level and corresponds to the name of a city, town, or tribal area. The sub-place name corresponds to a specific name of a suburb, ward, village, farm or informal settlement. There are 15 966 unique sub-places in South Africa. Enumeration areas (EA) are classified according to a set of criteria profiling land use and human settlement within an area. Every enumeration area is assigned to a magisterial district (MD) which is an administrative area created to serve the justice system through a network of 354 magisterial offices (Statistics South Africa 2004c).

According to the formal classification, the six Metropolitan Areas and 47 District Councils (also known as District Municipalities) are on the same hierarchical level (Figure 1). At a lower level, District Councils (Category C) are sub-divided into 231 Local Municipalities and 25 District Management Areas (DMAs) (Statistics South Africa 2004c). Out of these DMAs four are positioned across provincial boundaries. Of the 231 local municipalities (Category B) eight municipalities lie across provincial boundary lines. While the geographic structure of South Africa is intended to be hierarchical, cross-boundary entities at all seven levels occurs which complicates analyses. Demarcation also differs between Censuses done in 1996 and in 2001, which further complicates analyses when comparing the data.

Out of all seven hierarchical levels mentioned above it was decided that this study would be conducted at the municipal level. Important information was available at a provincial level, but the unit was too broad to assess biodiversity risk without losing the integrity of the data. The lack of adequate data at smaller hierarchal levels, like main place and sub place, eliminated these geographic levels as possible study units.

This study was thus done at a municipal level according to the new municipal boundaries of 2000 ignoring provincial boundaries thus excluding cross-boundary effects. All 262 municipalities of South Africa were included for analyses (Six Metropolitan areas, 231 local municipalities and 25 DMAs).

2.2. DATA

2.2.1. Data Sources

This desktop exercise used existing data to determine which variables would be suitable in a biodiversity risk assessment for South Africa. Not many recent datasets on the biophysical, social and economic aspects of South Africa were available at a municipal scale for the entire country for the same time period. As a result, data collected from different years ranging from 1980 – 2004 had to be used for the purpose of this study. Table 1 summarises the data used. Working with data collected in different years was not ideal especially when evaluating relationships between variables. But it was ensured that all the data collected for one variable were from the same year for all municipalities. However, results should still be interpreted conservatively. Datasets were also not all collected for the same units varying from quarter degree grid cells to municipalities. Care was also taken to preserve the integrity of the data by using weighted averages (e.g. adding the proportions of quarter degree grid squares (QDS) within each municipality when the boundaries of the QDS map and municipal borders map did not match) and maintaining the scale and resolution of base data. Data were always scaled up to municipality level and never down from provincial or national level.

Table 1. Description of the possible variables available in each category of Pressure, Stock and Response.

Variables	Description	Original Data Unit	Source
Pressure Variables			
Population Density Change	The change in the total population density from the year 1996 to 2001 expressed per square kilometre (km^2).	Headcounts	Census 1996 2001
Population Density	The number of people per square kilometre.	Headcounts	Census 2001
Wealthy Households	Percentage of the total number of households in the last two income categories (R1 228 801-R2 457 600 and R2 457 601 and more p.a.).	Household counts	Census 2001
Poor Households	Percentage of the total number of households in the first two income categories (No income and R1-R4 800 p.a.).	Household counts	Census 2001
Degraded Land	Percentage of total municipal area that is degraded.	1:250 000	National Land Cover Data 1996
Transformed Land	Percentage of total municipal area transformed by cultivation, forest plantations, urban and industrial areas, mining and quarries.	1:250 000	National Land Cover Data 1996
Threatened Species Density (Red Data Book)	Number of bird, butterfly, frog, scarabaeoid beetles, scorpions and mammals per QDS regarded as threatened, expressed as a weighted density per km^2.	Quarter degree grid squares (QDS)	NSBA 1980-2003
Stock Variables			
Species Density	Total number of bird, butterfly, frog, scarabaeoid beetles, scorpions and mammals per QDS, expressed as a weighted density per km^2.	QDS	NSBA 1980-2003
Endemic Species Density	Number of bird, butterflies, scarabaeoid beetles and mammals per QDS regarded as endemic, expressed as a weighted density per km^2.	QDS	NSBA 1980-2003
Vegetation Type Richness	Number of different vegetation types per km^2 in each municipality.	1: 250 000	Vegetation Map Beta 4 Version. SANBI 2004
Response Variables			
Protected Areas (Type 1)	Percentage of total municipal area under formal protection (National. provincial and municipal reserves).	> 1:250 000	NSBA 1980-2003
Protected Areas (Type 2)	Percentage of total municipal area part of private conservation areas, wildlife management areas, private nature reserves, national heritage sites, SANDF property, state land, bird sanctuaries, game sanctuaries, mountain catchment areas, DWAF forest areas or coastal reserves.	> 1:250 000	NSBA 1980-2003
Bioregional Plans (CAPE, SKEP, STEP)	Percentage of the total municipal area that is part of the bioregional plans CAPE SKEP and/or STEP.	1:250 000	CPU 2000, 2002a, 2002b

The 2001 Census data (Statistics South Africa 2003) on the demographic, social and economic characteristics of the population were included in this study because the data are reliable and useful in describing the socio-economic impact on biodiversity at the local municipal scale. Datasets included from the National Spatial Biodiversity Assessment (Rouget *et al.* 2004), addressed land use (National Land Cover data) and species distribution. Other datasets included for analyses were the Vegetation Map, Beta Version 4 (Mucina and Rutherford 2004) and Bioregional Plans (Conservation Planning Unit 2000; Conservation Planning Unit 2002a, b).

Several other useful datasets available on municipal scale like the Municipal Parks Budget, the Recreation Budget and Pollution data were identified and investigated as possible indicators of biodiversity risk, but these datasets could not be included in the study because they were not available for all of the 262 municipalities.

The datasets used are described below under the categories pressures, stocks and responses. Stocks represent the biological richness, endemism and extent of pristine habitat of an area. Pressure variables measure any threat to biodiversity, anything that might deplete stocks, for instance increased human population density. Response variables measure effort put into biodiversity conservation and the sustainable use of natural resources.

2.2.2. Pressure Data

2.2.2.1. Data Description

Variables: Population Density Change and Population Density

The direct association of biodiversity degradation with high human population densities and rate of change of population densities made them useful pressure variable candidates (Veech 2003). Population density was expressed as number of people in each municipality per square kilometre. The change in population density from 1996 to 2001 was calculated as the difference in population for the above 5 year period, divided by the area of the municipality. Change in population density was thus described per square kilometre for each municipality.

Variables: Wealthy Households and Poor Households

To measure the size and type of impact that people have on the environment, income is normally used, as it is a relatively good indicator of the extent of human pressure on the environment. Affluence play a direct role in the types of pressures being exerted on biodiversity as it reveals the type of lifestyle a person/household has and the type of resources being utilised. Both impoverished (World Bank 2002) and wealthy people (Lenzen and Murray 2003) are known to have negative impacts on the environment. Therefore instead of using the one variable of income, two measures: one measuring poverty and one measuring wealth, were included as pressure variables.

To measure poverty involves identifying the poor and constructing an index to measure the intensity of poverty (Ngwane *et al.* 2003). Therefore, an appropriate poverty cut-off limit had to be determined to measure poverty. The same had to be done to identify wealthy people. As individual income per month often hides the true distribution of income, because money earned is usually spent per household, the Census (2001) Average Household Income was used to derive measures of poverty and wealth.

There are three types of poverty lines namely: an absolute poverty line which is fixed at a value of income or expenditure that is necessary to acquire goods and services to satisfy basic needs; a relative poverty line which defines households as poor relative to others in the same society or economy; and a subjective poverty line which is based on what households perceive as their needs (Ngwane *et al.* 2001). No standardised national poverty threshold exists yet for South Africa. Therefore, economists primarily use the international standards of the World Bank of either the $1 or $2 a day as poverty lines in South Africa (Soubbotina 2004) which fits into the first type of poverty line mentioned. One more informal poverty line frequently used for South African circumstances is R3000 per person per annum (Van der Berg in mimeo). Census (2001) Average Household Income data was recorded in income brackets. The bottom two brackets (No Income and R1-R4800 per annum; or No Income and R1 – R400 per month) encompass both the $1 and $2 dollar a day poverty lines, as well as the R3000 per annum poverty line.

The proportion of the total number of households per municipality within these two bottom brackets was used to represent the very poor portion of the population. This was not the ideal way to represent the poor, but other datasets on poverty were not available for all 262 municipalities at the time.

Worldwide very little research has been done to construct affluence lines (Medeiros 2004). Due to a lack of any formal affluence line in South Africa, the proportion of the total number of households represented by the top two income brackets from census data (R1 228 801 - R2 457 600 p/a and R2 457 601 and more p/a) were used as the measuring wealth variable. Some work on affluence lines is currently being done by the Economics Department of the University of Stellenbosch, but the data were not yet published. The affluence line proposed includes the wealthiest 15% of households (Burger *et al.* 2004). This measure could not be used in this study as it was not possible to derive this information from the information in the Census income brackets.

Variables: Degraded and Transformed Land

A 1:250 000 Habitat Transformation Map created by the National Spatial Biodiversity Assessment (NSBA) (Rouget *et al.* 2004) classified the country into four land cover classes: natural, water bodies, degraded and transformed. These four classes of land cover were made up of several categories, namely cultivated lands, degraded lands, forest and woodlands, forest plantations, grasslands, mines and quarries, thicket and bush land, urban/built-up lands, water bodies and wetlands.

The two datasets used to create this Habitat Transformation Map were the National Land Cover data originally derived from 1996 LANDSAT satellite imagery (Fairbanks et al. 2000) by the Council for Scientific and Industrial Research (CSIR); and road data from the Environmental Potential Atlas for South Africa (ENPAT) compiled by the Department of Environmental Affairs and Tourism (DEAT) and the University of Pretoria (Reyers et al. 2001). The road categories included national routes, arterials, freeways, main, secondary and other roads. For this study the proportions of degraded and transformed land per municipality were calculated from this Habitat Transformation Map using ArcView GIS Version 3.3 (Esri 1998).

Only transformed area and degraded area were used as possible variables for the construction of the risk assessment index to avoid co-linearity. It must be stated here that due to the age and the range in accuracy of the 1996 National Land Cover data (from 50% to 90% accuracy depending on the geographical area) (Fairbanks *et al.* 2000), data must be treated conservatively. Irreversible loss and degradation of natural habitats are under represented, especially in areas like KwaZulu-Natal and the Eastern Cape where dramatic land cover changes such as increased crop cultivation, forestry and rural human settlements, has occurred since the survey was undertaken in 1996 (Meadows and Hoffman 2002). Data on degree of degradation is also lacking for the entire country and needs to be addressed in the future.

Variable: Threatened Species

Threatened species presence data from NSBA (Rouget *et al.* 2004) were included as a pressure variable expressed as threatened species density data. The distribution of these red data book species often coincide with areas with high biodiversity pressures (Ricketts and Imhoff 2003). See section 2.2.3.1 Stock Variables: Species Density and Endemic Species Density, for a description of the red data book species used and how the variable was calculated.

2.2.2.2. Limitations and other data considered

It must be stressed again that to work with variables from different dates and units are not ideal as it makes it very difficult to determine accurate results. The rapid increase in human population, land degradation and transformation in the past few years are almost certainly underrepresented for this study. The study had to use 2001 Census data and 1996 Land Cover data due to a lack of updated data. It would have been useful to include the 2000 National Land Cover Data but this was not possible, as the data have not yet been published.

Apart from Census data, availability of economic data for local municipalities were very scarce. Gross Domestic Product data was only available up to 1997 for Magisterial Districts, and since then only at Provincial level (available from Statistics South Africa).

As a result GDP per Magisterial Districts could not be used as a pressure variable because data were too old to truly reflect the current affluence of each municipality, and extrapolating the data to the municipal level would have resulted in too generalized data. In the same way the provincial GDP data could also not be used because it would involve downscaling information.

2.2.3. Stock Data

2.2.3.1. Data Description

Variables: Species Density and Endemic Species Density

From other studies (Driver *et al.* 2005) species data are shown to be an important layer for representing some elements of biodiversity. Even though South Africa is home to a high number of plant and animal species, data availability on species distribution at the municipal scale are very limited. Therefore, conservation planners often use surrogates to represent total biodiversity (Wilson *et al.* 2005; Caro and O'Doherty 1999). The most recent and accurate species distribution data are recorded per quarter degree grid square (QDS) (Rouget *et al.* 2004). Only six taxa groups were identified by the NSBA to have useful and adequate species distribution datasets that could be used in conservation planning (Rouget *et al.* 2004). These datasets were surveyed at the national level, have limited survey bias and sound taxonomic information. The taxa identified are birds, butterflies, frogs, mammals, scarabaeoid beetles and scorpions. For the purpose of this study the data had to be expressed per municipality before any further analysis could be done.

Datasets collected for all the species within the six taxa mentioned, did not reflect occurrence or abundance of species within each QDS, but rather the presence of the species per QDS (Rouget *et al.* 2004). Presence data expressed per QDS were recorded in four categories. They were: all recorded species, endemic species, threatened species and species of special concern (both endemic and threatened). Endemic species were those with a hundred percent of their distribution limited to South Africa. The endemic species recorded were of existing lists of endemic birds and mammals and new lists of endemic butterflies and scarabaeoid beetles identified and reviewed by experts. Species defined as being threatened were classified as either being critically endangered, endangered or vulnerable based on Red Data Books of birds (Barnes 2000), mammals (Friedmann and Daly 2004), frogs (Minter *et al.* 2004) and expert opinion in the absence of recently published Red Data Books.

Within each QDS all species of all the taxa were used to determine total recorded species, total number of endemic species and total number of threatened species. To determine the species density of each QDS, the total number of species per QDS were divided by the area of the QDS. The QDS layer was intersected with the municipal boundaries using ArcView GIS Version 3.3 (Esri 1998) to express species data per municipality. To determine what contribution each new polygon brings to the municipality in terms of species density, a weighted area had to be calculated for each newly formed polygon by dividing its own area (an entire QDS or part of a QDS that now falls within the specific municipal boundary) by the area of the municipality it now forms part of; which was then multiplied by the species density of the original QDS. The weighted species densities of each new polygon were then summed to determine the total species density for each municipality. The same was done to calculate threatened species density and endemic species density per municipality.

Variable: Vegetation Type Richness

The South African National Biodiversity Institute (SANBI) created a new Vegetation Map (Beta Version 4.0) for South Africa, Swaziland and Lesotho (Mucina and Rutherford 2004) which was used to determine how many different vegetation types occur in each municipality. The map described the most up to date vegetation information for South Africa. Vegetation patterns were mapped at a relatively fine scale (1:250 000) and 441 vegetation types were identified in South Africa, Lesotho and Swaziland and are classified into seven biomes (plus wetlands, deserts and infrastructure) with the Fynbos having the most diverse collection of vegetation types; the Savanna and Grassland biomes covering the largest area of South Africa. High numbers of vegetation types in a municipality represent high vegetation diversity which is a good indicator of biodiversity as fauna are more associated with vegetation types than specific plant species. The vegetation map was intersected with the municipality map and the number of different vegetation types found per municipality was counted and used as a stock variable. Infrastructure features on the map e.g. dams were omitted.

2.2.3.2. Limitations and other data considered

Species distribution data are often problematic. Some bias, both geographical and taxonomic exists in the datasets used. The datasets used are however the best sets available for South Africa. No plant species were included in the study; the reason for this is simply because of lack of readily accessible data on a national scale. Even though the PRECIS dataset from SANBI would have been extremely useful, it was unfortunately not available for this study.

The natural land remaining in each municipality was also considered as a possible variable but, as transformed and degraded land from the same dataset were already included as pressure variables, it was decided to exclude natural land.

2.2.4. Response Data

2.2.4.1. Data Description

Variable: Type 1 and Type 2 Protected Areas

Data on protected areas of South Africa were obtained from the National Spatial Biodiversity Assessment (Rouget *et al.* 2004). The data were of three types of protected areas. Type 1 included national, provincial and municipal protected areas as well as Department of Water Affairs and Forestry (DWAF) Forest Nature Reserves. Type 2 included mostly privately owned conservation areas, wildlife management areas, private nature reserves, national heritage sites, SANDF property, state land, bird sanctuaries, game sanctuaries, mountain catchment areas, DWAF forest areas and coastal reserves and botanical gardens. Type 3 included informal protected areas like private game farms and conservancies that do not provide long-term protection for biodiversity. The total area under Type 1 and Type 2 protection was separately determined with the use of ArcView GIS Version 3.3 (Esri 1998) for each municipality and used as two separate response variables.

Variable: Bioregional Plans

Bioregional plans defined in the introduction were also used as a measure of response. The ones included were CAPE, SKEP and STEP. The areas covered by these plans (Conservation Planning Unit 2000; Conservation Planning Unit 2002a; b) were intersected with the municipality boundaries to derive the percentage area of a municipality that was covered by one or more than one of these plans and used as a response variable called bioregional plans.

