CHAPTER 6

Incorporating potential land-use threats into regional biodiversity evaluation and conservation area prioritisation

Introduction

Humans have transformed almost half of the world's ice-free land surface area into agricultural and urban systems. Through this transformation humankind dominates (directly or indirectly) almost one third of the land's net primary productivity and uses 54% of the available freshwater (Vitousek *et al.*, 1997; Chapin *et al.*, 2000). In the absence of policy and behavioural changes, anthropogenic land-use impacts are said to become the largest threat facing terrestrial global biodiversity by the year 2100, particularly within the tropics (Chapin *et al.*, 2000; Sala *et al.*, 2000). Although there are several other drivers of biodiversity change, including changes in atmospheric CO_2 levels, nitrogen deposition and acid rain, land-use changes will have the largest impact mostly due to their destructive effects on habitat availability and consequent species extinctions (Sala *et al.*, 2000). Not only will these changes have implications for ecosystems, altering their processes and resilience to environmental change, but will also have important consequences for humankind due to increasingly threatened ecosystem services and products (Kunin & Lawton, 1996; McCann, 2000).

The establishment of conservation areas in which features of biodiversity are separated from processes that threaten their persistence in the wild, is one of the widely used approaches for addressing these threats (Pressey, 1998; Margules & Pressey, 2000). Shortcomings of existing conservation areas, the need for systematic conservation area selection procedures, as well as the need for these procedures to minimise threats facing regional biodiversity within selected areas has been widely researched (for review see Balmford *et al.*, 1998; Williams, 1998; Margules & Pressey, 2000) and discussed in Chapters 1 and 5, as well as Addendum II. The study in Addendum II, conducted in the three northern provinces of South Africa, focused on the need to identify and minimise current land-use threats facing biodiversity. The incorporation of measures of threat into conservation area selection is essential and has important implications for land-use planning, enabling the identification and therefore avoidance of areas of threat to biodiversity and highlighting areas where there may be conflicts between conservation and land-use development issues (Lombard *et al.*, 1997; Nantel *et al.*, 1998, Williams, 1998). These analyses in Addendum II illustrated how human land-use impacts increase the costs of achieving a representative conservation area network, decrease the flexibility of conservation options and in many cases actually conflict with areas irreplaceable to biodiversity conservation.

It is however, also important to remember that human land-use impacts are not static and will continuously evolve and spread as populations and their land-use and resource needs expand. This will subsequently further increase costs, decrease conservation options and increase the amount of conflict between the various forms of land-use and conservation. It is therefore essential that existing natural areas with high potential to become transformed by other land-uses be identified at as early a stage as possible in order to identify areas where there may be future conflict between these potential developments and existing biodiversity. These alternative forms of land-use include agriculture, forestry, mining, and urbanisation, as well as land degradation through overgrazing, fuel wood harvesting and alien plant invasions (Fairbanks *et al.*, 2000). There is thus a need for a conservation area selection technique which avoids areas that are currently largely transformed and also identifies areas crucial to biodiversity conservation requiring management because of high levels of transformation (Addendum II). In addition to this a technique that also identifies untransformed areas that are suitable for development will hopefully help to guarantee persistence of regional biodiversity (Pressey *et al.*, 1996; Williams, 1998).

These untransformed areas identified as highly suitable for alternative land-uses can then, applying the principle of flexibility (Pressey *et al.*, 1993), be avoided by conservation planners and used for development. If however these areas are irreplaceable due to rare or endemic biodiversity features (Pressey *et al.*, 1994; Ferrier *et al.*, 2000) they can be targeted as conservation priorities due to high biodiversity and threat values. A better understanding of the current and future patterns of threats (especially land-use threats) facing biodiversity will allow for more effective trade-offs between biodiversity conservation and development opportunities (Faith, 1995; Faith & Walker, 1996), as well as a more efficient allocation of limited conservation resources for areas most at risk (Margules & Pressey, 2000).

Pressey (1997) highlights the fact that many of the existing conservation area selection techniques say nothing about the relative need of areas selected for protection. Funding and resource shortages dictate that although a large number of areas may be identified as important to the representation of biodiversity, only a small number of them can be protected in the near future. As Cowling *et al.* (1999) point out, in order to maximise the retention of biodiversity features within a region, one must minimise the extent to which the original representation goals are compromised by habitat loss while the conservation area network is developing (a process that can take decades). It is therefore crucial to identify areas of high conservation value or urgency within this selected set of areas. These are areas with a high biodiversity, or irreplaceability value, as well as a high threat or vulnerability value (Faith & Walker, 1996; Pressey *et al.*, 1996; Pressey, 1997; Pressey, 1998; Cowling *et al.*, 1999).

Much work has been done on measuring biodiversity values of areas, and includes species richness, endemism and rarity of areas as well as complementary species richness discussed in Chapters 2 and 3 (Williams *et al.*, 1996; Williams, 1998; van Jaarsveld *et al.*, 1998b). Also included as a measure of biodiversity value are measures of irreplaceablity (Pressey *et al.*, 1994; Ferrier *et al.*, 2000), which illustrate how crucial a site is for achieving representation goals within a region due to its biodiversity feature content. Other measures of biodiversity value focus less on the biodiversity pattern of an area and more on the biodiversity processes within the region (Balmford *et al.*, 1998; Pressey, 1998). These techniques focus on the spatial surrogates for biodiversity processes and include measures of higher levels of the biodiversity hierarchy (Pressey, 1994; Noss, 1996; Maddock & du Plessis, 1999), environmental gradients (Noss, 1996; Cowling *et al.*, 1999) and measures of spatial and temporal turnover (Chapter 5; Rodrigues *et al.*, 2000). However, there is a large need for work on the inclusion of threat or vulnerability values of areas into conservation areas selection. (Chapter 5; Addendum II; Faith & Walker, 1996; Pressey *et al.*, 1996; Williams, 1998).

The present study therefore aims to address several shortcomings with existing conservation area selection techniques in an effort to incorporate current and potential threat values into conservation planning in the Northern Province of South Africa. First areas with high biodiversity value will be identified using all techniques mentioned previously. Second, areas within the province suitable for alternate land-uses will also be determined. The identified areas of high biodiversity value will then be investigated as to their land-use threats from existing and potential land-uses. Finally, using the biodiversity data available for the province, a conservation area network will be identified which avoids areas currently transformed and degraded while representing all known regional biodiversity. The areas selected will then be investigated in terms of their current and potential land-use threats in an attempt to prioritise areas for immediate conservation action.

It is important to note that the current study focuses only on the forms of land-use deemed important and likely threats to biodiversity within the Northern Province. These land-uses include cultivation (both rain-fed and irrigated), afforestation of various species of *Eucalyptus* and *Pinus*, as well as *Acacia mearnsii* (black wattle), and mining and quarrying. Although several other forms of land-use may also have impacts on biodiversity, these future forms of land-use are not taken into account. Livestock grazing may result in structural as well as compositional changes to vegetation, but under controlled conditions, does not usually result in major land-cover transformation or alteration in ecological function, and is considered to be more amenable with biodiversity conservation (Pressey, 1992; Mishra & Rawat, 1998; Allsopp, 1999). In addition to this the impacts of grazing on biodiversity are difficult to quantify and have not been fully investigated within the study region. Although areas of land-cover degradation are often indicative of overgrazing (Thompson, 1996; Newby & Wessels, 1997) and can be used as a current indication of threats to biodiversity, future patterns are difficult to predict. Therefore areas not suitable to the main land-uses of forestry, cultivation or mining were assumed to remain natural and unimpacted. Although urbanisation has direct effects on biodiversity, due to limited urban development in the province only current levels of urbanisation were considered in the determination of threats to regional biodiversity (Rottenborn, 1999).

Road networks, however, were evaluated as to the impacts of this form of infrastructure development on biodiversity. Although road networks occupy small areas, the ecological effects that roads have on regional biodiversity extend far beyond the edges of the road itself (Reijnen *et al.*, 1995; Forman & Alexander, 1998; Forman, 2000). Road networks affect landscapes and biodiversity in seven general ways: (1) increased mortality from road construction; (2) increased mortality from vehicle collisions; (3) animal behaviour modification; (4) alteration of the physical environment; (5) alteration of the chemical environment; (6) spread of exotic species, and (7) increased alteration and use of habitats by humans (from Trombulak & Frissell, 2000). As illustrated in Addendum I, road-effect zones can be used to provide an estimate of the potential threat to regional biodiversity through changing land-uses and increased future human impacts.

Methods

Study area

The Northern Province lies at an average 880m above sea level, with higher lying areas reaching just over 2000m in the escarpment and low lying regions in the lowveld of the Kruger National Park falling below 300m (see Figure 1 in Chapter 1). This varied elevation results in different rainfall regimes within the region. The province is largely a low summer rainfall area with an average rainfall of 500mm per annum. However there are areas within the higher lying escarpment which receive in excess of 1200mm per year, while other areas in the far north of the province receive less than 300 mm (Schultze, 1998). The temperatures recorded in the province are also variable, with an average temperature of 19°C falling to 16°C in the southern and central high lying highveld region, and climbing to 23°C in the lowlying subtropical lowveld (see Figure 1 in Chapter 1).

In a similar fashion to most of South Africa, the Northern Province has large tracts of untransformed land (Figure 1) (see Figure 4 in Chapter 1; Addendum I). There are few urban centres within the province (see Figure 3 in Chapter 1), therefore urbanisation and industrialisation do not pose a large threat within the province, accounting for only 1.6% of the area. Other forms of infrastructure occupy small areas of the province, e.g. the road network takes up less than 0.02% of the area. The province includes extensive areas of arable land and as a result 14% of the province has been transformed by cultivation. However due to the relatively low rainfall in most parts of the province, dryland (or rain-fed) cultivation at a commercial scale, which makes up two percent of the total cultivation in the province, is limited to the escarpment, mountainous regions and Springbok Flats where it is considered a viable land-use option. In the rest of the province rain-fed agriculture is not possible at a commercial scale and is limited to temporary and subsistence level cultivation, making up 38 and 48% of the total cultivation in the province respectively (see Table 2 in Chapter 1) (Fairbanks *et al.*, 2000).

Other areas under cultivation require irrigation, and because of the scarcity of suitable rivers in the province this form of cultivation is very limited making up three percent of the total cultivation at a commercial level and eight percent at a temporary level (Fairbanks *et al.*, 2000). In a similar fashion, afforestation within the province is limited (0.8% of the province) by the low levels of rainfall to the higher lying and moister escarpment. Despite its mineral wealth mines and quarries occupy only 0.1% of the land area (Wilson & Anhaeusser, 1998).

Thus, although the province is largely untransformed at present, it does contain substantial areas that are suitable for alternate land-uses. Afforestation, cultivation and mining are considered to be major land-uses that threatened biodiversity and all three are viable within the Northern Province.