2.2.4.2. Limitations and other data considered

Municipal budgets would have been good response measures to consider. Important gaps in money distribution between municipalities could have been identified explaining the level of conservation response per municipality. The Parks and Recreation Budget, the Air Pollution Budget, and the Capital Budget of municipalities (National Treasury 2003; MDB 2003) could have been possible response variables for determining biodiversity risk. Unfortunately information on these budgets was not available for all 262 municipalities and could not be included. In order to determine biodiversity risk of municipalities and compare their results, all the data used needs to be available for each municipality. Similarly, other sources like research data, museum collections and genetic data only exist for parts of the country and could also not be used.

2.3. DATA COLLATION

To collate and analyse available pressure, stock and response data per municipality, the programmes ArcView GIS Version 3.3 (Esri 1998), Microsoft Excel, Microsoft Access and Statistica Version 6 (Statsoft 2003) were used. Data analysed in ArcView GIS Version 3.3 (Esri 1998) where projected to Albers Equal Area Projection (WGS 84, Central Meridian 25, Standard Parallels -24 and -33).

Many datasets were considered to be included in this study, but in the end thirteen variables were identified that would adequately represent biodiversity risk. There was large variation in municipal size and human population density of the municipalities, thus each variable had to be standardised before comparisons between municipalities could be made. The two economic pressure variables, poor households and wealthy households, were standardised by total number of households per municipality. While population density change (pressure variable), population size (pressure variable), degraded land (pressure variable), transformed land (pressure variable), threatened species density (pressure variable), endemic species density (stock variable), species density (stock variable), vegetation type richness(stock variable), as well as protected areas Type 1 and Type 2 (response variables), and cover by regional plan (response variable) were standardised by municipal area (km^2).

These standardised variables were analysed using Spearman Correlation Analyses and Principal Component Analysis. Subsequently each municipal value for a particular variable was expressed as a proportion of the maximum value in the set, in other words the variables were normalised. The value for each municipality for each variable was thus transformed to a number between zero and one, with the score of one allocated to the municipality that had the largest value (largest contribution) for that particular variable. These transformed (normalised) versions of the data were used to construct the new index. It should be noted that the meaning of the term normalised here is not the same as when it refers to data being manipulated (usually using ln or log) to obtain normalised distributions of the data.

2.4. ANALYSIS

2.4.1. Exploratory Analysis

The standardised raw dataset was first described and then tested for normality with Kolmogorov-Smirnov ($p < 0.05$) and Lilliefors ($p < 0.05$) tests. The variables were found to be not normally distributed (Statsoft 2003). Five of the thirteen variables could not be transformed with the help of mathematical procedures such as log, ln, square root and power. It was decided to use the non-parametric test, Spearman Correlation Analysis, to quantify broad relationships between variables. This is the most common type of correlation used for non-parametric data and it measures the relationship between two or more variables.

The correlation coefficient (r) determined to what extent variables were correlated with each other (StatSoft 2003). Variables were said to have significant strong relationships with each other, when $p < 0.05$ and $r > 0.4$ or $r < -0.4$.

Principal Component Analysis (PCA) is a multivariate statistical technique used to reduce the dimensionality of a dataset of variables (Dunteman1989). It was used to analyse the available thirteen variables by determining firstly whether these variables could be reduced to only those that adequately summarise the original information, and secondly whether any patterns in the data existed which could not be found by analysing each variable separately (Quinn and Keough 2002). Principal Component Analysis can be based on either a covariance matrix or a correlation matrix. The form of PCA used in this study uses a correlation matrix as the starting point of the analysis (Dunteman 1989).

To reveal patterns in the data, this method used multidimensional scaling to determine lines of best fit, which explain variation. These lines are called principal components. The axis that determined which had the best fit was called principal component one and explained most of the variance. The second axis, principal component two, was completely independent of the first axis and explained an additional part of the variance and so on for all other components.

The commonly used Kaiser's rule (Kaiser, 1960) was applied to the results, and only those components whose eigenvalues were higher than one were chosen, because they usually explain most of the variation when the PCA is based on a correlation matrix (Quinn and Keough 2002). The reason for this is because each observed variable contributes one unit of variance to the total variance. If the eigenvalue is greater than 1, then each principal component explains at least as much variance as 1 observed variable (Kaiser, 1960).

Another reason why a correlation matrix instead of a covariance matrix was used in this study was because it ignores the variance differences between variables. Especially when the variables were measured in different units as was the case in this study. For each component, a group of variables that explain most of its variance can be identified. PCA is therefore a useful tool to reveal which variables belonging to which component, characterise which municipalities.

2.4.2. Index Construction

2.4.2.1. Appropriateness of the National Biodiversity Risk Assessment Index (NABRAI) at a Sub-National Scale

The preferred biodiversity risk assessment index for the purpose of this study should highlight municipalities with high biodiversity stocks under immense threats that have limited resources to aid in biodiversity management. Of all the indices reviewed the National Biodiversity Risk Assessment Index (NABRAI) (Reyers *et al.* 1998; Reyers and James 1999) prioritisation method was found to be potentially the most appropriate index to be implemented at the municipal scale to assess biodiversity risk in South Africa. The index uses measures of pressures, stocks as well as responses to assess biodiversity risk on a national scale and is simplistic, flexible and easy to understand by both the implementer and the interpreter. The inclusion of response variables is seen as a major improvement on other indices and because of its success, is part of the appeal of wanting to explore the use of the index on a sub-national scale.

To test the appropriateness of the NABRAI at the sub-national (municipal) scale, the variables described in Table 1, were incorporated in the following NABRAI equations. These equations were originally intended for the national scale:

$$PR = (chn + pop + we + po + deg + trf + rdb)/7 \qquad \text{Equation 1}$$

$$ST = (pr1 + pr2 + bio)/3 \qquad \text{Equation 2}$$

$$RE = (sp + end + veg)/3 \qquad \text{Equation 3}$$

where: PR = pressure value; ST = stock value, RE = response value, chn = population density change rank, pop = population density rank, we = wealthy households rank, po = poor households rank, deg = degraded land rank, trf = transformed land rand, rdb = threatened species density rank, sp = species density rank, end = endemic species density rank, veg = vegetation type richnessrank, pr1 = Type 1 protected areas rank, pr2 = Type 2 protected areas rank and bio = bioregional plan cover rank.

The National Biodiversity Risk Assessment Index (NABRAI) was thus constructed using the following equation:

NABRAI = $2PR / (RE + ST)$……………… Equation 4

Pressure is the negative component, and response and stock are the positive components in the equation. The reason, for the pressure value (PR) being multiplied by two, was to weigh the negative component equally with the two positive components (Reyers and James 1999). The final NABRAI value calculated for each municipality allowed them to be ranked from those facing highest biodiversity risk (highest value given the highest rank score of 262) to those facing the lowest biodiversity risk (ranked 1).

2.4.2.2. Problems with implementing the NABRAI at a Sub-National Scale

Using the variables identified for the South African municipalities case (Table 1), the NABRAI only highlighted municipalities with high pressures; regardless of what stock and response values were in place. Even when a municipality had very low stocks, a high threat value overruled its significance and the municipality was identified with so-called high biodiversity risk. The other two components (stock and response) therefore did not play a large enough role in the NABRAI index when applied on the municipal level. The NABRAI thus did not comply with the definition of a biodiversity risk assessment index defined for the purpose of this study; and could not be used in its original form to assess biodiversity risk in South Africa. Resources cannot be allocated to municipalities just on the basis of threat status; other components have to be taken into account too.

As the reasoning behind the NABRAI and its outcomes was still relevant and no other index that was evaluated could adequately assess biodiversity risk at the South African municipal scale according to the definition as stated above, it was decided to amend the original NABRAI be more appropriate at the municipal scale of South Africa.

2.4.2.3. Amending NABRAI to create the Municipal Biodiversity Risk Assessment Index (MuBRAI)

Amending the NABRAI to fit the municipal scale proved to be difficult and several options were tested. The final amended index was called the Municipal Biodiversity Risk Assessment Index (MuBRAI). In order to obtain similar outcomes at the sub-national scale as what was obtained at the national scale i.e identify areas with high risk of imminent biodiversity loss, the same approach and methodology was used to construct the MuBRAI as was used to construct the NABRAI. Variables used in the MuBRAI were also grouped into biodiversity stock, pressures and response categories as was done for NABRAI, and data was also expressed either as per km^2 or percentage to correct for distortions caused by differences in land area, populations size and species richness between different areas as was done for NABRAI.

To overcome the problem that the new index mainly highlights municipalities with high pressures regardless of all else, it was decided to amend the original NABRAI equation by counting the pressure (PR) and stock (ST) values together and then dividing with the response (RE) value. This ensured that municipalities with both high pressures and high stock would receive high final MuBRAI scores.

From the upgraded version of the NABRAI (Reyers and James 1999), the pressure value that stood alone above the line was multiplied by two to balance the equation. In the MuBRAI equation the response value stands alone underneath the line. It was not deemed necessary to multiply the response value with two, as it was found to make no difference in the final rank of the municipalities.

The Municipal Biodiversity Risk Assessment Index (MuBRAI) was thus constructed using the following equation:

$$\text{MuBRAI} = (PR + ST) / RE \ldots\ldots\ldots\ldots \quad \text{Equation 5}$$

where: PR = pressure value; ST = stock value; RE = response value.

The MuBRAI used normalised variables. By expressing these variables as values between zero and one it made them unit free/unit less, weight and importance not concealing the effect each one has on the total score for each municipality. In other words, disparities are not hidden by ranks. All thirteen variables were used to calculate the values of pressure, stock and response with the following equations:

$PR = (chn + pop + we + po + deg + trf + rdb)/7$ .... Equation 6

$ST = (pr1 + pr2 + bio)/3$ …………………………………………………….. Equation 7

$RE = (sp + end + veg)/3$ …………………………………………………… Equation 8

where: chn = normalised population density change, pop = normalised population density, we = normalised wealthy households, po = normalised poor households, deg = normalised degraded land, trf = normalised transformed land, rdb = normalised threatened species density, pr1 = normalised Type 1 protected areas, pr2 = normalised Type 2 protected areas, bio = normalised bioregional plan cover, sp = normalised species density, end = normalised endemic species density, veg = normalised vegetation type richness. (For descriptions, units and sources of these datasets see Table 1.)

Fifty four municipalities did not have any Type 1 or Type 2 protected areas and are also not part of a bioregional plan. Consequently, they had response values of zero, which is not permitted in the MuBRAI equation. To ensure that the equation did not have to divide by zero and that these municipalities' response values would not weigh heavier than other municipalities, all of them were given the same response value of a power smaller than the smallest response value for all the other municipalities.

2.4.3. Comparing MuBRAI with and without Response Values

To prove that the inclusion of response variables in the MuBRAI is an improvement on other approaches it was decided to compare MuBRAI with and without the response value, where:

MuBRAI (with response value) = $(PR + ST) / RE$ ………………………… Equation 5

MuBRAI* (without response value) = $PR + ST$ ……………………………. Equation 9

A table summarising the pressure, stock and response values, MuBRAI* value, MuBRAI* rank, MuBRAI value and MuBRAI rank for all the municipalities was compiled to compare the outcome of the two different MuBRAI equations.

2.4.4. Final Statistical Analysis

The three measures of pressure, stock and response were subjected to Spearman Correlation Analysis to determine the relationship between each other.

3. RESULTS

3.1. EXPLORATORY ANALYSIS

3.1.1. Descriptive Statistics

Several datasets were tested as possible variables for the construction of the biodiversity risk assessment index. Incomplete datasets and co- linearity between variables were used to exclude candidate datasets. The remaining variables are described in Table 1. These variables were classed as measures of stock, pressure and response.

The results of initial analyses of the datasets in Table 1 are summarised in Table 2. Each variable was expressed either per km^2 or as a percentage, depending on its original unit. It was found that the mean population density change per municipality was 8.453 people/km^2 (±31.786) and that the mean population density per municipality was 80.322 people/km^2 (±202.860) (Table 2). Large variations occurred in both these variables, which were not reflected in their means. The variance can mainly be ascribed to the uneven distribution of people across the country. The results confirmed that City of Johannesburg is the most densely populated municipality (maximum population density of 1962 people per km^2) in the country and is also growing the fastest (maximum population density change of 357 people per km^2) (Table 2). Municipalities found to have no permanent residents living there were the DMAs called Schuinsdraai Nature Reserve, O'Conners Camp and Mdala Nature Reserve. It was calculated that of the 262 municipalities surveyed, sixty-four municipalities had negative population density change with Vulamehlo municipality in KwaZulu-Natal having the largest negative population density change. It was interesting to note that between 1996 and 2001, no population density change was recorded in the Breede River municipality in the Western Cape.

It was found there are a mean of 31.5% (±14%) poor households and a mean of 0.3% (±0.3%) wealthy households present within each municipality (Table 2). The largest concentration of rich households, almost 4% of the households in the municipality, lived in the Overberg District Management Area in the Western Cape. Jozini in KwaZulu-Natal had the largest percentage of poor households living there (58% of its households). Households living in the seven DMAs demarcated as protected areas did not fall in either the extremely poor or wealthy household categories as these municipalities showed negative population density changes and very low population density numbers.

Table 2. Descriptive statistics of the possible variables investigated for construction of the Biodiversity Risk Index for South Africa.

Variables	Unit	Mean	Minimum	Maximum	Variance	Standard Deviation
Pressure Variables						
Population Density Change	per km^2	8.453	-19.714	356.853	1010.330	31.786
Population Density	per km^2	80.322	0.000	1962.070	41152.070	202.860
Wealthy Households	%	0.293	0.000	3.600	0.000	0.330
Poor Households	%	31.466	0.000	57.900	2.000	13.800
Degraded Land	%	6.413	0.000	58.000	1.000	9.940
Transformed Land	%	22.550	0.000	93.900	4.000	19.640
Threatened Species Density	per km^2	0.012	0.001	0.042	0.000	0.007
Stock Variables						
All Species Density	per km^2	0.401	0.100	1.252	0.030	0.184
Endemic Species Density	per km^2	0.016	0.000	0.049	0.000	0.011
Vegetation Type Richness	per km^2	0.541	0.040	14.700	0.000	1.140
Response Variables						
Protected Areas (Type 1)	%	7.591	0.000	99.400	4.000	20.040
Protected Areas (Type 2)	%	1.688	0.000	53.200	0.000	5.430
Bioregional Plans	%	20.206	0.000	100.000	15.000	38.990

The analysis revealed a mean degraded land area of 6% (±10%) per municipality, but fifty one municipalities did not have any degraded land explaining the relatively large standard deviation for the variable (Table 2). Anagang municipality in the Limpopo Province was found to be the most degraded. The percentage mean transformed land area of 23% (±20%) was higher than the percentage degraded land area per municipality. Almost 94 % of KwaDukuza in KwaZulu-Natal has been transformed. This makes it the municipality with the highest percentage transformed land in the country with the Swartland in the Western Cape coming second with 79% of land transformed (mainly Renosterveld).

From the results it is evident that DMAs are not as threatened by anthropogenic threats as the rest of the municipalities. The results indicate that Oviston Nature Reserve (Eastern Cape), Mdala Nature Reserve (Mpumalanga), Golden Gate Highlands National Park (Free State) contains no extremely wealthy households, no extremely poor households and no degraded or transformed land and this is only the case because nobody permanently lives there or utilises the natural resources.

For threatened species density the results revealed a mean of 0.01 species per km^2 (±0.007) with the maximum density of species found in Mtubatuba in KwaZulu-Natal (Table 2). Pretoria, City of Cape Town, City of Johannesburg, Kruger National Park, Kamberg Nature Reserve and St. Lucia were also among those municipalities with very high threatened species densities. Moshaweng in the North Western Province had the lowest threatened species density.

For all species the mean density was 0.4 species per km^2 (±0.18) with a maximum density of 1.25 species per km^2 found in Mtubatuba (Table 2). The lowest density was found in Namaqualand in Northern Cape Province. Endemic species density had a mean of 0.02 species per km^2 (±0.01). Stellenbosch was shown to have the largest density of endemic species of 0.05 species per km^2 (±0.01), with George and Knysna second and third. It was also noted that all three municipalities fall within the Cape Floristic Kingdom of the Western Cape. For vegetation type richnessthe mean calculated was 0.5 vegetation types per km^2 (±1). The maximum vegetation type richnesswas found in Mdala Nature Reserve (Mpumalanga) and the minimum in the Benede Oranje DMA in the Northern Cape.

From the results of the response variables, the mean percentage area of Type 1 protected areas was found to be greater than for Type 2 protected areas (Table 2). Some municipalities, especially some of the DMAs, comprise almost entirely Type 1 protected areas like the Golden Gate Highlands National Park in the Free State. The municipalities that had the largest areas covered with Type 2 protected areas were the Lowveld DMA in Mpumalanga with 53% and Witzenberg in the Western Cape with 40% cover. Sixty-five municipalities had no Type 1 protected areas, 161 municipalities had no Type 2 protected areas and 60 municipalities had neither Type 1 nor Type 2 protected areas.

3.1.2. Spearman Correlation Analyses

From the Spearman correlation analysis it appeared that the pressure variables are significantly correlated with one another (Table 3). Positive significant correlations were found between population density change and population density ($p < 0.05$ and $r = 0.58$). These two variables are both significantly positively correlated with transformed land, threatened species density and total species density (Table 3). Poor households correlated positively with both population density as well as with degraded land. The stock variable, species density, had a positive correlation with transformed land ($p < 0.05$ and $r = 0.43$) and a very strong positive correlation with threatened species density ($p < 0.05$ and $r = 0.89$) (Table 3). Endemic species density correlated weakly but positively with species density ($p <0.05$ and $r = 0.41$) and stronger with threatened species density ($p <0.05$ and $r = 0.57$) and bioregional plans ($p < 0.05$ and $r = 0.45$). Bioregional plans correlated positively with Type 2 Protected Areas. The only negative correlation in this dataset existed between bioregional plans and poor households (Table 3).

Table 3. Spearman correlation analyses for variables used to construct the MuBRAI ($p < 0.05$; $r > 0.4$ or $r < -0.4$).

Variables	chn	pop	we	po	deg	trf	rdb	sp	end	veg	pro1	pro2	bio
Population Density Change (chn)		0.58				0.50	0.49	0.53					
Population Density (pop)				0.46		0.69	0.43	0.53		0.41			
Wealthy Households (we)													
Poor Households (po)					0.53								-0.49
Degraded Land (deg)													
Transformed Land (trf)								0.43					
Threatened Species Density (rdb)								0.89	0.57	0.66			
Species Density (sp)									0.41	0.68			
Endemic Species Density (end)										0.55			0.45
Vegetation type richness(veg)													
Protected Areas Type 1 (pro1)													
Protected Areas Type 2 (pro2)													0.51
Biorregional Plans (bio)													

3.1.3. Principal Component Analysis (PCA)

The usual guideline is that principal components with Eigenvalues greater than one usually explain the bulk of the variation (Quinn and Keough 2002). A scree diagram (plots of eigenvalues for each component against the component number) was also helpful in identifying the obvious break where the first components explain most of the variation (Quinn and Keough 2002). Using these methods, normally only the first three principal components are significant, but in this case, four principal components were identified and retained (Table 4). Out of the thirteen principal components analysed, the first four merely represented 66.84 % of the total variance. This is an indication that the variables are largely independent of each other and that each one is needed to describe the variation.

Table 4. Principal Component Analyses (PCA) proportional variable contributions and eigenvalues explaining the contribution of each component to the total variation. The principal contributions toward each component are indicated in bold.

	Variable Contribution			
Variables	PC 1	PC 2	PC 3	PC 4
Population Density Change	**0.121512**	0.084842	0.040446	**0.159599**
Population Density	**0.120182**	0.109889	0.032087	**0.122222**
Wealthy Households	0.017554	0.014102	0.124524	0.048705
Poor Households	0.037757	**0.208761**	0.027104	0.080596
Degraded Land	0.018075	0.062971	0.039724	0.020081
Transformed Land	0.056270	0.093241	0.019494	0.027367
Threatened Species Density	**0.191968**	0.007750	0.063576	0.054795
Species Density	**0.191873**	0.026713	0.064736	0.037450
Endemic Species Density	0.129879	0.035435	0.012889	**0.159852**
Vegetation Type Richness	0.036139	0.065687	**0.194205**	0.047625
Protected Areas Type 1	0.028223	**0.115975**	**0.181090**	0.094280
Protected Areas Type 2	0.033219	0.048973	0.001346	0.099933
Bioregional Plan	0.017350	**0.125658**	**0.198779**	0.047495
Eigenvalue	*3.25*	*2.55*	*1.58*	*1.30*
% Contribution to Total Variation	*25.02*	*19.65*	*12.17*	*10.00*
% Cumulative Contribution	*25.02*	*44.67*	*56.85*	*66.84*

The values displayed for each variable in each principal component in Table 4 indicate each variable's contribution to the total variance of that component. In the first principal component (PC 1) the bulk of the variation was the result of the pressure variables threatened species density, population density and population density change, and the stock variable species density. The contribution of PC 1 to the total variance is 25.02%.

Principal component two (PC 2) was driven by poor households and the response variables Type 1 protected areas and bioregional plans (Table 4). PC 2 adds 19.65% to the total variance. It is important to note that poverty and bioregional plans are negatively correlated with each other ($p < 0.05$ an $r < -0.49$) (Table 3), which could have some significance when interpreting the data. The variance of PC 3 was mainly driven by response variables bioregional plans, Type 1 protected areas and vegetation type richness(Table 4). The first three principal components together explained 56.85% of the total variance.

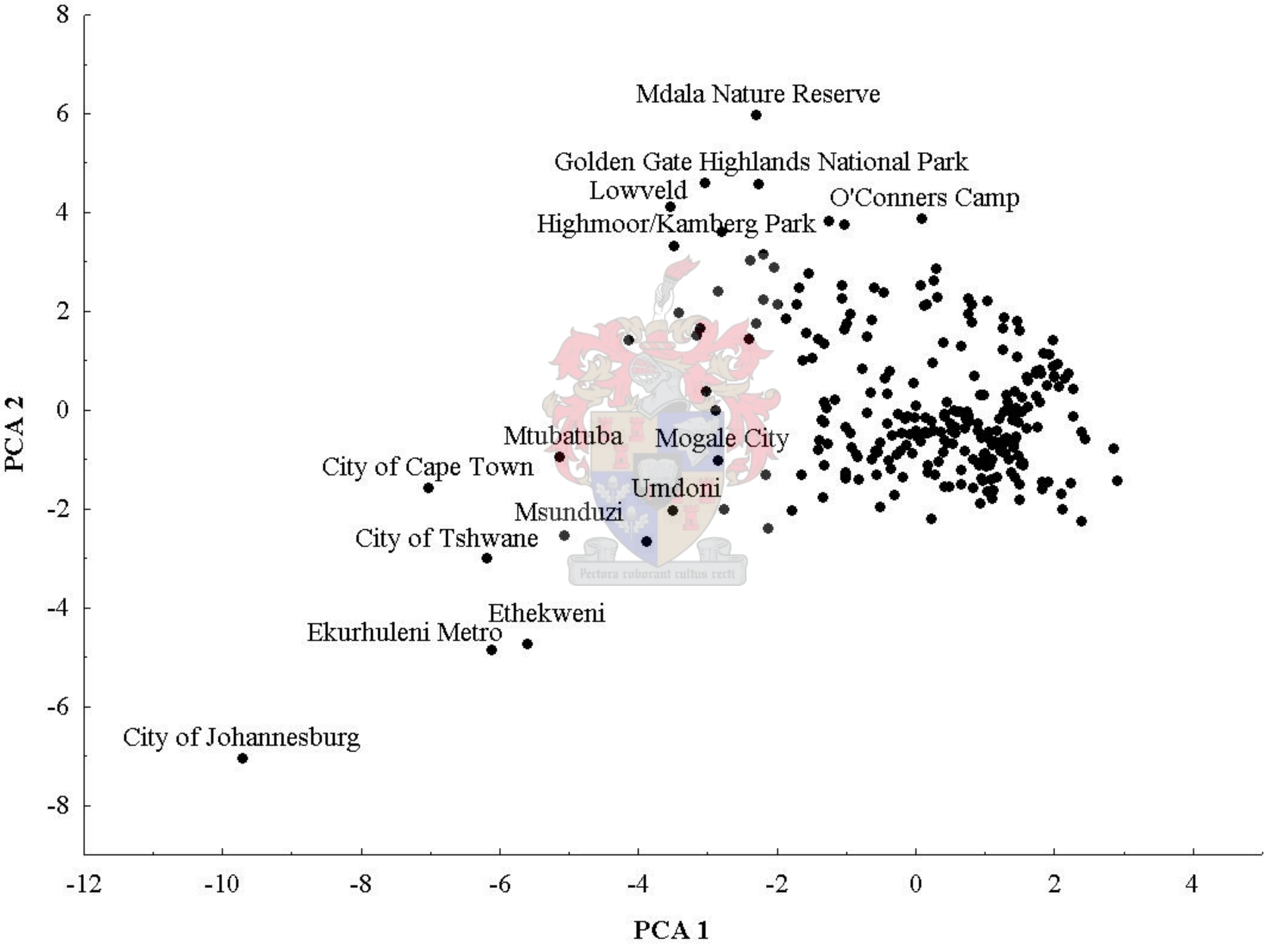

Figure 2a. PCA scaling plot of the first two principal components for all 262 municipalities based on a correlation matrix of pressure, stock and response variables.

The five Metropolitan Areas City of Johannesburg Metro, East Rand (Ekurhuleni Metro), City of Cape Town, Pretoria (City of Tshwane Metro), Durban (Ethekwini) were the main contributors to the variation expressed in principal component one (PC 1) and were clearly displayed as the outliers on Figure 2a along the negative side of the x-axis. The results from Table 4 strengthened the patterns observed because these municipalities were associated with relatively high species density, high threatened species density, high human population density and a high change in human population density.

The outliers on Figure 2a along the y-axis are the municipalities that contribute the most variation to PC 2. They are Mdala Nature Reserve, Overberg DMA, Golden Gate Highlands National Park, Lowveld, O'Conners Camp and Mountain Zebra National Park. They were highlighted mostly due to their strong association with Type 1 protected areas. Not many (if any) people live in these DMAs, which explained why this group is also highlighted by PC 1.

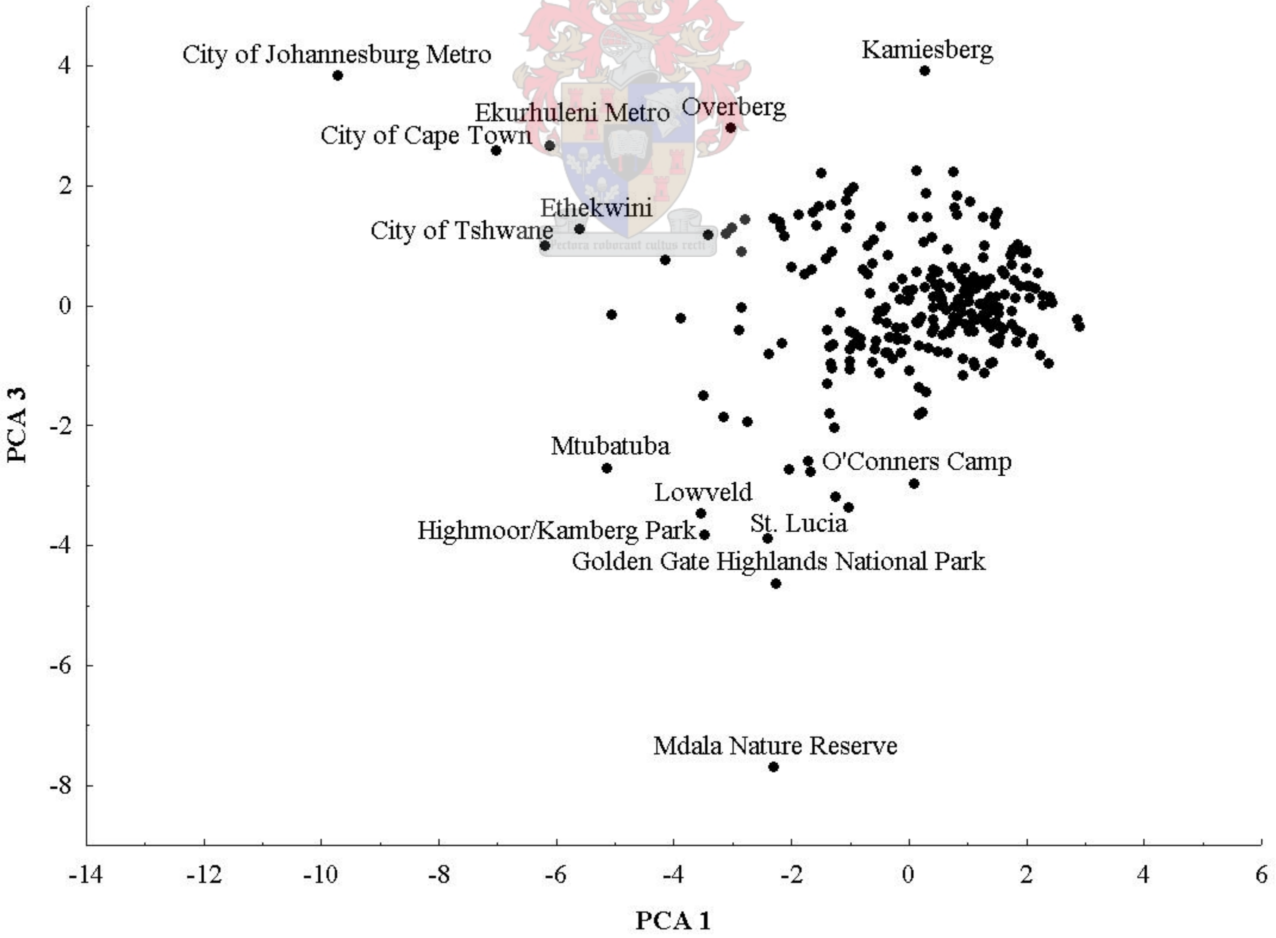

Figure 2b. PCA scaling plot of the first and third principal components for all 262 municipalities based on a correlation matrix of pressure, stock and response variables.

From Figure 2b three clusters could be observed. The largest cluster represented all municipalities that do not add significantly to the variation in either PCA 1 or PCA 3. The variation in PCA 3 was mostly driven by Type 1 protected areas, vegetation type richness and bioregional plans. The municipalities that clustered on the negative side of the PCA contained large Type 1 protected areas, large vegetation type richness and no bioregional plans. They were Mdala Nature Reserve (Mpumalanga), Golden Gate Highlands National Park (Free State), St Lucia Park (KwaZulu-Natal), Highmoor/Kamberg Park (KwaZulu-Natal), and Lowveld. As said before, PCA 1 was mostly driven by high population density, high population density change, high threatened species density and high species density which were evident from the cluster of Metropolitan areas highlighted on the graph (Figure 2b). Mtubatuba in KwaZulu Natal was identified as having the highest species densities as well as threatened species densities from all 262 municipalities.

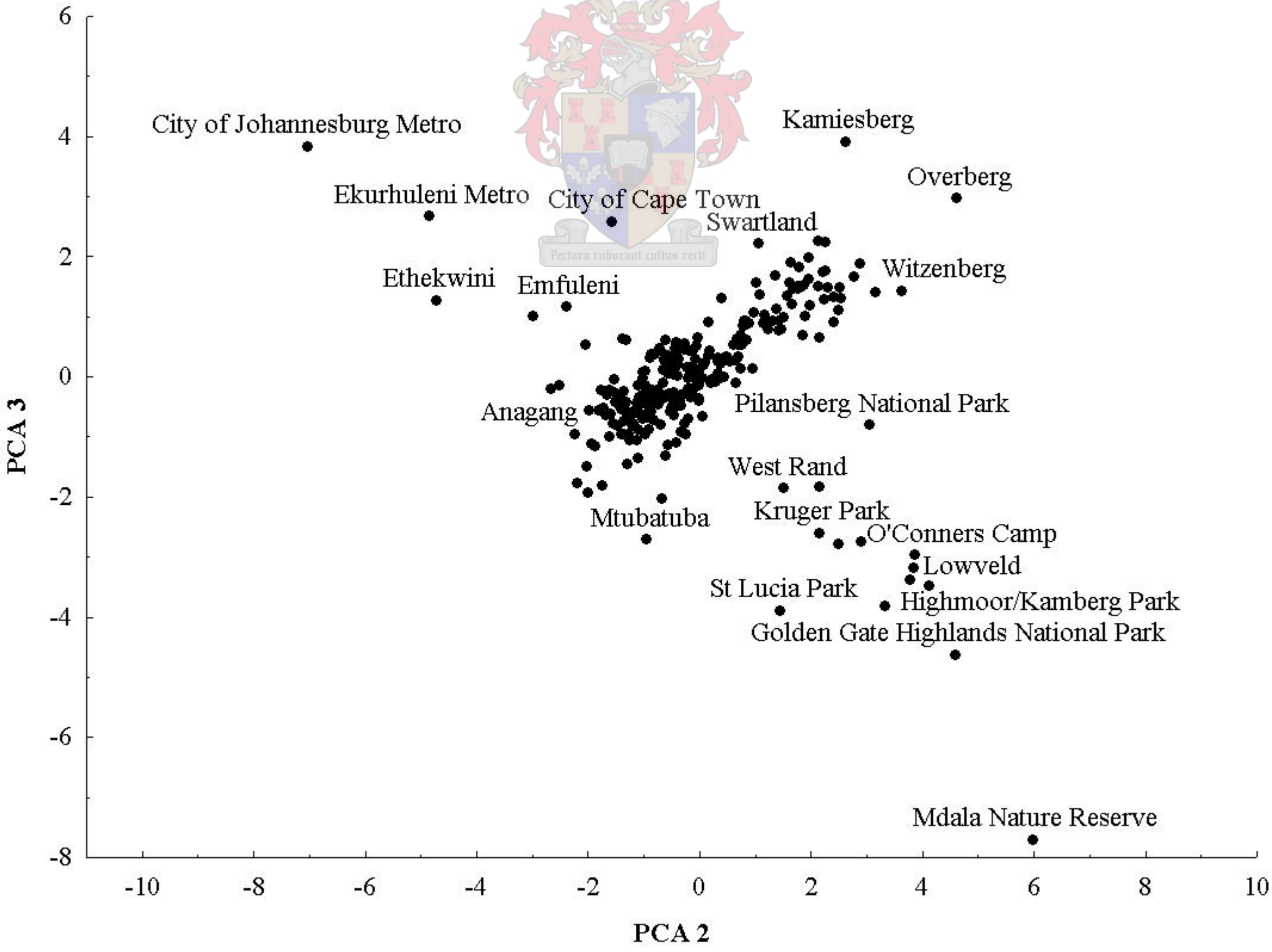

Figure 2c. PCA scaling plot of the second and third principal components for all 262 municipalities based on a correlation matrix of pressure, stock and response variables.