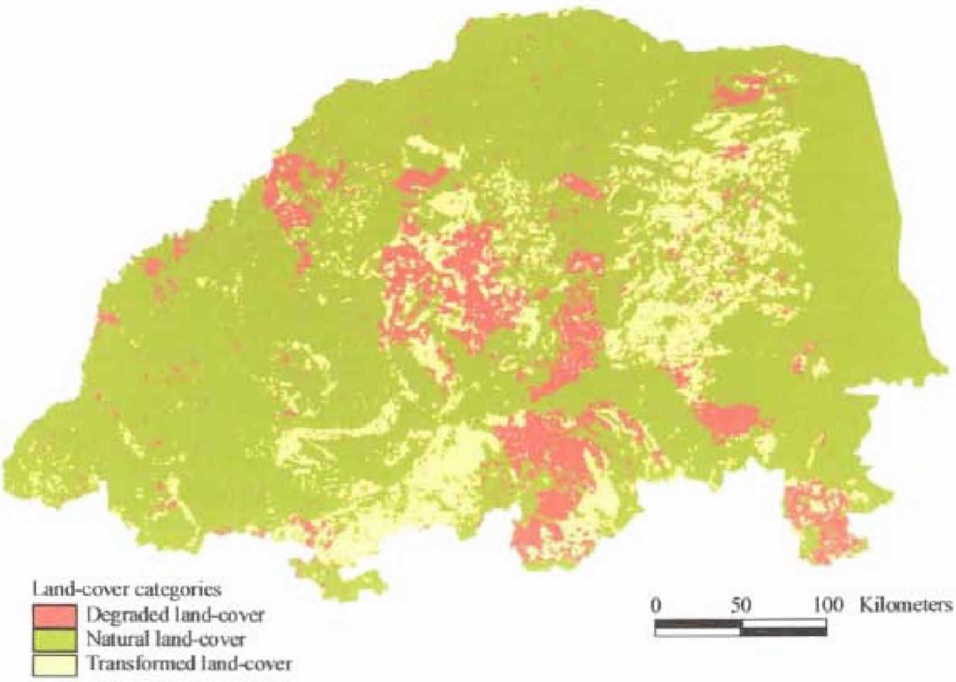

Figure 1: Study area of the Northern Province showing areas of land-cover change. Land-cover categories from Chapter 5.

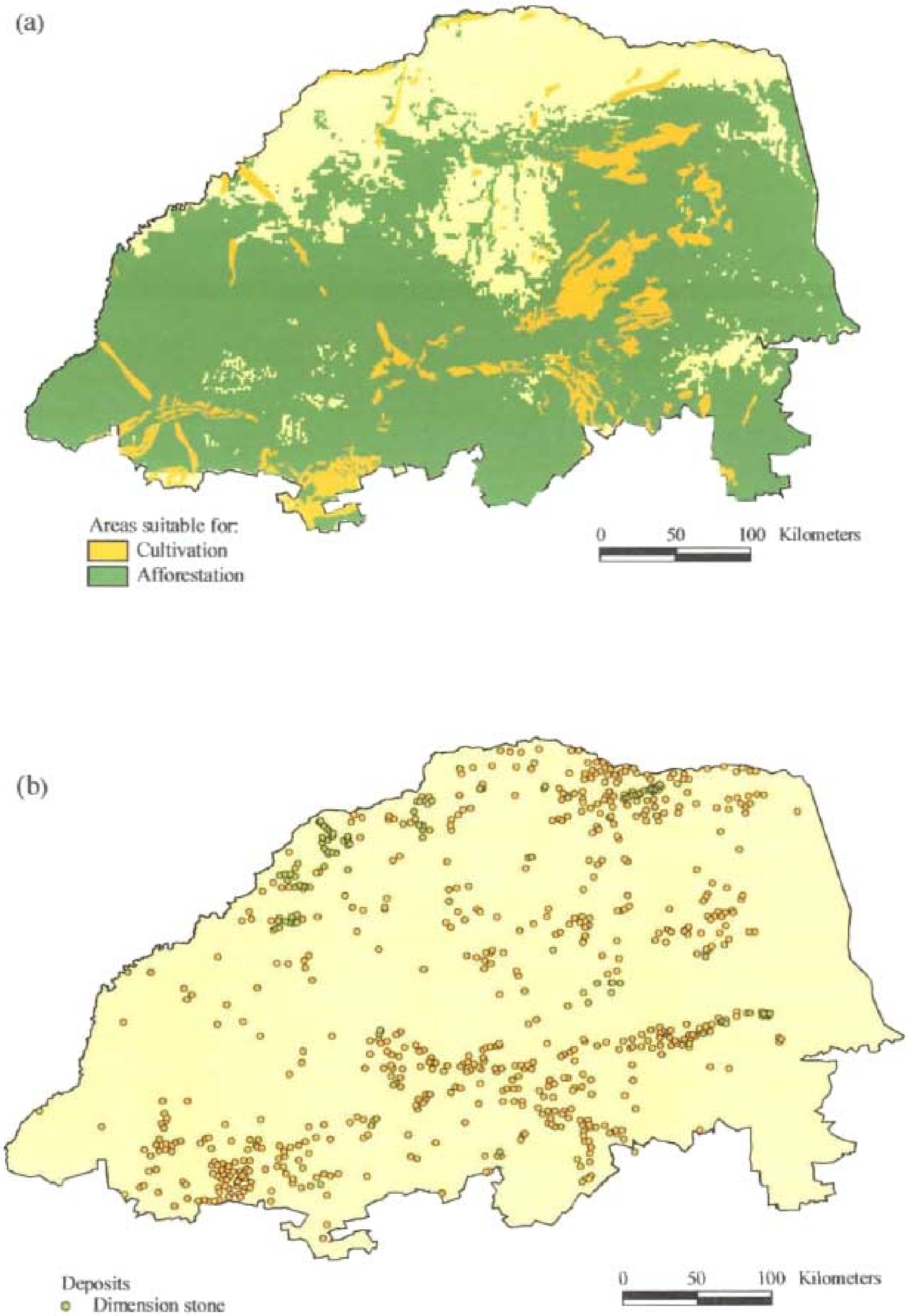

Figure 2: Northern Province showing areas of: (a) high suitability for: cultivation (both irrigated and rain-fed) and forestry, and (b) known mineral and dimension stone deposits.

The low rainfall within the province, as well as new water laws within South Africa (DWAF, 1996) limit the potential for further afforestation or dryland cultivation. However there are large areas which would be suitable for cultivation and afforestation (especially of specialised species) within the province (Figure 2a) (Fairbanks, 1997). In addition the province has large mineral fields, as well as unexploited mineral and dimension stone deposits (Figure 2b) which may have serious implications for regional biodiversity. The province includes 15 vegetation types falling largely within the savanna biome, as well as smaller parts of the forest and grassland biome on the escarpment and in the mountain ranges (Low & Rebelo, 1996; see Figure 2 in Chapter 1).