The outliers on the y-axis represent the municipalities that contributed the most to PC 3 (Figure 2c). Principal component three was driven by the response variables Bioregional plans and Type 1 Protected Areas. Those municipalities with high values for PC 3 were those with small values for these two variables. Those outliers highlighted on the negative axis for PC 3 had large values. Again, as in the previous two graphs, not a lot of variation was evident from the bulk of the municipalities, but two outlier groups existed: one of highly urbanised areas (Metropolitan areas mostly) and the other of DMAs which mostly consisted out of reserves with few or no people living in them.

3.2. INDEX CONSTRUCTION

3.2.1. Pressure Measure

In Figure 3 the degree of pressure calculated from Equation 6 exerted on each municipality is displayed. It was found that pressures were mostly concentrated in urban areas and rural municipalities known for their high population densities and high levels of degradation and transformation like the municipalities in the provinces of Gauteng, Limpopo Province, Eastern Cape and KwaZulu- Natal.

The top municipalities identified that face the highest pressures in the country were City of Johannesburg, East Rand, Durban, Tswane, City of Cape Town, Hlabisa, uMhlathuze and Umdoni (the last three situated in KwaZulu-Natal), Bushbuckridge (CBLC 6), Msunduzi and Mtubatuba (both in KwaZulu-Natal) (Figure 3, Table 5). Most of these highly threatened municipalities fall within KwaZulu-Natal and their associated vegetation types include the KwaZulu-Natal Coastal Belt, Midlands Mistbelt Grasslands, Ngongoni Veld or the Eastern Valley Bushveld vegetation types (Mucina and Rutherford 2004).

The municipalities in the sparsely populated central western side of the country (in the Karoo biome), seemed to be least affected by the seven combined pressures.

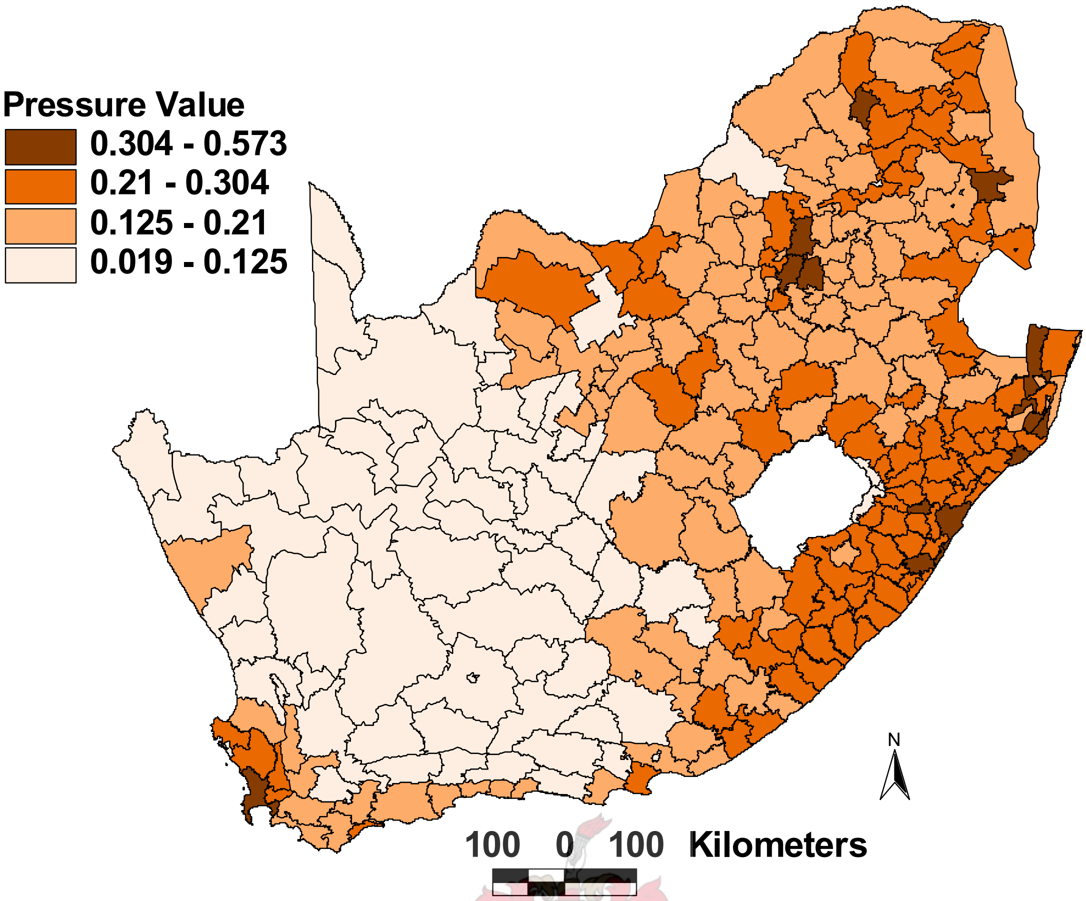

Figure 3. Pressure measure of 262 municipalities. The darkest areas highlight municipalities facing highest pressures.

3.2.2. Stock Measure

Highest stock values, calculated with Equation 7, were found in Mtubatuba (KwaZulu-Natal), Stellenbosch (Western Cape), Msunduzi (KwaZulu-Natal), Highmoor/Kamberg Park (KwaZulu-Natal) and George (Western Cape). See Table 5 and Figure 4 for the stock values for each of the 262 municipalities. Mtubatuba had the highest species density which contributed significantly to why it also had the overall highest stock value of all the municipalities. For the same reason George was rated high because it had the second highest endemic species density in the country. From Figure 4 stock is spread mainly along the Western Cape and KwaZulu-Natal coast with patches of high stock occurring in Gauteng province. It also seemed as if high stock values occurred in municipalities with high population densities (Metropolitan Areas). The dark patch of municipalities in the Drakensberg vicinity represented municipalities that contain fairly high species levels as the diversity in vegetation types and moist climate provide important habitats. Some of the most important vegetation types of the area include Southern Drakensberg Highland Grassland, Northern Drakensberg Highlands Grassland and uKhahlamba Basalt Grasslands (Mucina and Rutherford 2004).

The municipalities highlighted in the Western Cape mostly represented the diversity of the Fynbos biome. Overall municipalities of the Limpopo Province had very low stock numbers as well as Kalahari DMA (Northern Cape), Molopo (North West), Benede Oranje DMA (Northern Cape) and Mier (Northern Cape) having the lowest stock numbers.

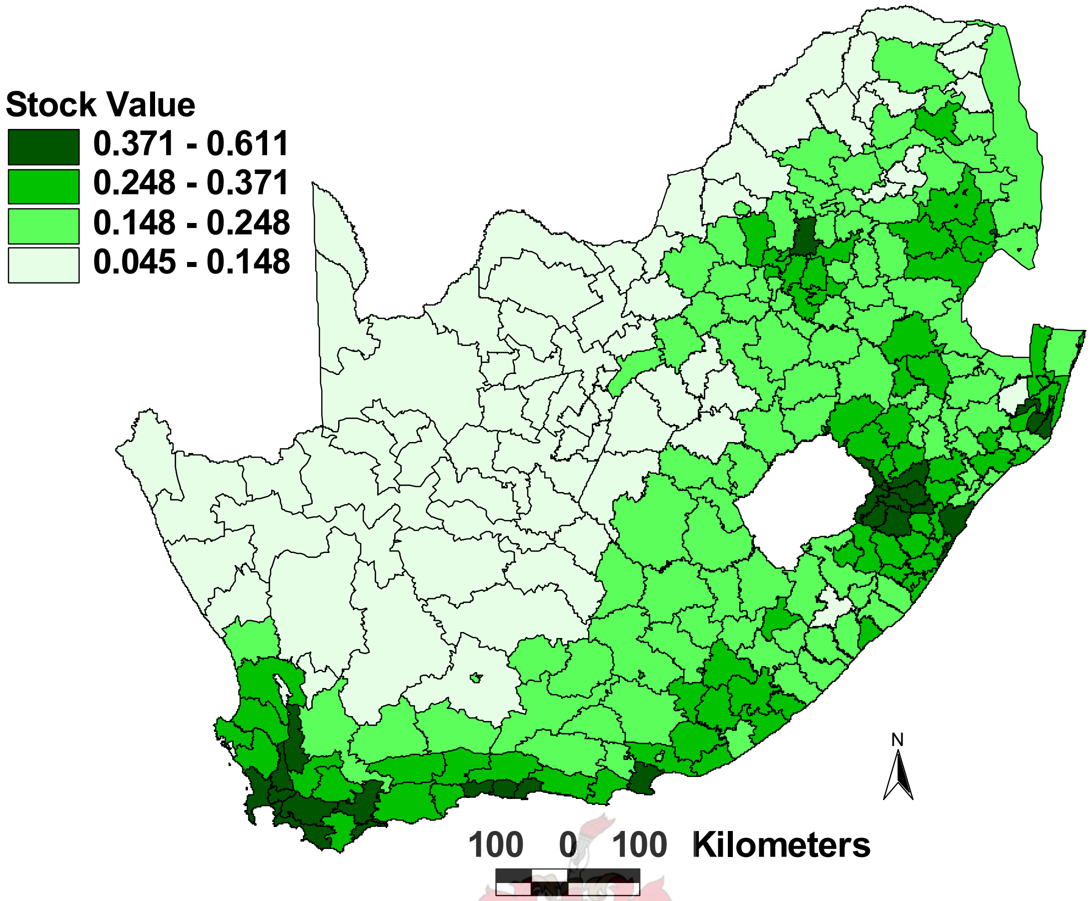

Figure 4. Stock measure of 262 municipalities. The darkest areas highlight municipalities with highest stock values.

3.2.3. Response Measure

The majority of municipalities with high responses (darker areas), calculated from Equation 8, are situated around the west and southern coast and corresponded strongly with existing bioregional plans (Figure 5). Overberg DMA and the Witzenberg municipalities in the Western Cape and the Mountain Zebra National Park in the Eastern Cape had the highest response values. Kruger National Park and the Drakensberg also stood out as having large responses in place due to the size of the park (Figure 5). On average protected areas vary between 1000 – 10 000 ha, with only a few being larger than 100 000ha (Rouget *et al.* 2004). Fifty four municipalities were found to have none of the three response measures measured in place (Figure 5). In Table 5 response measures for each municipality are listed.

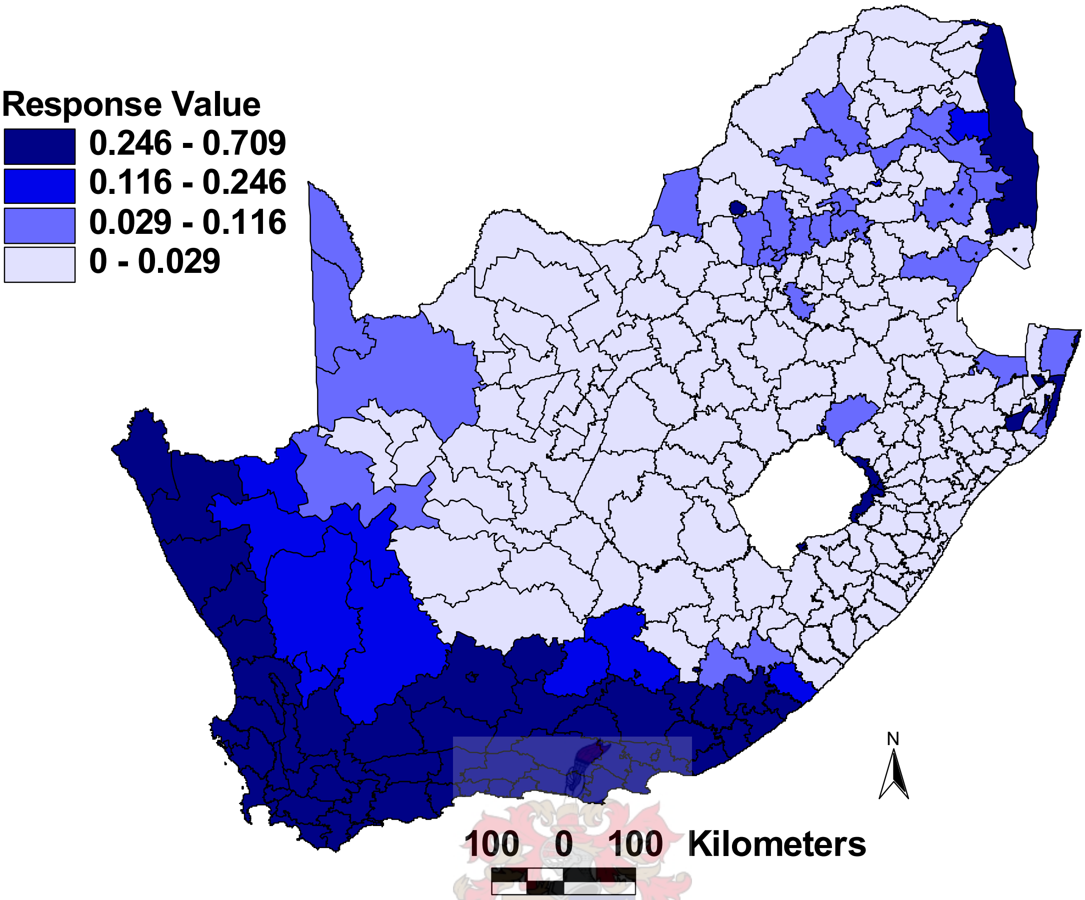

Figure 5. Response measure for 262 municipalities. The darkest areas highlight municipalities receiving highest responses.

3.2.4. MuBRAI Measure

The darkest coloured municipalities in Figure 6 were identified as having the greatest biodiversity risk according to the Municipal Biodiversity Risk Assessment Index calculated from Equation 5. They were Umdoni, Richmond, uMuziwabantu and Ubuhlebezwe, Mkhambathini, KwaDukuza (all KwaZulu-Natal municipalities) and Randfontein (Gauteng). Not one of them had any of the three response measures in place. Together with having no responses in place, Umdoni had fairly large pressures and large stocks. Namaqualand DMA (Northern Cape), Breede River DMA (Western Cape), West Coast DMA (Western Cape), Nama Khoi (Northern Cape) and Richtersveld (Northern Cape) exhibited the lowest biodiversity risk. They had little pressures and large responses in place.

The MuBRAI equation allocates the highest total MuBRAI value to the municipality that shows the highest biodiversity risk. Municipalities were therefore arranged according to their total MuBRAI value, from highest to lowest, in Table 5. Each of the pressure, stock and response values which make up the MuBRAI value were also displayed in this table giving further transparency to the index.

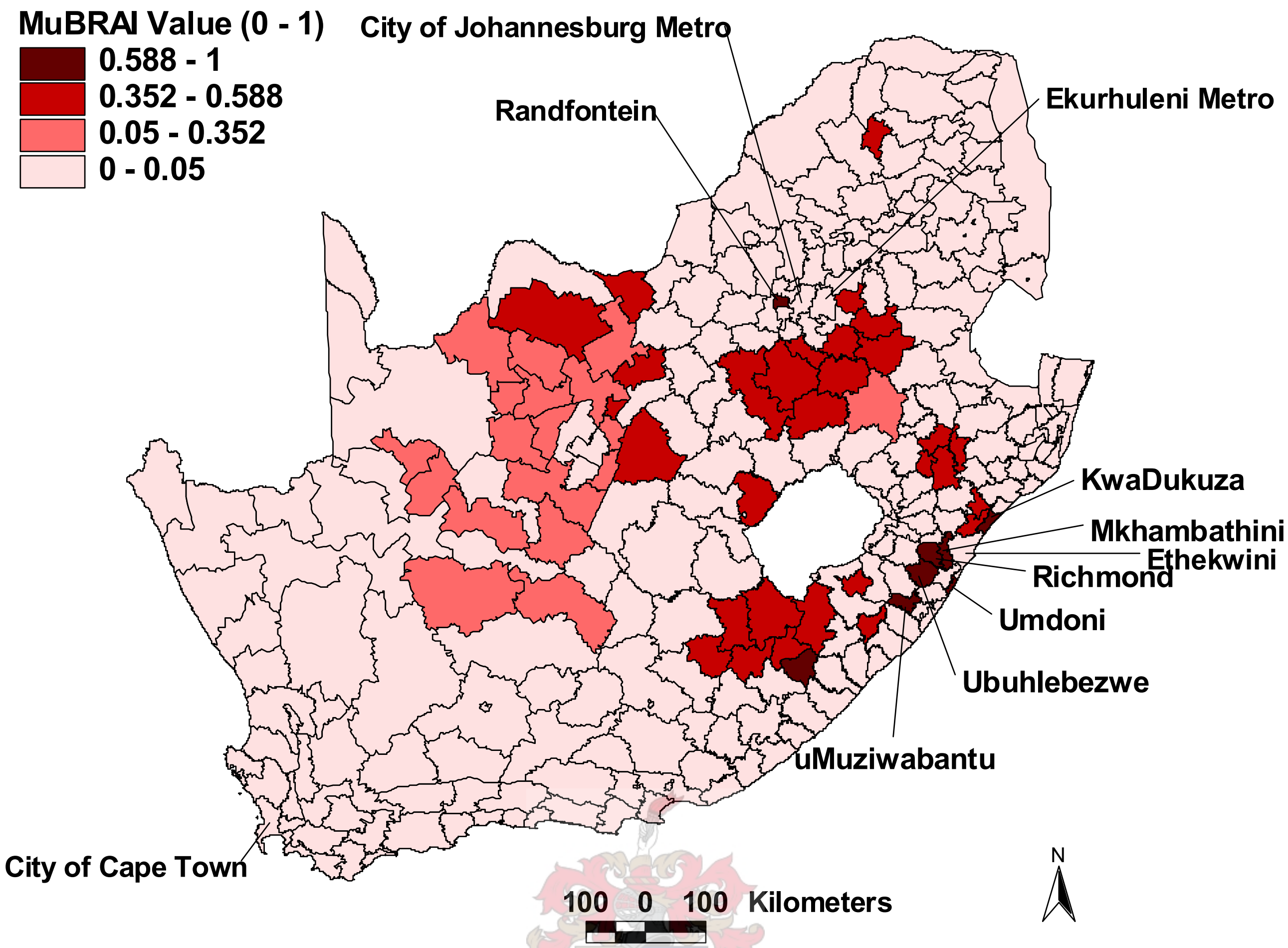

Figure 6. MuBRAI values for 262 municipalities expressed as values between 0 and 1. The darkest areas highlight municipalities facing highest biodiversity risk.

3.2.5. MuBRAI* Measure - Effects of omitting Response measures

The darkest coloured municipalities in Figure 7 were identified as having the greatest biodiversity risk when MuBRAI* was calculated from Equation 9, excluding a response value. Mtubatuba was ranked with the highest biodiversity risk. Of the top ten municipalities with high biodiversity risk, five were Metropolitan Areas. They were City of Johannesburg, City of Cape Town, Ethekweni (Durban), City of Tswane (Pretoria) and Ekhurhuleni Metro (East Rand). Those municipalities that exhibited the lowest biodiversity risk was Namaqualand DMA, Benede Oranje and !Kheis all situated in the Northern Cape.

Comparing Figure 6 with Figure 7 it is clear that the distribution of biodiversity risk is very different when the response value is not included. The focus of the index shifts from identifying municipalities with high pressure, high stocks and low conservation responses to highlighting those municipalities with only high pressures and stocks, regardless of what responses they have in place. The Metropolitan Areas highlighted in Figure 7 are good examples of municipalities that face many pressures, but also receive large amounts of money for conservation action. Because these responses are not equated these areas look worse off than they actually are.

Municipalities were arranged according to their original MuBRAI value, from highest to lowest, in Table 5. Each of the pressure, stock and response values which make up the MuBRAI value, together with the MuBRAI* value and MuBRAI* rank were also displayed in this table giving further transparency to the index.

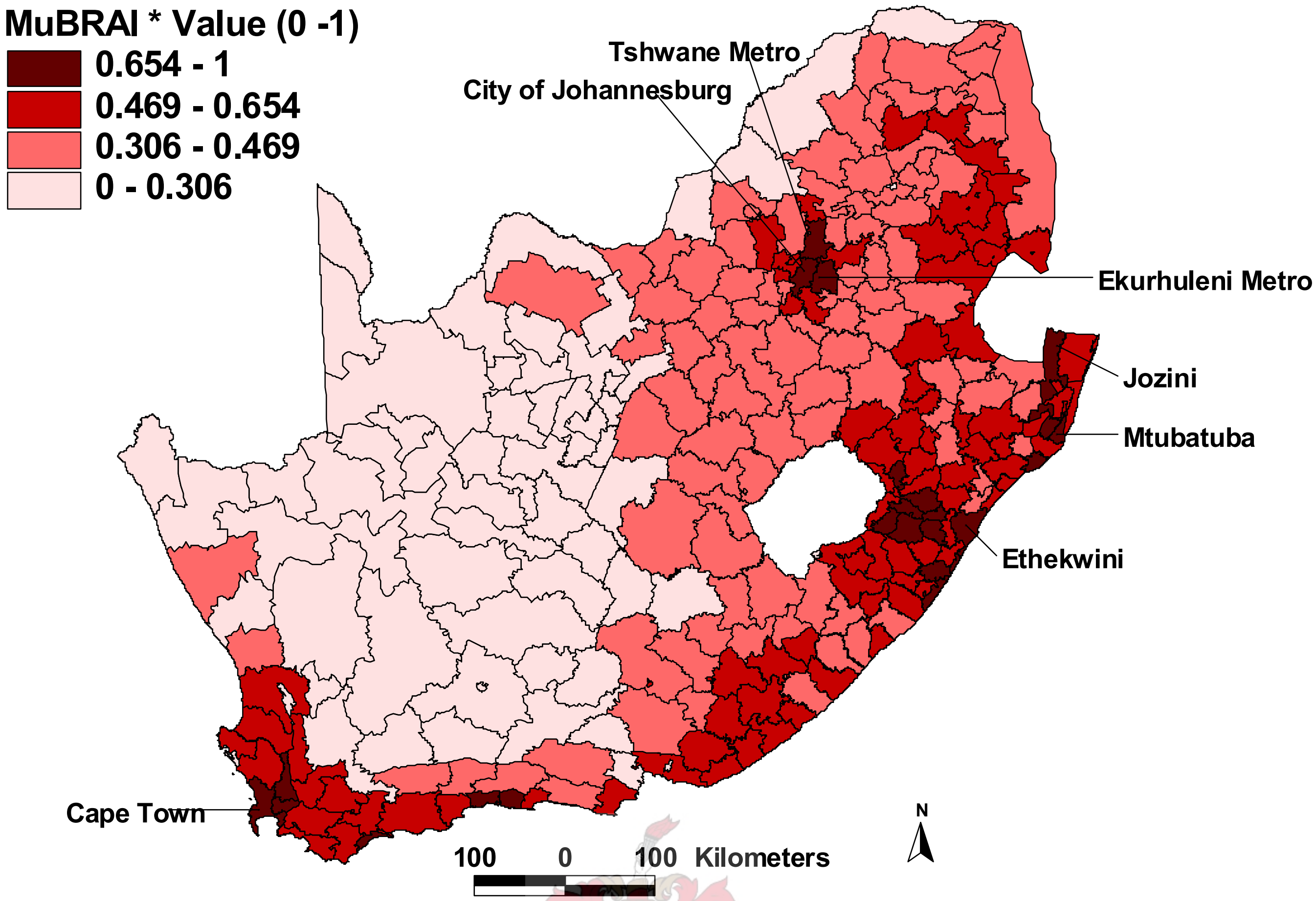

Figure 7. MuBRAI* values for 262 municipalities expressed as values between 0 and 1 where MuBRAI* = PR + ST. The response variable was excluded for comparison purposes. The darkest areas highlight municipalities having highest combinations of pressures and stock.

Table 5. MuBRAI scores for all 262 municipalities arranged from highest to lowest biodiversity risk.

Municipal Code	Municipal Name	Pressure Value (PR)	Stock Value (ST)	Response Value (RE)	MuBRAI* Value (PR + ST)	MuBRAI* Rank (262-1)	MuBRAI Value $\frac{(PR+ST)}{(RE)}$	MuBRAI Rank (262-1)
KZ212	Umdoni	0.335	0.462	7.47E-09	0.796	257	1.07E+08	262
KZ227	Richmond	0.252	0.359	7.47E-09	0.610	238	8.17E+07	261
KZ214	uMuziwabantu	0.271	0.301	7.47E-09	0.572	230	7.66E+07	260
KZ5a5	Ubuhlebezwe	0.275	0.292	7.47E-09	0.567	228	7.59E+07	259
KZ226	Mkhambathini	0.218	0.314	7.47E-09	0.532	211	7.13E+07	258
KZ292	KwaDukuza	0.300	0.230	7.47E-09	0.530	209	7.09E+07	257
GT412	Randfontein	0.253	0.252	7.47E-09	0.506	196	6.77E+07	256
EC137	Engcobo	0.280	0.188	7.47E-09	0.468	177	6.27E+07	255
KZ242	Nqutu	0.300	0.166	7.47E-09	0.466	174	6.23E+07	254
KZ5a3	Matatiele	0.195	0.257	7.47E-09	0.452	169	6.04E+07	253
EC152	Ntabankulu	0.285	0.158	7.47E-09	0.443	157	5.93E+07	252
KZ233	Indaka	0.267	0.172	7.47E-09	0.440	152	5.88E+07	251
FS173	Mantsopa	0.186	0.240	7.47E-09	0.426	143	5.71E+07	250
EC138	Sakhisizwe	0.169	0.255	7.47E-09	0.424	141	5.67E+07	249
EC141	Elundini	0.252	0.171	7.47E-09	0.424	139	5.67E+07	248
KZ293	Ndwedwe	0.255	0.165	7.47E-09	0.420	136	5.62E+07	247
KZ244	Msinga	0.241	0.177	7.47E-09	0.418	135	5.59E+07	246
KZ294	Maphumulo	0.243	0.171	7.47E-09	0.414	131	5.55E+07	245
NP352	Aganang	0.315	0.097	7.47E-09	0.413	130	5.52E+07	244
EC136	Emalahleni	0.211	0.199	7.47E-09	0.410	126	5.49E+07	243
MP306	Dipaleseng	0.175	0.234	7.47E-09	0.409	125	5.48E+07	242
EC142	Senqu	0.197	0.188	7.47E-09	0.385	114	5.16E+07	241
FS204	Metsimaholo	0.177	0.207	7.47E-09	0.384	112	5.14E+07	240
MP311	Delmas	0.201	0.179	7.47E-09	0.379	107	5.08E+07	239
FS193	Nketoana	0.213	0.160	7.47E-09	0.372	102	4.98E+07	238
MP307	Govan Mbeki Municipality	0.169	0.192	7.47E-09	0.361	95	4.83E+07	237
KZ241	Endumeni	0.167	0.193	7.47E-09	0.360	94	4.82E+07	236
EC143	Maletswai	0.136	0.218	7.47E-09	0.353	89	4.73E+07	235
FS205	Mafube	0.182	0.164	7.47E-09	0.347	85	4.64E+07	234
NW381	Setla-Kgobi	0.237	0.109	7.47E-09	0.346	83	4.63E+07	233
FS203	Ngwathe	0.185	0.159	7.47E-09	0.344	81	4.60E+07	232
NW391	Kagisano	0.274	0.060	7.47E-09	0.333	76	4.46E+07	231
MP305	Lekwa	0.154	0.177	7.47E-09	0.331	74	4.43E+07	230
FS201	Moqhaka	0.156	0.159	7.47E-09	0.315	63	4.22E+07	229
NW393	Mamusa	0.189	0.126	7.47E-09	0.314	62	4.20E+07	228
EC133	Inkwanca	0.119	0.182	7.47E-09	0.301	56	4.03E+07	227
FS182	Tokologo	0.166	0.127	7.47E-09	0.294	54	3.93E+07	226
CBLC7	Phokwane	0.171	0.109	7.47E-09	0.280	51	3.75E+07	225
NC093	Magareng	0.142	0.126	7.47E-09	0.269	45	3.60E+07	224
NW394	Greater Taung	0.179	0.077	7.47E-09	0.255	42	3.42E+07	223
NC091	Sol Plaatje	0.116	0.134	7.47E-09	0.250	40	3.34E+07	222
NW1a1	Moshaweng	0.182	0.063	7.47E-09	0.246	37	3.29E+07	221
NC073	Emthanjeni	0.097	0.118	7.47E-09	0.215	28	2.88E+07	220
NW392	Naledi	0.114	0.093	7.47E-09	0.207	25	2.77E+07	219
CBLC1	Ga-Segonyana	0.125	0.080	7.47E-09	0.206	23	2.75E+07	218
NC076	Thembelihle	0.101	0.093	7.47E-09	0.194	21	2.59E+07	217
NC01B1	Gamagara	0.091	0.097	7.47E-09	0.188	20	2.51E+07	216
NC086	Kgatelopele	0.094	0.085	7.47E-09	0.178	18	2.39E+07	215
NC083	||Khara Hais	0.086	0.087	7.47E-09	0.173	16	2.31E+07	214
NC078	Siyancuma	0.081	0.088	7.47E-09	0.169	15	2.26E+07	213
NC085	Tsantsabane	0.088	0.072	7.47E-09	0.159	12	2.13E+07	212

Table 5. MuBRAI scores for all 262 municipalities (Continued).