Databases

All spatial data used in the study were projected in an Albers equal area projection, based on Clarke 1880 Spheroid with 24° E as the central longitude and –18°S and –32°S as the standard parallels. All analyses were performed in Geographic Information Systems (GIS) using ArcInfo and ArcView (with Spatial Analyst) (ESRI, 1998). Each of the spatial coverages used are described below.

<u>Species distribution data</u>

Distribution data on several vertebrate, invertebrate and plant taxa used to investigate areas of high biodiversity value are available for the study area (see Table 3 in Chapter 1). However due to the taxonomic inconsistencies and survey biases (Freitag & Mansell, 1997; Hull *et al.*, 1998; Muller, 1999; Koch *et al.*, 2000) found within a large majority of these databases it was decided to only include databases on the well studied taxa with sound distribution data and taxonomy. These taxa include the birds, mammals and to a lesser extent the butterflies (Harrison, 1992; Freitag & van Jaarsveld, 1995; Freitag *et al.*, 1998; Muller, 1999). The database included 48803 unique records for 565 bird species, 2062 records for 328 butterfly species and 7040 records for 214 mammal species. In this study most of the analyses focussed on the bird distribution data due to its well-assessed quality and reliability. The other taxa are only employed for the final analysis. These distribution records ranged from point localities to 15' x 15' grid cell records, and were therefore generalised up to the 15' x 15' (~ 700 km^2) grid cell resolution for the purposes of this study.

<u>Vegetation data</u>

A GIS layer of the vegetation types defined by Low and Rebelo (1996) was used to determine current and future impacts on these areas within the province. These vegetation types are defined as units with similar vegetation structures, ecological processes and important species (Low & Rebelo, 1996). This layer also serves as a broad-scale surrogate for regional biodiversity (see Chapter 4).

Protected area coverage

A GIS layer of the national and provincial protected areas (DEAT, 1996) was used to determine extent of existing protected areas. These protected areas all fall within IUCN categories I and II. A comprehensive layer of private reserves is currently unavailable.

Land-cover data

This layer utilised the National Land-cover database for South Africa (Thompson, 1996; Fairbanks *et al.*, 2000). This is derived from a series of 1:250000 scale geo-rectified maps, based on seasonally standardised, single date LANDSAT TM satellite imagery captured during the 1994-95 period (Fairbanks & Thompson, 1996; Thompson, 1996; Fairbanks *et al.*, 2000). In a similar fashion to Chapter 5 and Appendices 1 and 2, these 31 land-cover classes were grouped into three categories of natural, degraded and transformed land-cover (Figure 1). The transformed class was then further subdivided into cultivated, forestry, mining and urban areas.

Road-effect zone

The spatial extent of ecological effect of roads, or road-effects, can be used as an ecological indicator that directly represents impacts on biodiversity. The affected distances were estimated in a similar fashion to the one used in Addendum I in a hierarchical manner from Stoms (2000) using estimates of spatial extent of the road-effect zone from reviews mentioned previously, as well as from local studies (Milton & Macdonald, 1988). The road-effect zone of large main roads was assumed to be larger (1km on either side of the road) than that of smaller farm roads (100m) (see Addendum I). This zone was determined from road segments from the South African Surveyor General (1993) 1:500000 scale map series files. These were buffered in a standard geographic information system operation to the distance related to its class. The roads in protected areas were excluded from this analysis as the road-effect in national parks is of limited biodiversity concern.

Suitable areas for afforestation, cultivation and mining

Areas suitable for afforestation by eucalyptus, pine and wattle species, the main species used in the forestry industry within the Northern Province, were evaluated using an afforestation potential land evaluation developed by the CSIR (Fairbanks, 1997). This evaluation uses a GIS modelling approach, based on fuzzy sets logic techniques, using information on climate and soils (Fairbanks, 1997). The suitability for summer rainfall pure types of *Eucalyptus camaldulensis*, *E. nitens*, *E. saligna*, *E. tereticornis*, and *E. urophylla*, as well as *Pinus elliottii*, *P. patula*, *P. taeda* and *Acacia mearnsii* (black wattle) were classified. This evaluation used one minute by one minute grid cell data on several physiologically based climate variables including median annual precipitation, mean annual temperature, mean maxima of the hottest month (January), mean minima of the coldest month (July) and seasonal precipitation patterns. In addition broad soil pattern and soil depth were used from 1:250000 soil types mapped by the Institute for Soil, Climate and Water (ISCW, Agricultural Research Council). Suitabilities of species were then grouped into five potential classes: (see Fairbanks, 1997).

0-20% = Highly unsuitable

20-40% = Unsuitable

40-60% = Low suitability

60-80% = Suitable

80-100% = Optimal

For the purposes of this study only areas with a greater than 60% suitability were considered likely biodiversity threat areas.

Areas suitable for maize, wheat and sorghum cultivation were calculated in two ways. First, potential for rain-fed crop production was mapped from land types (MacVicar, 1974; Land Type Survey Staff, 1986, Schoeman & Scotney, 1987) by the ISCW (ARC). This was based on mean annual rainfall (>550mm), soil depth, soil form, clay percentage and slope at 1:250000 scale (for example see Smith, 1998). Areas with a greater than 60% suitability were then classified as regions suitable for rain-fed or dryland agriculture. Second, potential for irrigated crop production was extracted from Schoeman *et al.* (1986), using landtype information, expert knowledge on irrigation schemes, the availability of water and Landsat MSS data to map extant areas of irrigation.

Data from the Metallogenic Map dataset and SAMINDABA (2000) provided in digital format by the Council for GeoScience was used to estimate the potential impacts of mining and quarrying in the province. Localities of deposits and mines for the top 20 minerals and 5 dimension stone types were buffered with a 1km buffer in order to derive a layer of what the potential ecological impacts of mining and quarrying in the area could be (Table 1). These localities were of varying deposit statuses including:

Occurrence: a naturally occurring commodity, usually in outcrop, on which subsurface exploratory work has or has not been carried out or is in progress, and which has not yet been proved to be economically viable or is very unlikely to become viable in future

Deposit: an occurrence at which subsurface exploratory work has proved that the quality and quantity of the commodity(ies) are such that exploitation has been, or is currently feasible, or is very likely to become feasible in future. This term automatically applies to all producing mines, past and present.

Potential threat

These layers on potential land-use impacts and road-effect zones will then be combined to provide a layer of all potential land-use threats within the region. This allows for the evaluation of overlap with current land-uses and determination of impact on areas that are as yet untransformed, especially those important to biodiversity conservation.

Table 1: Mineral and dimension stone deposits in the Northern Province.

Mineral or dimension stone type	Number of known deposits
Gold	87
Platinum	15
Chrome	21
Titanium	23
Copper	119
Lead	23
Zinc	5
Nickel	25
Iron	65
Vanadium	26
Manganese	19
Andalusite	12
Antimony	6
Tin	40
Coal	6
Fluorspar	34
Phosphate	18
Limestone	23
Magnesite	38
Vermiculite	6
Diamond (alluvial)	9
Diamond (in kimberlite)	6
Quartzite/Sandstone	3
Granite/Quartz-porphyry/Syenite	6
Gabbro/Dolerite/Norite	6
Shale/Slate/Jaspilite/Schist	13
Marble	71

Land-use impacts

Analyses were performed on these data layers to investigate the current and potential land-use scenarios for the Northern Province. Using the current and potential land-use layers available one could ascertain how much of the area suitable for the various land-uses was actually being used or still remained untransformed as an indication of threats facing the province. Similarly the vegetation types could be assessed as to the amount of natural land remaining within each vegetation type, and the percentage of that land that is suitable for other land-uses. In this way vegetation types could be prioritised for conservation action.

Biodiversity value

Because of the high quality of the bird species distribution database it was largely employed in this section of the analysis. Traditional priority conservation areas including richness and rarity hotspots were identified. Due to the fact that there are very few known species limited to the Northern Province, endemic hotspots were not applicable. Areas containing priority species were selected. These priority species were identified based on Freitag & van Jaarsveld's, (1997) Regional Priority Score (RPS) technique. This technique uses a combination of relative rarity, endemicity, vulnerability and taxonomic distinctiveness of each species to determine how important they are within the region (see Freitag & van Jaarsveld., 1997 for formulae and descriptions of the techniques). Grid cells containing the top five and ten percent of these priority species were then identified. Additionally grid cells of biodiversity conservation importance were identified using CPlan (Pressey *et al.*, 1993; Pressey & Logan, 1997; Cowling *et al.*, 1999; Ferrier *et al.*, 2000). These areas are irreplaceable (site irreplaceability = 1) grid cells for a target of 100% species representation i.e. they contain species not recorded anywhere else in the province.

Complementary networks of conservation areas selected by richness-based algorithms (Chapter 2,3,4 and 5), land-use constrained (LUC) algorithms (Chapter 5; Addendum II) and beta diversity (BD) algorithms (Chapter 5) were selected for all bird species. The richness-based algorithm selects a complementary set of grid cells that represents all species at least once. The LUC algorithm does the same, while attempting to avoid areas currently largely transformed and degraded. The BD algorithm also represents all species once in a complementary fashion, but focuses on areas with high turnover in species diversity (beta diversity). These areas were all identified using a 50% level of preselection; this means that species in grid cells which are more than 50% protected by the provincial and national protected area network were assumed to be already represented and were excluded from subsequent selection procedures. The databases used were the most recently updated and revised; these datasets and the outputs may therefore differ from those in previous chapters. Another algorithm, which identifies complementary grid cells required to represent 10% of each vegetation type, was also employed. This vegetation based algorithm also used a 50% level of preselection, taking the percentage of each vegetation type represented within grid cells more than 50% protected into account. These areas were then investigated as to the current and potential land-use threats they face.

Conservation area prioritisation

The areas of high biodiversity value identified are all of importance in terms of their biodiversity content. However, due to the limited number of these areas that can be protected immediately some form of priority ranking for conservation action is essential. Using the current and potential land-uses within each of these areas one can investigate which of them need immediate attention. With this in mind, a final set of grid cells, a potential provincial conservation plan, will be identified to complement the existing protected areas using all data available, including species and vegetation type data. This set of grid cells will aim to represent all known biodiversity (all bird, butterfly and mammal species, as well as 10% of each vegetation type) within the region, while at the same time avoiding areas that are largely currently transformed and degraded using a land-use constrained (LUC) algorithm (Chapter 5; Addendum II). This combined algorithm is a species richness-based complementary algorithm. It identifies grid cells containing the most complementary species to ones already selected. These grid cells are then used as preselected grid cells which are then added on to represent 10% of each vegetation type (the species first vegetation based combined algorithm from Chapter 4). During the selection of these grid cells areas of high land use change are avoided (see Chapter 5 & Addendum II).

Each of these grid cells will then be investigated as to their area already transformed, the area suitable for other land-uses and the number of different land-uses that could be practised within that grid cell. The grid cells will be ranked from 1-55 according to increasing levels of suitability for various land-uses, area of road-effects and the number of alternate land-uses for which they are suitable. They will also be ranked from 55-1 according to increasing levels of natural vegetation remaining. Therefore a grid cell with high suitability for a large number of land-uses, a large road-effect zone and little natural vegetation remaining will be ranked close to 55 for all categories. These ranks will be averaged for each grid cell and this will then provide a priority ranking of these areas for conservation action.