Municipal Code	Municipal Name	Pressure Value (PR)	Stock Value (ST)	Response Value (RE)	MuBRAI* Value (PR + ST)	MuBRAI* Rank (262-1)	MuBRAI Value (PR+ST) / (RE)	MuBRAI Rank (262-1)
NC077	Siyathemba	0.080	0.078	7.47E-09	0.158	11	2.11E+07	211
NCDMACB1	Kalahari	0.099	0.058	7.47E-09	0.157	10	2.10E+07	210
NC074	Kareeberg	0.075	0.074	7.47E-09	0.149	8	1.99E+07	209
FS195	Phumelela	0.161	0.234	7.47E-08	0.395	118	5.29E+06	208
NC084	!Kheis	0.059	0.059	7.61E-07	0.118	3	1.55E+05	207
MP312	Emalahleni	0.178	0.191	7.61E-06	0.369	100	4.84E+04	206
KZ253	Utrecht	0.169	0.259	2.03E-05	0.428	145	2.11E+04	205
EC151	Mbizana	0.299	0.196	4.44E-05	0.495	191	1.12E+04	204
KZ232	Emnambithi/ Ladysmith	0.197	0.276	5.03E-05	0.474	181	9.42E+03	203
NW384	Ditsobotla	0.163	0.150	3.65E-05	0.314	60	8.60E+03	202
FS184	Matjhabeng	0.196	0.146	5.41E-05	0.342	79	6.32E+03	201
EC05b2	Umzimvubu	0.287	0.179	1.72E-04	0.466	173	2.70E+03	200
KZ274	Hlabisa	0.352	0.432	3.92E-04	0.784	255	2.00E+03	199
KZ265	Nongoma	0.287	0.118	2.17E-04	0.405	124	1.87E+03	198
KZ225	Msunduzi	0.327	0.515	4.81E-04	0.842	259	1.75E+03	197
KZ213	Umzumbe	0.318	0.328	4.33E-04	0.645	243	1.49E+03	196
NP332	Greater Letaba	0.239	0.150	2.94E-04	0.389	115	1.32E+03	195
NP03A2	Makhuduthamaga	0.287	0.090	3.28E-04	0.377	106	1.15E+03	194
EC154	Port St Johns	0.249	0.300	6.21E-04	0.549	221	884.319	193
KZ221	uMshwathi	0.280	0.306	7.58E-04	0.586	232	772.324	192
NW375	Moses Kotane	0.188	0.110	4.60E-04	0.298	55	647.223	191
EC155	Nyandeni	0.240	0.188	7.31E-04	0.427	144	584.461	190
KZ245	Umvoti	0.252	0.298	9.85E-04	0.550	223	558.279	189
Durban	Ethekwini	0.414	0.381	1.46E-03	0.795	256	543.943	188
NW403	City Council of Klerksdorp	0.155	0.171	8.40E-04	0.325	69	386.968	187
FS181	Masilonyana	0.143	0.143	8.81E-04	0.286	53	324.272	186
CBLC5	Greater Tubatse	0.183	0.167	1.18E-03	0.350	88	297.487	185
KZ261	eDumbe	0.211	0.212	1.50E-03	0.424	140	283.230	184
NW371	Moretele	0.283	0.180	1.65E-03	0.463	171	280.801	183
KZ285	Mthonjaneni	0.236	0.260	1.78E-03	0.496	192	279.285	182
East Rand	Ekurhuleni Metro	0.427	0.320	2.79E-03	0.747	253	267.894	181
NCDMA07	Bo Karoo	0.060	0.073	4.99E-04	0.133	5	266.447	180
KZ223	Mooi Mpofana	0.213	0.378	2.49E-03	0.591	234	237.078	179
EC156	Mhlontlo	0.265	0.130	1.74E-03	0.395	119	226.761	178
NP343	Thulamela	0.240	0.130	1.71E-03	0.371	101	216.337	177
NW382	Tswaing	0.212	0.138	1.72E-03	0.349	87	203.524	176
KZ5a4	Greater Kokstad	0.210	0.288	2.46E-03	0.499	193	202.967	175
FS163	Mohokare	0.151	0.180	1.77E-03	0.331	75	186.894	174
FS192	Dihlabeng	0.195	0.217	2.26E-03	0.411	128	182.252	173
KZ283	Ntambanana	0.223	0.192	2.61E-03	0.416	132	159.025	172
GT421	Emfuleni	0.303	0.245	3.95E-03	0.548	220	138.774	171
KZ263	Abaqulusi	0.200	0.210	3.03E-03	0.410	127	135.508	170
NP354	Polokwane	0.270	0.209	3.55E-03	0.479	183	135.039	169
FS185	Nala	0.249	0.134	2.97E-03	0.383	111	128.729	168
KZ5a2	Kwa Sani	0.218	0.413	5.01E-03	0.631	241	126.071	167
KZ281	Mbonambi	0.292	0.244	4.37E-03	0.535	212	122.531	166
NP331	Greater Giyani	0.246	0.115	3.34E-03	0.362	96	108.155	165
NP344	Makhado	0.204	0.190	3.87E-03	0.394	117	101.604	164
NW402	Potchefstroom	0.159	0.223	3.82E-03	0.382	109	99.958	163
FS172	Mangaung	0.184	0.197	3.87E-03	0.381	108	98.375	162
KZ282	uMhlathuze	0.348	0.352	7.20E-03	0.700	250	97.158	161

Table 5. MuBRAI scores for all 262 municipalities (Continued).

Municipal Code	Municipal Name	Pressure Value (PR)	Stock Value (ST)	Response Value (RE)	MuBRAI* Value (PR + ST)	MuBRAI* Rank (262-1)	MuBRAI Value (PR+ST) / (RE)	MuBRAI Rank (262-1)
NW401	Ventersdorp	0.162	0.180	3.88E-03	0.342	78	87.965	160
NP353	Molemole	0.215	0.129	4.17E-03	0.344	80	82.515	159
MP302	Msukaligwa	0.160	0.217	4.65E-03	0.377	105	81.068	158
City of Johannesburg Metro		0.573	0.342	1.15E-02	0.915	261	79.806	157
KZ222	uMngeni	0.238	0.495	9.30E-03	0.733	252	78.807	156
EC132	Tsolwana	0.142	0.185	4.22E-03	0.327	72	77.564	155
CBLC2	Kungwini	0.191	0.254	5.79E-03	0.446	160	76.943	154
GT423	Lesedi	0.174	0.259	5.77E-03	0.433	147	74.969	153
EC121	Mbhashe	0.250	0.200	6.03E-03	0.450	167	74.609	152
KZ252	Newcastle	0.207	0.284	6.61E-03	0.491	187	74.307	151
KZ235	Okhahlamba	0.248	0.338	8.16E-03	0.587	233	71.918	150
NP342	Mutale	0.225	0.137	5.13E-03	0.363	98	70.710	149
KZ211	Vulamehlo	0.250	0.293	7.68E-03	0.543	218	70.651	148
KZ224	Impendle	0.264	0.425	1.08E-02	0.689	249	63.622	147
FS161	Letsemeng	0.124	0.121	3.86E-03	0.245	36	63.361	146
NW374	Kgetlengrivier	0.157	0.166	5.16E-03	0.324	66	62.701	145
MP303	Mkhondo	0.217	0.225	7.10E-03	0.442	154	62.226	144
MP313	Middelburg	0.175	0.217	6.49E-03	0.393	116	60.510	143
NC071	Ubuntu	0.089	0.112	3.33E-03	0.200	22	60.049	142
MP314	Highlands	0.150	0.288	7.36E-03	0.438	151	59.519	141
FS191	Setsoto	0.228	0.195	7.11E-03	0.423	138	59.505	140
KZ234	Umtshezi	0.210	0.337	9.32E-03	0.547	219	58.715	139
KZ215	Ezingoleni	0.245	0.331	9.98E-03	0.576	231	57.725	138
KZ284	uMlalazi	0.231	0.286	9.10E-03	0.516	200	56.732	137
GT414	Westonaria	0.183	0.221	7.15E-03	0.404	123	56.530	136
FS171	Naledi	0.164	0.190	6.27E-03	0.354	90	56.452	135
KZ236	Imbabazane	0.293	0.335	1.15E-02	0.628	240	54.668	134
KZ266	Ulundi	0.259	0.195	8.41E-03	0.454	170	53.997	133
EC157	King Sabata Dalindyebo	0.274	0.156	8.05E-03	0.431	146	53.519	132
KZ254	Dannhauser	0.246	0.246	9.26E-03	0.492	188	53.128	131
CBLC3	Greater Marble Hall	0.270	0.128	7.56E-03	0.398	120	52.565	130
NP366	Bela-Bela	0.178	0.196	7.46E-03	0.374	104	50.053	129
KZ291	eNdondakusuka	0.259	0.210	9.89E-03	0.469	178	47.385	128
CBLC6	Bushbuckridge	0.328	0.225	1.20E-02	0.552	224	45.854	127
EC05b1	Umzimkhulu	0.281	0.282	1.28E-02	0.563	227	44.053	126
NC072	Umsombomvu	0.101	0.159	5.94E-03	0.260	43	43.737	125
KZ272	Jozini	0.304	0.333	1.47E-02	0.637	242	43.401	124
EC153	Qaukeni	0.238	0.199	1.01E-02	0.437	150	43.252	123
CBLC8	Merafong City	0.153	0.221	8.64E-03	0.373	103	43.163	122
NW383	Mafikeng	0.227	0.141	8.65E-03	0.368	99	42.579	121
KZ286	Nkandla	0.228	0.217	1.05E-02	0.445	159	42.332	120
CBLC4	Greater Groblersdal	0.204	0.181	9.42E-03	0.385	113	40.853	119
NP03A3	Fetakgomo	0.251	0.094	9.34E-03	0.345	82	36.931	118
NW395	Molopo	0.173	0.057	6.34E-03	0.230	32	36.285	117
KZ216	Hibiscus Coast	0.282	0.365	1.86E-02	0.647	244	34.722	116
MP322	Mbombela	0.213	0.261	1.38E-02	0.475	182	34.413	115
KZ5a1	Ingwe	0.294	0.393	2.14E-02	0.687	248	32.147	114
MP304	Seme	0.189	0.275	1.46E-02	0.464	172	31.864	113
NW404	Maquassi Hills	0.176	0.149	1.07E-02	0.325	68	30.351	112
FS162	Kopanong	0.131	0.171	9.98E-03	0.301	57	30.178	111
NC075	Renosterberg	0.096	0.122	7.24E-03	0.218	29	30.150	110

Table 5. MuBRAI scores for all 262 municipalities (Continued).

Municipal Code	Municipal Name	Pressure Value (PR)	Stock Value (ST)	Response Value (RE)	MuBRAI* Value (PR + ST)	MuBRAI* Rank (262-1)	MuBRAI Value $\frac{(PR+ST)}{(RE)}$	MuBRAI Rank (262-1)
EC144	Gariep	0.114	0.165	1.02E-02	0.278	49	27.299	109
GT411	Mogale City	0.268	0.301	2.24E-02	0.569	229	25.367	108
NP351	Blouberg	0.219	0.107	1.34E-02	0.327	71	24.474	107
FS183	Tswelopele	0.210	0.129	1.44E-02	0.339	77	23.550	106
NP04A1	Maruleng	0.261	0.219	2.10E-02	0.481	185	22.857	105
Pretoria	City of Tshwane Metro	0.402	0.371	3.44E-02	0.772	254	22.467	104
NCDMA09	Diamondfields	0.055	0.085	6.39E-03	0.140	6	21.963	103
KZ273	The Big 5 False Bay	0.223	0.313	2.58E-02	0.536	214	20.801	102
NW396	Lekwa-Teemane	0.125	0.148	1.38E-02	0.272	48	19.673	101
FS194	Maluti a Phofung	0.229	0.310	3.15E-02	0.539	215	17.120	100
NP364	Mookgopong	0.196	0.163	2.17E-02	0.359	93	16.535	99
MP324	Nkomazi	0.234	0.207	2.76E-02	0.442	155	16.023	98
NP362	Lephalale	0.155	0.092	1.55E-02	0.247	38	16.012	97
NC092	Dikgatlong	0.135	0.127	1.65E-02	0.263	44	15.880	96
NP361	Thabazimbi	0.116	0.106	1.40E-02	0.222	30	15.875	95
GT422	Midvaal	0.167	0.283	2.90E-02	0.450	166	15.516	94
NP333	Greater Tzaneen	0.272	0.252	3.49E-02	0.524	207	15.000	93
MP301	Albert Luthuli	0.210	0.258	3.16E-02	0.468	176	14.811	92
NP341	Musina	0.169	0.103	2.01E-02	0.271	46	13.509	91
KZ271	Umhlabuyalingana	0.266	0.215	3.65E-02	0.481	184	13.183	90
NP367	Mogalakwena	0.205	0.123	2.74E-02	0.328	73	11.997	89
MP321	Thaba Chweu	0.177	0.343	4.36E-02	0.520	204	11.941	88
NP365	Modimolle	0.144	0.158	2.65E-02	0.302	58	11.424	87
NW372	Madibeng	0.219	0.206	3.77E-02	0.425	142	11.282	86
KZ275	Mtubatuba	0.323	0.611	8.71E-02	0.933	262	10.715	85
MP316	Dr JS Moroka	0.257	0.160	4.39E-02	0.417	134	9.491	84
NP334	Ba-Phalaborwa	0.203	0.159	3.84E-02	0.362	97	9.420	83
NW373	Rustenburg	0.201	0.248	4.81E-02	0.450	165	9.337	82
GT02b1	Nokeng tsa Taemane	0.134	0.223	3.84E-02	0.358	91	9.311	81
NW385	Zeerust	0.154	0.125	3.11E-02	0.279	50	8.982	80
KZ262	uPhongolo	0.193	0.210	4.83E-02	0.402	122	8.336	79
MP315	Thembisile	0.166	0.193	4.35E-02	0.358	92	8.228	78
MP323	Umjindi	0.178	0.358	6.74E-02	0.536	213	7.954	77
EC135	Intsika Yethu	0.256	0.188	6.33E-02	0.444	158	7.015	76
NC082	Kai !Garib	0.070	0.077	2.17E-02	0.146	7	6.748	75
EC134	Lukanji	0.181	0.267	7.06E-02	0.447	163	6.333	74
GTDMA41	West Rand	0.164	0.356	8.95E-02	0.519	203	5.804	73
NP355	Lepele-Nkumpi	0.219	0.164	7.08E-02	0.382	110	5.399	72
NC081	Mier	0.106	0.045	4.20E-02	0.151	9	3.603	71
EC122	Mnquma	0.226	0.176	1.50E-01	0.402	121	2.680	70
NCDMA08	Benede Oranje	0.061	0.051	4.21E-02	0.112	2	2.658	69
EC131	Inxuba Yethemba	0.129	0.190	1.36E-01	0.319	64	2.348	68
MPDMA32	Lowveld	0.118	0.424	2.47E-01	0.542	217	2.199	67
City of Cape	Town	0.401	0.458	4.02E-01	0.859	260	2.135	66
Port Elizabeth	Nelson Mandela	0.231	0.436	3.46E-01	0.667	246	1.929	65
KZDMA22	Highmoor/Kamberg Park	0.110	0.499	3.33E-01	0.609	237	1.829	64
WC024	Stellenbosch	0.264	0.560	4.53E-01	0.824	258	1.818	63
WC044	George	0.208	0.497	4.10E-01	0.705	251	1.718	62
EC125	Buffalo City	0.238	0.323	3.41E-01	0.561	226	1.644	61
WC014	Saldanha Bay	0.222	0.334	3.40E-01	0.556	225	1.634	60

Table 5. MuBRAI scores for all 262 municipalities (Continued).

Municipal Code	Municipal Name	Pressure Value (PR)	Stock Value (ST)	Response Value (RE)	MuBRAI* Value (PR + ST)	MuBRAI* Rank (262-1)	MuBRAI Value (PR+ST)/(RE)	MuBRAI Rank (262-1)
KZDMA27	St Lucia Park	0.176	0.354	3.28E-01	0.530	208	1.616	59
FSDMA19	Golden Gate Highlands National Park	0.045	0.487	3.33E-01	0.532	210	1.594	58
WC047	Plettenberg Bay	0.157	0.451	3.84E-01	0.608	236	1.584	57
KZDMA43	Mkhomazi Wilderness Area	0.115	0.390	3.22E-01	0.504	195	1.564	56
MPDMA31	Mdala Nature Reserve	0.024	0.485	3.26E-01	0.509	198	1.560	55
EC123	Great Kei	0.195	0.321	3.36E-01	0.516	199	1.535	54
WC023	Drakenstein	0.222	0.450	4.38E-01	0.672	247	1.534	53
KZDMA23	Gaints Castle Game Reserve	0.091	0.403	3.24E-01	0.494	190	1.526	52
WC048	Knysna	0.167	0.488	4.36E-01	0.656	245	1.505	51
WC015	Swartland	0.220	0.300	3.46E-01	0.519	202	1.502	50
EC124	Amahlathi	0.189	0.311	3.42E-01	0.500	194	1.462	49
WC034	Swellendam	0.164	0.386	3.76E-01	0.549	222	1.460	48
EC105	Ndlambe	0.165	0.355	3.57E-01	0.520	205	1.457	47
EC108	Kouga	0.164	0.355	3.59E-01	0.519	201	1.448	46
WC031	Theewaterskloof	0.195	0.396	4.09E-01	0.592	235	1.447	45
EC126	Ngqushwa	0.224	0.247	3.34E-01	0.470	180	1.407	44
WC033	Cape Agulhas	0.184	0.308	3.53E-01	0.492	189	1.395	43
EC127	Nkonkobe	0.222	0.285	3.77E-01	0.507	197	1.345	42
WC032	Overstrand	0.147	0.393	4.04E-01	0.540	216	1.337	41
WC043	Mossel Bay	0.139	0.327	3.52E-01	0.467	175	1.326	40
EC101	Camdeboo	0.101	0.182	2.14E-01	0.283	52	1.320	39
NWDMA37	Pilansberg National Park	0.200	0.234	3.31E-01	0.434	149	1.312	38
EC104	Makana	0.137	0.310	3.47E-01	0.446	161	1.288	37
EC128	Nxuba	0.165	0.257	3.34E-01	0.422	137	1.263	36
NC066	Karoo Hoogland	0.064	0.099	1.30E-01	0.163	13	1.253	35
WC042	Langeberg	0.144	0.305	3.63E-01	0.449	164	1.236	34
WC013	Bergrivier	0.150	0.296	3.62E-01	0.446	162	1.233	33
WCDMA03	Overberg	0.233	0.391	5.10E-01	0.624	239	1.224	32
WC012	Cederberg	0.121	0.319	3.71E-01	0.440	153	1.186	31
WC026	Breede River/Winelands	0.117	0.353	4.18E-01	0.469	179	1.123	30
ECDMA14	Oviston Nature Reserve	0.041	0.308	3.20E-01	0.348	86	1.087	29
EC106	Sunday's River Valley	0.147	0.304	4.18E-01	0.450	168	1.077	28
WCDMA04	South Cape	0.086	0.327	3.86E-01	0.412	129	1.069	27
WC025	Breede Valley	0.130	0.359	4.60E-01	0.489	186	1.063	26
WC045	Oudtshoorn	0.085	0.331	4.01E-01	0.417	133	1.039	25
WC022	Witzenberg	0.133	0.390	5.09E-01	0.523	206	1.027	24
EC109	Kou-Kamma	0.106	0.328	4.28E-01	0.433	148	1.012	23
EC102	Blue Crane Route	0.120	0.226	3.43E-01	0.346	84	1.010	22
CBDMA4	Kruger Park	0.134	0.188	3.19E-01	0.323	65	1.010	21
CBDMA3	Schuinsdraai Nature Reserve	0.036	0.172	2.16E-01	0.208	26	0.966	20
WC011	Matzikama	0.108	0.217	3.41E-01	0.324	67	0.951	19
WCDMA05	Central Karoo	0.082	0.150	2.46E-01	0.233	33	0.947	18
NC067	Khâi-Ma	0.059	0.073	1.47E-01	0.132	4	0.902	17
NC064	Kamiesberg	0.167	0.146	3.55E-01	0.313	59	0.882	16
ECDMA13	Mountain Zebra National Park	0.092	0.351	5.09E-01	0.443	156	0.870	15
WC041	Kannaland	0.069	0.257	3.92E-01	0.326	70	0.832	14
EC107	Baviaans	0.089	0.224	3.91E-01	0.314	61	0.803	13
EC103	Ikwezi	0.104	0.168	3.44E-01	0.272	47	0.791	12

Table 5. MuBRAI scores for all 262 municipalities (Continued).