Results

Land-use impacts

Table 2 and Figure 3 illustrate that 78.4% of the province is either suitable for alternate forms of land-use or affected by the road-effect zone. Of that area 71.87% is still natural, while 18.4% is already transformed and 9.73% degraded. This already transformed area is made up of cultivated land (86.18%), urban areas (7.75%), forestry (5.48%) and mining (0.5%). Forestry potentially poses one of the largest threats to the area with over 75% of the province being suitable for afforestation, largely through *Eucalyptus camaldulensis* and *E. tereticornis*. Pine and wattle plantations each threaten only about 2.5% of the land. Cultivation, mostly rainfed, is possible in 8.7% of the province.

Table 2: Land area potentially suitable for land-uses and/or impacted on by road-effects in the Northern Province.

General land-use	Land-use type		Area suitable (km^2)	Area suitable (%)	Average area in grid cells (%)
Forestry			93084.35	75.65	61.04
	Eucalyptus		93016.64	75.59	60.99
		camaldulensis	86793.40	70.54	56.91
		nitens	1804.84	1.47	1.18
		saligna	4713.29	3.83	3.09
		tereticornis	33532.35	27.25	21.99
		urophylla	4254.59	3.46	2.79
	Pinus		3071.46	2.50	2.01
		elliottii	3040.30	2.47	1.99
		patula	1151.85	0.94	0.76
		taeda	1563.57	1.27	1.03
	Acacia	*mearnsii*	3055.43	2.48	2.00
Cultivation			10728.95	8.72	7.04
	Rainfed		8144.47	6.62	5.34
	Irrigated		2750.56	2.24	1.81
Mining			1957.42	1.59	1.29
	Mineral		1694.59	1.38	1.11
	Dimension stone		292.43	0.24	0.19
Road-effect			5772.54	4.69	3.78
Total area suitable			96451.94	78.38	63.95

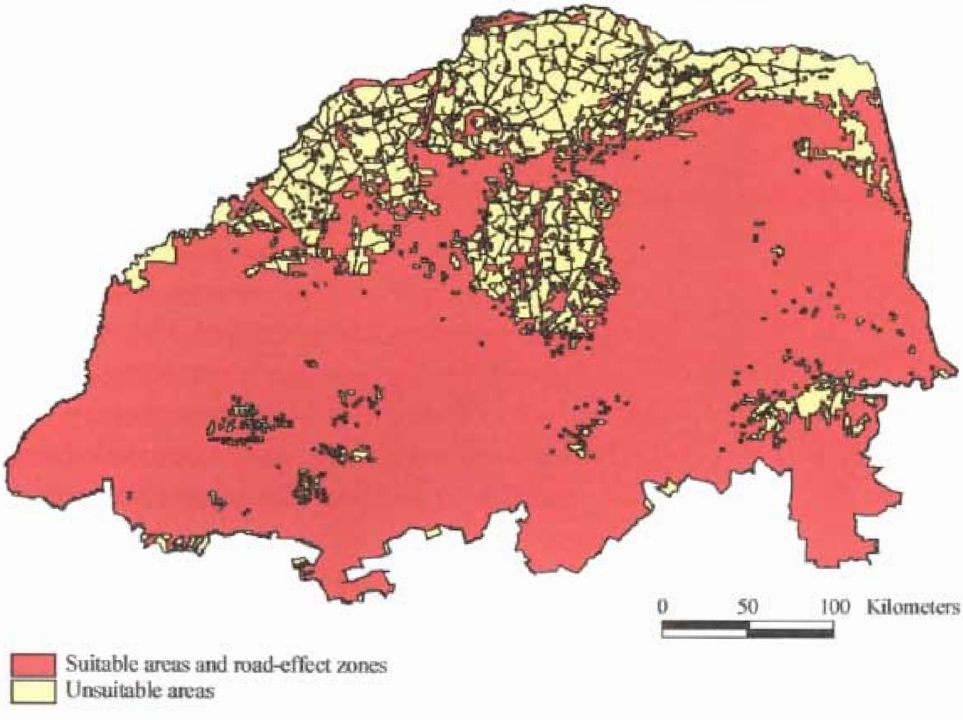

Figure 3: Areas suitable for afforestation, cultivation and mining as well as areas within road-effect zones.

Mining and quarrying can potentially occur in 1.6% of the area, while road-effects impact on almost 5% of the province. Table 2 also illustrates the average area within all 15' x 15' grid cells suitable for the various forms of land-use and/or exposed to road-effects. Similar patterns described in the previous paragraph are once again evident. On average 64% of the area within grid cells can be potentially impacted on by land-uses or roads, primarily through commercial forestry, followed by cultivation and finally road-effects and mining. Figure 4 illustrates the current land-cover occurring within areas suitable for alternate land-uses, as well as within the road-effect zones. It is evident that most of the areas suitable for various land-uses are not currently occupied by these specific land-uses. Most of the potential land-uses and road-effects occur in largely natural areas. The second form of existing land-cover type found within these potentially suitable areas is cultivation followed by degraded areas.

Table 3 presents the results of the vegetation analysis. It illustrates the percentage natural area remaining within the vegetation types as well as the percentage of that remaining natural vegetation suitable for alternate land-uses and/or impacted on by road-effects. Most of the vegetation types have large tracts of natural vegetation remaining. Only the Clay Thorn Bushveld, Mixed Lowveld Bushveld, and Sour Lowveld Bushveld contain less than 60% natural vegetation. Most of these largely natural vegetation types are highly suitable for alternate land-uses or are impacted on by road-effects. The Sweet Bushveld, Mopane Bushveld and Soutpansberg Arid Mountain Bushveld are possible exceptions with just over 50% suitable and/or contained within the road-effect zone.

Biodiversity value

Table 4 lists all potential priority conservation areas identified in this study, using a wide variety of approaches, along with the number of grid cells they require. Richness hotspots and irreplaceable grid cells require the least amount of land area (4.65%), while rarity hotspots and grid cells containing species with high RPS scores require the most (from 14.9-35.8%). The areas identified are not largely transformed at present, all containing approximately 70% natural vegetation. However, a large proportion of these areas of high biodiversity value is suitable for alternate land-uses. Once again afforestation poses the largest threats, followed by cultivation, road-effects and mining. Similarly, the combined algorithm selects grid cells that are currently largely untransformed but have a high suitability for forestry and cultivation. The area required by this algorithm (25%) is large in comparison with the other areas identified, with the exception of the grid cells representing species with the top 10% RPS scores.