Municipal Code	Municipal Name	Pressure Value (PR)	Stock Value (ST)	Response Value (RE)	MuBRAI* Value (PR + ST)	MuBRAI* Rank (262-1)	MuBRAI Value (PR+ST) / (RE)	MuBRAI Rank (262-1)
NC065	Hantam	0.070	0.106	2.34E-01	0.176	17	0.751	11
ECDMA10	Aberdeen Plain	0.085	0.168	3.46E-01	0.253	41	0.731	10
WC053	Beaufort West	0.083	0.124	2.97E-01	0.207	24	0.696	9
ECDMA44	O'Conners Camp	0.019	0.208	3.31E-01	0.227	31	0.685	8
WCDMA01	West Coast	0.111	0.138	3.70E-01	0.249	39	0.673	7
WC052	Prince Albert	0.059	0.175	3.61E-01	0.233	34	0.647	6
WCDMA02	Breede River	0.041	0.204	3.79E-01	0.244	35	0.644	5
WC051	Laingsburg	0.054	0.160	3.55E-01	0.214	27	0.603	4
NCDMA06	Namaqualand	0.037	0.058	1.61E-01	0.095	1	0.588	3
NC062	Nama Khoi	0.063	0.100	3.42E-01	0.164	14	0.478	2
NC061	Richtersveld	0.089	0.093	3.89E-01	0.182	19	0.467	1
Average for each variable		*0.189*	*0.228*	*0.099*	*0.417*		9.78E+06	
Maximum value		*0.573*	*0.611*	*0.510*	*0.933*		1.07E+08	
Corresponding MuBRAI rank for maximum		*157*	*85*	*32*	*85*		*262*	
Minimum value		*0.019*	*0.045*	*7.47E-09*	*0.095*		*0.467*	
Corresponding MuBRAI rank for minimum		*8*	*71*	*209-262*	*3*		*1*	

The municipalities were ordered from highest to lowest MuBRAI value in Table 5. The table gives valuable information on the present state of stock, pressure and response in each municipality and also express what the MuBRAI would look like if it, like many other indices, omits the response measure. Minimum and maximum values for each category can also be derived from this table coupling them to specific municipalities. City of Johannesburg Metro had the largest combined pressure in the country and Mtubatuba municipality contained the highest stocks in the country in terms of total animal species and endemic animal species densities and vegetation type richness. The Witzenberg municipality showed the most responses because it falls entirely within a bioregional plan and contains large Type 1 and especially Type 2 protected areas (mountain catchment area).

The pressure, stock and response value for each municipality can be broken up further into their component variables, revealing the character of each municipality explaining their particular positions in the MuBRAI rank. The municipality with the highest sum of pressure and stock was Mtubatuba in KwaZulu-Natal. Its high stock value influenced this value the most.

City of Johannesburg had the second highest value for this category and it was influenced the most by its high pressure value. Namaqualand in the Northern Cape had the lowest sum of pressure and stock value (Table 5).

From the raw data, the variables that contributed the most to Umdoni’s high pressure value were population density change, population density and threatened species density. Species density and vegetation type richness contributed the most to its high stock value. Richmond in KwaZulu-Natal ranked as the municipality with the second highest biodiversity risk (Table 6) and had the variables transformed land and threatened species density contributing the most to its high pressure value. Species density, and in a lesser way vegetation type richness, contributed the most to its high stock value.

Richtersveld in Northern Cape faced the least biodiversity risk (Table 5). The stock variables, Type 1 protected areas and bioregional plans contributed the most to its low risk value. It had a low pressure value due to low degraded and transformed land and low population density. Nama Khoi municipality, also in the Northern Cape, showed the second lowest biodiversity risk. It falls entirely within a bioregional plan and had low pressure values.

From the raw data described in Table 2, City of Johannesburg had the highest population density and highest change in population density in the country. The Overberg DMA in the Western Cape had the highest concentration of rich households and Jozini in KwaZulu-Natal the largest number of poorest households. Degradation was measured the highest in Aganang (Limpopo) with the highest transformation measured in KwaDukuza (KwaZulu-Natal). Mtubatuba in KwaZulu-Natal had the highest threatened species density and species density. Stellenbosch in the Western Cape had the highest endemic species density. The highest vegetation type richness was present within Mdala Nature Reserve (Mpumalanga). The bioregional plans covered many of the western and southern coast municipalities by a hundred percent. No specific municipality could be highlighted as having the highest response in this regard.

3.2.6. Spearman Correlation Analyses

The final pressure, stock and response values were subjected to Spearman Correlation Analysis. A correlation was significant when $p < 0.05$ and $r > 0.4$ or $r < -0.4$. From the results, only stock and response showed weak, but significant positive correlations with each other (Table 6).

Table 6. Spearman correlation analysis for the Pressure, Stock and Response values which is used to construct the MuBRAI.

	Pressure Value	Stock Value	Response Value
Pressure Value		**0.31**	**-0.21**
Stock Value			**0.42**
Response Value			

4. DISCUSSION

4.1. DISTRIBUTION OF STOCKS, PRESSURES AND RESPONSES

This study highlighted the fact that the distribution of biodiversity, human population and activity as well as conservation efforts are not distributed evenly across the surface of South Africa. The implication for municipalities is that, in terms of biodiversity conservation, a single solution will not work everywhere. There is a need for fine scale planning, better land-use plans, conservation plans and innovative decision-making. The lack of resources available to implement such initiatives necessitates prioritisation. The Municipal Biodiversity Risk Assessment was found to be particularly useful in prioritising municipalities for conservation action. The first steps taken were collating data and identifying important variables as indicators of biodiversity risk for South Africa at the municipal scale. Three important components for measuring biodiversity risk were identified. They were stocks, which represent the biological richness, endemism and extent of pristine habitat of an area; pressures which represent any threat to biodiversity and might deplete stocks; and responses which represent the effort put into biodiversity conservation and the sustainable use of natural resources. Important correlations were identified between some of the variables identified to represent these three groups. These are discussed below.

From the results, the three biodiversity stock variables: total species density, endemic species density and vegetation type richness correlated positively with each other. . Higher biodiversity stocks were found along the coast, from the Western Cape eastwards up to and including KwaZulu-Natal and certain inland areas (eastern and northern parts of the country).

Similarly, the results seem to support the heterogeneity of the distribution of pressures across the country. Pressures seem to concentrate more in municipalities known for their high human population densities and high human population density changes. It was interesting to note that most of these municipalities were also situated along the coast, with some inland within the eastern and northern parts of the country, such as the Johannesburg Metropolitan Area. Metropolitan Areas were especially identified as having high pressures.

Whilst interpreting the heterogeneous distributions of both the stocks and pressures per municipality, it became evident that these measures followed the same distribution trend. Municipalities with high stocks also appeared to endure high pressures, such as Mtubatuba and Msunduzi municipalities in KwaZulu-Natal and Cities of Johannesburg and Cape Town Metropolitan Areas. From the Spearman correlations, total species density positively correlated with human population density and population density change which could corroborate other findings that humans and species tend to follow the productivity gradient of a region (Cincotta *et al.* 2000; UCS 2000; Balmford *et al.* 2001; Ricketts and Imhoff 2003; Chown *et al.* 2003; Van Rensburg *et al.* 2004). This productivity gradient appears to be associated with the rainfall gradient from west to east, and supports highly productive ecosystems that in return support high levels of biodiversity (Andrews and O'Brien 2000; O'Brien *et al.* 2000; Van Rensburg *et al.* 2002). It is speculated that people prefer to stay in these areas because of resource availability, economic benefit and health conditions, which would also explain why human populations in these biodiversity rich areas continue to grow more rapidly than in other areas (Cincotta *et al.* 1990).

An alternative explanation of why pressures and stocks tend to be associated with each other could possibly be sampling bias. From the literature, sampling bias in favour of urban areas, protected areas and road networks are evident (Freitag *et al.* 1998). Sampling bias along roads are usually obvious when the sampling points fall within 10km of the road network. Proximity to universities, museums and other institutions involved with collecting data often contributes to trends displaying high stock values for urban areas (areas with large pressures) (Freitag *et al.* 1998). However, the datasets used in this study are the best available for South Africa, have limited survey bias and are based on sound taxonomic information.

It is not always the density and growth rate of human populations that impact on biodiversity and influence where conservation action can be applied or not. Socio-economic status of people and their associated land uses also play a major role, especially when the area proposed for conservation action is impoverished (Hoffman *et al.* 1999). Poverty could contribute significantly to biodiversity loss, especially when it results in land degradation, as the correlation between the variables representing extremely poor households and land degradation suggests.

Poor households, especially those living in rural environments, rely heavily on the natural environment for survival. Therefore, bad agricultural practises and dense populations in small areas resulting from historic land use planning, especially during the Apartheid Era, could be some of the main reasons why degradation is strongly associated with poverty in South Africa (Hoffman *et al.* 1999). Due to inappropriate land use planning the Eastern Cape is the most severely degraded province in the country (Hoffman *et al.* 1999). The Eastern Cape contains productive ecosystems, high human population densities exacerbated by former homelands, like Transkei and Ciskei, and their related human activities, especially crop and stock farming, and overexploitation of biodiverse areas (Hoffman *et al.* 1999). In the Limpopo Province, degradation is also severe, especially in the former homeland areas of Venda, Lebowa and Gazankulu. KwaZulu-Natal is also affected, particularly in communal areas along the escarpment.

As more and more humans live in and go about their activities in biodiversity rich areas, it directly affects biodiversity by isolating already insufficient protected areas. Because of this, biodiversity has to depend only on these isolated protected areas for survival in many regions. Under increasing climate change, with water as the limiting factor (Schulze *et al.* 2001), fewer areas will become available to sustain both biodiverse rich areas and high human population densities and their associated activities (Van Rensburg *et al.* 2004). Scientists have expressed their concern that conflict between anthropogenic land uses like agriculture, mining, forestry and urban and industrial development and conservation might increase (more rapidly) in the future (Balmford *et al.* 2001, Ricketts and Imhoff 2003).

The problem of addressing competition between anthropogenic land uses and conservation is a difficult and sensitive issue, especially in a developing country like South Africa. One possible solution to the problem could be to, instead of identifying purely highly biodiverse areas that might have many anthropogenic threats as priority conservation areas, rather select areas with less competition that are slightly less biodiverse (Van Rensburg *et al.* 2004). With the data collated for this risk assessment, it would be possible to identify such areas in the future, as most of the necessary datasets are already collated and available at the municipal scale. It would also be crucial for such a study to include the economic value of land in order to prioritise conservation areas.

Viewing the stock, pressure and response trends of South Africa, it became evident that responses in the form of conservation areas did not correspond with either the current stock or pressure distributions due to their historical *ad hoc* demarcation. Even though IUCN has suggested that 10% of each vegetation type should be protected, this is not the case in South Africa. Only 6% of the entire country is formally conserved within Type 1 or Type 2 protected areas and in most instances these reserves are not even optimally placed. Only Mountain Fynbos areas and Savannas are well protected within these areas (Rouget *et al.* 2004). Bearing in mind that reserves were not originally demarcated at the municipal scale, but at the national scale, it was still distressing to find that fifty four municipalities out of the total 262 municipalities do not have any of the measured responses (bioregional plans and conservation areas) in place.

Like Driver *et al.* (2005), this study found the ecosystems (as defined by Driver *et al.* 2005) in the Grasslands, Maputoland Pondoland, Albany Thicket, Wildcoast and in the Lowland Fynbos to be especially under-protected. These ecosystems were also the areas highlighted by this study as containing both large stocks and pressures.

As suspected, there is a huge gap in conservation responses in biodiverse areas with high pressures at the municipal scale. With current initiatives, such as the proclaimed bioregional plans of CAPE, SKEP and STEP, it is intended to identify such areas for conservation within these regions. Once such areas are identified, the implementation phase will also filter down to the municipal scale. Bioregional plans are “generic” responses that initiate conservation orientated research and management of bioregions without having a physical presence or value (Cowling *et al.* 2003; Younge and Fowkes 2003).

As there is a lack of measurable conservation responses in South Africa, it was decided to include bioregional plans as a response variable for the purpose of this study to give an indication of the level of involvement of each municipality in conservation initiatives. This variable representing the bioregional plan coverage in each municipality showed large variation because of extremes in the data. Some municipalities had a hundred percent coverage, but most of the municipalities had no coverage by any bioregional plan. From the results it was obvious that the current initiatives are either not adequate or not sufficiently established yet to meet conservation needs on the municipal scale. It was clear that additional rapid, robust prioritisation methods are required to facilitate prioritised conservation action at the municipal scale.

4.2. IMPORTANCE OF INCLUDING RESPONSE MEASURES IN BIODIVERSITY RISK INDICES

Not surprisingly, the results of the original MuBRAI and the amended MuBRAI* were very different. Excluding the response measure in the amended MuBRAI*, important areas with high numbers of stock facing serious pressures were still identified, but were not put into perspective. The urgency of implementing conservation responses could therefore not be determined, because the existing responses in these critical areas were not considered. The results of the amended MuBRAI* highlighting biodiversity risk areas, especially along the coast and in Metropolitan Areas, corroborate with what was found in other studies (Cowling *et al.* 2003; CAPE 2004; Driver *et al.* 2005), but do not really contribute anything new to the literature. As a result of these previous studies, conservation attention such as implementing bioregional programmes, are already being focused in many of these areas identified by the amended MuBRAI*. Five of the six Metropolitan Areas were included in the top ten highest biodiversity risk municipalities. As discussed earlier, these areas are at high risk of biodiversity loss, but are already receiving national and international attention.

It is therefore clear that in terms of distributing resources to protect and rehabilitate as much areas with high biodiversity risk as possible, it is extremely important knowing what conservation responses are in place and how current resources, budgets and donations are being spent. Municipalities identified with high biodiversity risk according to the original MuBRAI are therefore more representative of areas that urgently need conservation attention as they have not yet been identified by other prioritisation methods. This exercise clearly showed how easily municipalities, with reasonable quantities of stock facing large pressures, but with no conservation responses in place could slip through the cracks if municipalities are not assessed holistically. The inclusion of a response measures in the final MuBRAI is therefore a major improvement on other approaches.

4.3. INTERPRETING VARIABLES AND THE FINAL MUBRAI RESULTS

For this Biodiversity Risk Assessment to have a practical application, the identified variables had to be collated into some interpretable format that could facilitate informed decision-making regarding the allocation of resources to municipalities for conservation action. The Municipal Biodiversity Risk Assessment Index (MuBRAI) was developed for this purpose and prioritised municipalities that have high biodiversity stocks and pressures and low responses in place.

The MuBRAI rank should be interpreted with caution when deciding which municipalities should be prioritised for conservation action. Since the final MuBRAI value for a particular municipality represents thirteen variables, expressing all influences as a single compressed value, it implies that detail will get lost in the final ranking, which could lead to misinterpretation. The user must be aware of how the rank was assimilated and of all the assumptions that have been made.

The MuBRAI ranking system was designed to incorporate measures of biodiversity pressures, stock and responses. The addition of measures of responses made this index especially unique; otherwise it would have (as many other methods before it) prioritised areas that already have adequate responses in place. For instance, the Cape Floristic Area that receives many international responses. It was felt by some that government resources are too limited to spend on areas with sufficient responses in place and was one of the main reasons why the MuBRAI was created - to exclude areas with large responses and rather focus on biodiverse areas under great pressure that do not have adequate responses in place.

Being designed for this purpose, it was important that the MuBRAI equation includes all three components of pressures, stocks and responses in order to give a holistic picture of the biodiversity risk status of each municipality. The assessment identified fifty four municipalities with no response measures in place, with the result that these municipalities were automatically ranked as high biodiversity risk municipalities, even though their biodiversity stocks were not necessarily high. This was contrary to the original definition of the MuBRAI, which aimed to highlight areas with high pressure, high stocks and low responses.

The way the results from the MuBRAI are interpreted will depend on the user and the reason for using the index. If the index is going to be used literally, the user should be aware that municipalities with no response measures whatsoever are ranked “higher” than they should have been in terms of their stocks and pressures. For this reason, the index should rather be used in collaboration with other prioritisation methods.

It should also be realised that municipalities identified by the MuBRAI as high biodiversity risk areas are not necessarily the optimal municipalities to actually allocate additional conservation resources to. In terms of land prices and feasibility of land preservation, these identified municipalities might be in competition with other more sustainable land uses. In such a case where alternative land uses are a better option than conservation in terms of sustainable development of the country, alternative municipalities need to be identified that have similar biodiversity importance and less competition in terms of land prices and demand, and will make for a better option of biodiversity conservation (Rickett and Imhoff 2003). This being said, it is not suggested that entire municipalities should be demarcated for development without retaining some biodiversity within their boundaries. Resources should be allocated to all municipalities, but where possible, should rather be focused on municipalities where it can make the biggest difference in terms of biodiversity conservation.

This concept brings about an altogether new set of issues that falls outside the scope of this study. Principal Component Analysis (PCA) was used to determine the underlying relationships between the variables chosen for the MuBRAI without their independent variances influencing the results (Dunteman 1989; Quinn and Keough 2002). Three types of municipalities (Local, Metropolitan Areas and District Management Areas) were naturally separated during these analyses due to the type of variables contributing most to their scores. These differences were not evident from the final MuBRAI results as the final MuBRAI measure mainly highlighted areas with large biodiversity stocks and large pressures with low responses. The index provided a holistic answer, neglecting to identify which variables contributed most to the position of each municipality within the MuBRAI rank. According to the PCA results, the variance of the data was mostly explained by PC 1, which was driven by the variables: human population density, human population density change, threatened species density and total species density. Graphically, the local municipalities were found to cluster around the mean as they showed medium scores for these variables. Metropolitan Areas on the other hand, formed an outlier group because they represented areas with high scores for the variables driving PC 1 and they represented most of the variation observed in PC 1. The District Management Areas (DMAs) also formed an outlier group. They represented areas with low scores for the pressure variables driving PC 1, but high scores for the variables driving PC 2. DMAs contributed the most to the variation observed in PC 2.

Results from the PCA thus provided additional information which could, together with the results from the Spearman correlations and the final index, assist in understanding relationships between variables, and why municipalities were alike or different in terms of their biodiversity risk. It could also provide insight as to why they were ranked in that specific order in the final MuBRAI rank. The analyses were illustrative and not exhaustive; therefore the MuBRAI (or at least the principals of the method) can be used elsewhere or at different scales to measure biodiversity risk using either different or similar variables.

4.4. MUBRAI AS A USEFUL DECISION MAKING TOOL

The location of ecological processes and species ranges are often used to identify areas for conservation action, but as these distributions mostly follow biogeographic boundaries rather than political boundaries, they are difficult to manage as most legal and regulatory systems are based on political units (Ricketts and Imhoff 2003). Logistically it is therefore more sensible to implement conservation initiatives at political scales, like the municipal scale, rather than at larger biogeographic scales that do not correspond with political boundaries, which in turn would require cooperation between different managerial bodies. The Municipal Biodiversity Risk Assessment is one such an initiative that prioritises conservation effort on the municipal scale. The final results from the assessment should be used as a barometer for national government to measure how effectively resources are being distributed.

The results from the Municipal Biodiversity Risk Assessment can be applied in various ways for resource management and decision making purposes. The first and most straightforward way is to use the MuBRAI to identify municipalities with high biodiversity risk, taking into account that some assumptions have been made. In so doing, those municipalities in need of immediate attention are highlighted and can be attended to immediately. Umdoni in KwaZulu-Natal was identified as the municipality with the highest biodiversity risk, followed by Richmond in the same province. The second strength of this assessment is that it standardized all variables by the size of municipalities; therefore municipalities of different sizes can be compared. Thirdly, it is possible to break down the index into its underlying components (stock, pressure and response values and also its thirteen comprising variables) making it more versatile whereby not only the final rank is of use. The reason why a certain municipality has a certain position in the MuBRAI rank can now be traced giving further depth and credibility to the interpretation of the rank.

The Municipal Biodiversity Risk Assessment had a relatively fine scale approach, which helped to quickly identify areas in need of immediate conservation attention whilst not requiring large amounts of resources, time and people to coordinate and implement the action, as is the case with larger initiatives. Spatial scale is an attribute that greatly affects the interpretation of the state of biodiversity within a specific geographic area (Rey Benayas and de la Montana 2003; Rickett and Imhoff 2003). Knowing this and the fact that there is no clear scale at which to measure biodiversity, a multiple scale approach is normally required when it comes to measuring biodiversity risk. Although single scale approaches are easier to conduct and are very informative on that level, it cannot capture the hierarchical nature of biodiversity operating at various spatial scales (Rouget *et al.* 2003b). For this reason, the results from the assessment have to be used in conjunction with results of other local, national or international scale initiatives to describe the overall state of biodiversity in context. Fortunately, because of the various levels of the assessment, it allows for alternative interpretation and can support various national and international conservation goals in identifying current threats, stocks and responses of an area, which could contribute in identifying hotspots, centres of endemism or future parks. For instance, the Biodiversity Risk Assessment is currently favourably placed to facilitate the implementation of the National Spatial Biodiversity Assessment (NSBA) (Driver *et al.* 2005), by identifying important local municipalities within these larger identified priority areas that will need to be capacitated to fulfil the overarching vision for the region. The results from the MuBRAI strongly corresponded with the nine terrestrial priority areas identified by the NSBA. Municipalities with high biodiversity risk according to the MuBRAI corresponded especially well with the identified areas in the Wet and Dry Grasslands, the South Eastern Escarpment, the Maputoland Pondoland, the Albany Thicket and Wild Coast and the Cape Floristic Region defined by Rouget *et al.* (2004).

A major part of this study was spent on collating biodiversity data at the municipal scale. This database should be further explored and applied to identify areas within municipalities that need conservation attention. Once a particular municipality has been identified by the MuBRAI as having high biodiversity risk, the results should be applied to assist in implementing detailed conservation action which can include the formation of protected area networks, identifying areas outside formal reserves for conservation and assisting better natural resource management (Rey Benayas and de la Montana 2003).

4.5. LIMITATIONS OF THE STUDY AND FUTURE WORK

The Convention on Biological Diversity 2010 Biodiversity Targets challenged the scientific community to provide a detailed understanding of the rates of biodiversity change by 2010 and although this study contributed in meeting these goals by identifying municipalities with high biodiversity risk, more still needs to be done if South Africa wants to rise to the challenge. For all countries, the lack of good quality data and diversity of data that is balanced across all habitats, ecosystems and species were found to be one of the biggest hurdles in meeting the 2010 challenge (Balmford *et al.* 2005; Dobson 2005). This is especially true for South Africa as the results of the NSBA (Driver *et al.* 2005) and this study confirmed.

The data used in this study were attained from different years and in different units and therefore had to be treated conservatively. The results of this study could have given a more comprehensible description of biodiversity risk within South Africa if additional and updated datasets had been available at this scale, such as data on plant species, species abundance, distribution of alien invasive species, pollution, recent National Land Cover, Gross Domestic Product (GDP) and parks and recreation budget. Information from Integrated Development Plans and Spatial Development Frameworks and other documents would also have been useful, but were not available for all 262 municipalities.

LANDSAT data are of the most valued datasets on land use for South Africa, but is unfortunately almost outdated by the time it gets published. This study made use of 1996 Land Cover Data since the 2000 dataset had not yet been published. As significant land use changes have taken place over the country in the past nine years, especially in areas in KwaZulu-Natal, transformed and degraded areas were underestimated for this study. Land use data mostly measure outright transformation of cover and seldom the degree of degradation. This also needs to be addressed in the future.

Apart from the age and format of the data, the reliability of data is also a factor to be considered. Especially species data should be used cautiously when assessing biodiversity status of a region, as datasets can sometimes be flawed through human error, be biased or incomplete (Wessels *et al.* 2003). This is a universal problem; therefore great efforts are being put into addressing the matter internationally (Royal Society Report 2003) and locally with initiatives like the South African Reptile Conservation Assessment currently underway to update reptile species data. SANBI have also been mandated to be the manager of biodiversity data for South Africa (Rouget and Egoh 2003). However, the best available surrogate data for biodiversity were used and it is believed that at least biodiversity patterns were adequately represented. It is recommended that more research and effort should go into obtaining and refining biodiversity datasets and standardising the scale and format the data should be collected at and conform to. Building up such a database will benefit this particular Biodiversity Risk Assessment as well as other conservation planning initiatives in South Africa. This is not an unrealistic goal as the Conservation Planning Unit of CapeNature Conservation has already compiled a database that includes spatial biodiversity data per municipality for the Western Cape (http://cpu.uwc.ac.za). This database could be expanded to include data for the entire country.

As stated before, the MuBRAI equation was designed to rank municipalities using measures of stock, pressure and response. Fifty four municipalities, mostly concentrated in the Northern Cape, Limpopo, KwaZulu-Natal and the Eastern Cape did not have any responses in place. The result was that they were ranked higher than they should have been in terms of their biodiversity stock and pressures. The lack in adequate response measures on the municipal level was evident from this study and calls for improvement.

From the final MuBRAI results many of the top priority municipalities that face the largest biodiversity risks, occurred in KwaZulu-Natal, like Umdoni, Richmond and uMuziwa. Incidentally, this province is also the greatest impacted in terms of HIV/Aids in the country (Makubalo *et al.* 2003). HIV/Aids most definitely impacts on biodiversity (ABCG 2002).

In the future, HIV/Aids will have to be considered as a permanent source of pressure on the environment and will have to be become an integral part of strategies determining conservation priorities. An indicator representing the impact that HIV/Aids has on biodiversity should strongly be considered as an additional pressure measure for the MuBRAI in the future. HIV/Aids mostly impacts on the natural resource sector mainly through loss of human capacity for natural resource management and change in type of land use and type of resources utilized (ABCG 2002). Unfortunately, very little information on this subject is available, but as South Africa is one of the leaders in HIV/Aids related research, there is confidence that such data will become available in the near future.

5. CONCLUSION

Prioritisation of where conservation action should be focused in South Africa is absolutely essential to ensure effective conservation of biodiversity in the future. Lately, more attention has been given to selecting and prioritising areas to achieve explicit conservation goals in South Africa, with systematic conservation planning playing a major role (Reyers *et al.* 2000; Cowling *et al.* 2003; Rouget *et al.* 2003a, b; Driver *et al.* 2005). In South Africa, more is known about biodiversity now than ever before, but with the incidence of high levels of poverty, a reality in most municipalities, more emphasis is given to the economic and social legs of sustainability at the municipal level. More effort is therefore necessary to make municipalities realise that healthy biodiversity is necessary for human well being (MA 2005).

Institutional conditions and the policy environment play an important role in biodiversity management. Municipalities administrate and manage most of the land in South Africa, but are in general not aware of the importance of biodiversity. Lack of capacity, guidance and training and poor governance at the municipal level therefore prohibits the successful mainstreaming of biodiversity into local planning.

Indices are powerful tools to get information across when directed at the right audience. The MuBRAI is directed at the municipal scale that should be used by appropriate decision makers, politicians, conservationists, conservation planners and international donors to assist local municipalities in their task, required by law (NEMA (Act No.107 of 1998), Biodiversity Act (Act No. 10 of 2004) and the Amended Protected Areas Act (Act No. 31 of 2004)), to plan and act for a sustainable future within their area of jurisdiction. Managing environmental resources will ensure the enhancement of human welfare and poverty reduction.

Conceptually, the MuBRAI is very similar to the NABRAI, which was implemented at a national scale by Reyers et al. (1998). Both studies identified the need for a wider range of variables to better assess biodiversity risk. Only thirteen appropriate variables were identified at the municipal scale. These variables were grouped into pressure, stock and response categories used to calculate the MuBRAI value. A high MuBRAI value indicated high risk. Multivariate analyses enabled the identification of the most important variables contributing to high MuBRAI values. Exploratory statistics revealed that the variables included in the index were weighted equally, and were independent of each other with no co-variation between them and each contributing to the index.

The principle disadvantage of the MuBRAI was that it may have been too sensitive in measuring responses, or rather measuring the lack of them. Problems with the data included are that some datasets were incomplete (e.g. protected areas data), outdated (e.g. 1996 National Land Cover Data), inappropriate in terms of scale (e.g. species data) and sometimes biased.

However, a prioritisation method does not have to be flawless to be useful. The MuBRAI has several strengths. The most important one is that it allows for prioritisation of resources by identifying important municipalities with high biodiversity risk with inefficient conservation responses in place. The inclusion of a response measure is a major improvement on other indices. From the results, the municipality with the highest percentage response in place was the Witzenberg municipality in the Western Cape. City of Johannesburg faces the largest pressures and Mtubatuba in KwaZulu-Natal contains the largest stock. Overall the municipalities of KwaZulu-Natal and the Eastern Cape exhibit the highest biodiversity pressure, of which Umdoni municipality in KwaZulu-Natal faced the largest pressure. Other qualities of the MuBRAI are that it is systematic, simplistic, flexible and spatially explicit. The index can be broken down to its various components for more in depth analysis, it can accommodate updates of variables and can be expanded in the future. It is easy to understand by both the implementer and the interpreter and is therefore a useful decision making tool.

The assessment identified certain data gaps. These were supported by other conservation planning studies and calls for improvement of spatial data at the appropriate scales (Rouget et al. 2004; Driver et al. 2005). One of these gaps is the lack of response data and is problematic as alternative ways to conserve biodiversity outside reserves is limited and will become essential for the survival of biodiversity due to range shifts as a result of global climate changes and continued encroachment of land degradation through anthropogenic activities in reserves. Other data gaps were the lack of economic data measuring Gross Domestic Product (GDP); updated land use data measuring degree of degradation; updated point locality species data, especially for threatened species; alien invasive vegetation data; and plant species data. Data on effects of HIV/Aids on biodiversity and data on global climate change should also be considered. There is thus an urgent need for updated, detailed, finer scaled biodiversity data to efficiently and holistically assess biodiversity.

Apart from the fact that South Africa has a lack of spatial data, it is also true that existing data was badly managed up until recently. Fortunately SANBI as part of their new mandate and responding to the requirements of the National Environmental Management: Biodiversity Act (Act No. 10 of 2004), is currently undertaking this role of managing biodiversity data for South Africa (Rouget and Egoh 2003). To reduce the risk of duplicating work, existing datasets must first be inventoried before new data is accumulated. Data should be collected at the appropriate scale depending on the objective of the study.

Conserving biodiversity does not always entail conserving the physical environment, but often calls for social upliftment. Part of prioritising municipalities for biodiversity risk would then also include social upliftment. Local communities have an important role to play in conservation. Through education and providing a better quality of life for people the risk on biodiversity can be significantly reduced, especially in rural areas where people will not have to rely on the unsustainable use of natural resources to survive. As with data management, resource management is crucial. This is a major challenge, because focusing resources on the wrong places would be just as wasteful as allowing biodiversity loss to continue.

This index, like most others, focuses predominantly on terrestrial biodiversity. More information on freshwater and marine systems needs to be collected and included in prioritisation indices, if we want to holistically assess biodiversity risk in the future. Some conservation plans, such as the Greater Addo Elephant National Park (GAENP) has already attempted to spatially integrate information from the terrestrial, freshwater and marine sectors. This serves as an example to encourage this holistic approach being adopted and applied more widely.

The Biological Convention called for updated and informed biodiversity information to achieve their 2010 goal of reducing biodiversity loss around the world. Due to methodological differences there is still considerable disagreement between various methods of assessing biodiversity across the world. There is a need for a more sophisticated understanding of biodiversity risk to address this issue. Although South Africa is still far reaching the 2010 target, this study contributed to the process by collating data at the scale of implementation, identifying data gaps and prioritising areas of biodiversity concern. Although there is still much to be done, it is encouraging to see how advanced South Africa is in terms of actually implementing its conservation plans.

A successful biodiversity risk assessment index was constructed that was sensitive to the South African biodiversity situation. The MuBRAI was able to confidently identify municipalities with high biodiversity risk as confirmed by similar results from other studies such as the National Spatial Biodiversity Assessment. It also provides valuable information at the municipal level to assist in identifying areas for conservation action that are at high risk of imminent biodiversity loss.

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