Figure 5 illustrates the grid cells selected by the final combined algorithm based on one representation of all bird, butterfly and mammal species as well as 10% of each vegetation type. This algorithm contained a land-use constraint component and attempted to avoid grid cells largely currently transformed and degraded. The grid cells are colour coded according to their priority rank calculated from the average threat ranks of the grid cells provided in Table 5.

Table 3: Remaining natural vegetation within each of the vegetation types of the Northern Province as well as the percentage of that area suitable for alternate land-uses.

Vegetation type	Remaining natural area (%)	Natural area suitable (%)
Afromontane Forest	77.61	98.94
Mopane Shrubveld	100	84.51
Mopane Bushveld	92.05	55.79
Soutpansberg Arid Mountain Bushveld	83.79	51.16
Waterberg Moist Mountain Bushveld	90.24	95.21
Lebombo Arid Mountain Bushveld	98.77	87.73
Clay Thorn Bushveld	48.68	99.34
Sweet Bushveld	78.12	51.55
Mixed Bushveld	65.68	85.90
Mixed Lowveld Bushveld	59.73	92.06
Sweet Lowveld Bushveld	94.37	88.26
Sour Lowveld Bushveld	51.72	95.37
Kalahari Plains Thorn Bushveld	86.03	95.69
Moist Sandy Highveld Grassland	48.28	100.00
North-eastern Mountain Grassland	81.61	99.83

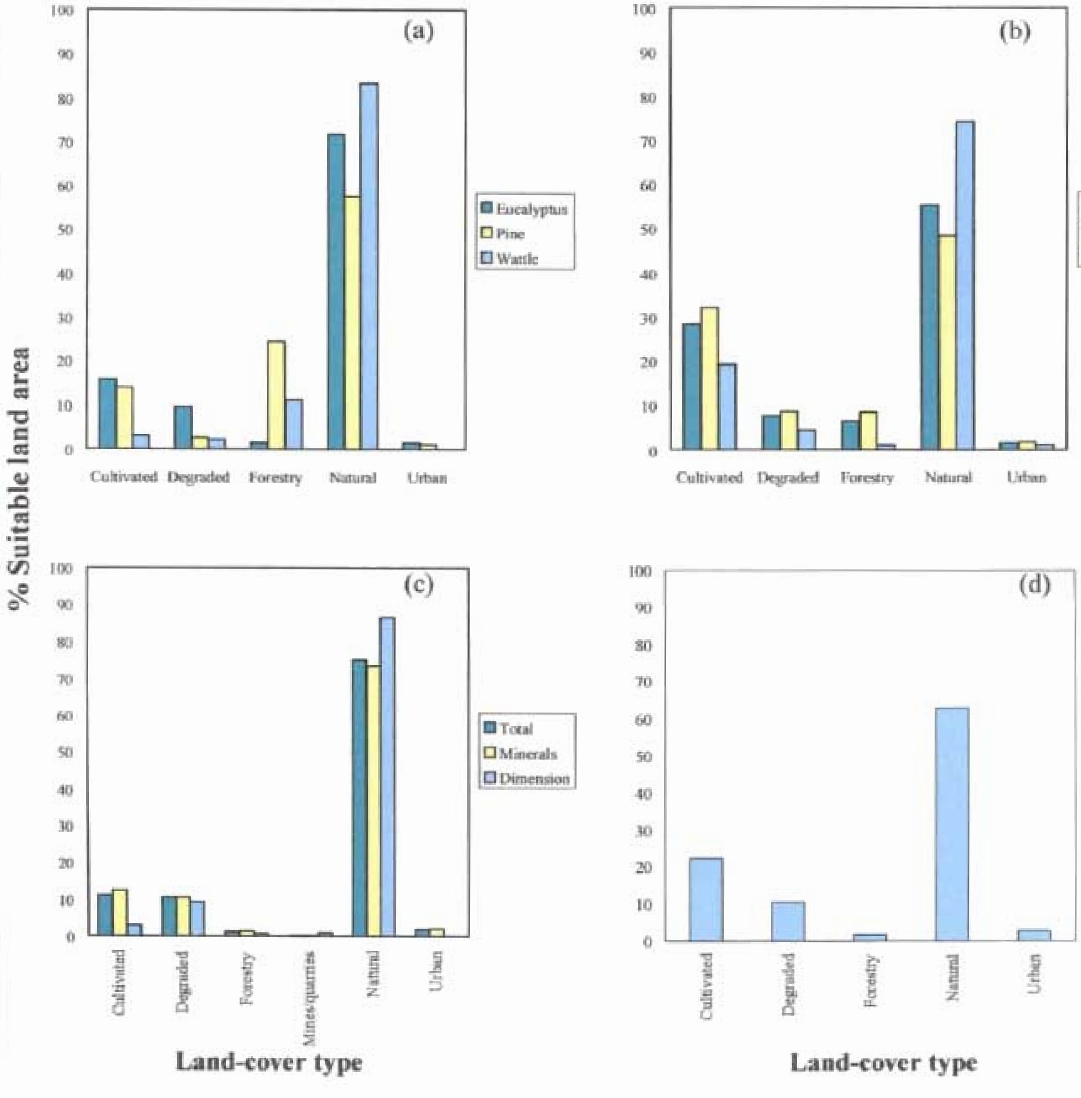

Figure 4: An investigation into the current land uses within areas suitable for alternate land uses. An evaluation of the degree of overlap between areas suitable for: (a) forestry, (b) cultivation, (c) mining, or (d) impacted on by road-effect zones, and current land-cover.

Table 4: Percentage area required, currently transformed, potentially suitable for a variety of alternative land-uses and impacted on by road-effects within grid cells of high biodiversity value.

Conservation area	Required	Transformed	Suitable	Forest	Eucalyptus	Pine	Wattle	Cultivated	Rainfed	Irrigated	Mine	Mineral	Dimension stone	Road-effect
Richness hotspot	4.65	38.63	62.13	60.11	60.11	12.73	7.40	19.83	19.45	0.47	0.62	0.57	0.05	7.63
Rarity hotspot	14.88	31.67	64.18	62.06	62.05	7.47	5.39	12.68	10.64	2.12	1.38	1.34	0.04	4.70
RPS (5%)	17.67	27.93	69.36	67.97	67.76	3.96	3.06	8.08	7.35	0.77	1.05	0.96	0.12	4.56
RPS (10%)	35.81	31.30	69.43	67.49	67.38	4.59	4.22	9.82	8.40	1.66	1.30	1.24	0.09	4.51
Irreplaceable sites	4.65	29.05	42.62	41.55	41.55	1.07	0.62	3.01	1.35	1.66	0.79	0.75	0.03	2.74
Richness algorithm	7.91	26.69	46.84	45.48	45.48	5.56	1.73	9.71	8.73	1.03	0.93	0.89	0.04	4.51
LUC algorithm	9.30	23.89	54.17	52.40	52.37	5.67	3.74	7.10	5.50	1.64	1.21	1.17	0.04	3.90
Beta diversity algorithm	11.16	25.47	61.50	58.81	58.81	4.34	1.44	6.51	4.67	1.87	1.23	1.18	0.06	4.68
Vegetation algorithm	9.30	22.85	60.77	57.88	57.88	1.88	2.64	8.67	6.71	2.38	1.60	1.03	0.63	4.23
Combined algorithm	**25.58**	**26.05**	**66.00**	**63.61**	**63.52**	**5.34**	**4.87**	**10.00**	**8.30**	**1.85**	**1.45**	**1.33**	**0.15**	**4.78**

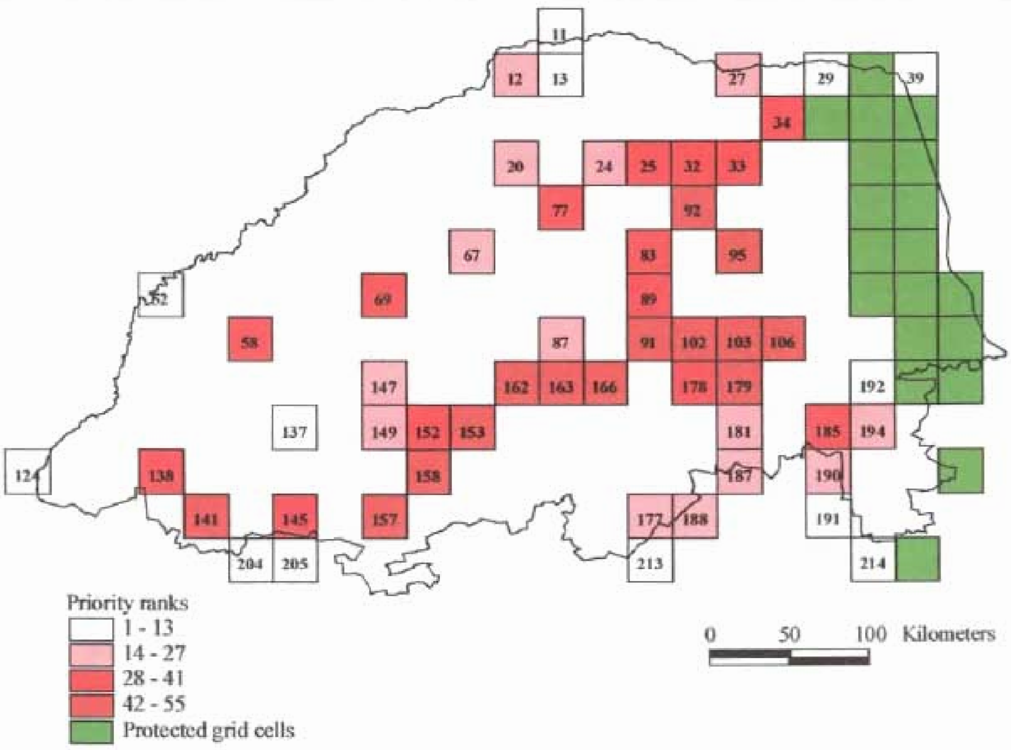

Figure 5: Priority ranks due to land-use threats facing grid cells selected by a species and vegetation combined algorithm including a land-use constraint. Numbers in grid cells represent grid cell codes (see Column 1 in Table 5). High ranks (i.e. dark red) illustrate high priority.

Table 5: Grid cells selected by combined algorithm and the ranked threats they face. The highest priority rank (55) denotes the grid cell under highest threat.

Grid cell code	Natural	Suitability	Cultivated	Mining	Forestry	Road-effect	Number of threats	Average threat rank	Priority rank
179	45	52	49	54	50	43	45	48.3	55
153	39	50	47	50	44	53	54	48.1	54
157	46	41	48	47	40	55	55	47.4	53
102	52	54	55	13	52	46	48	45.7	52
92	40	51	52	36	55	39	41	44.9	51
163	29	49	21	53	48	52	53	43.6	50
162	23	48	40	44	47	49	50	43.0	49
91	55	55	53	12	51	47	21	42.0	48
103	48	34	54	32	34	45	47	42.0	47
95	51	53	34	43	54	21	29	40.7	46
158	30	42	25	46	41	48	49	40.1	45
106	18	44	51	31	46	44	46	40.0	44
141	28	40	45	49	35	38	40	39.3	43
166	41	43	41	38	43	24	31	37.3	42
33	43	37	50	29	42	27	32	37.1	41
152	37	39	39	30	39	37	39	37.1	40
83	31	27	22	51	24	50	51	36.6	39
32	36	31	43	48	31	28	33	35.7	38
185	33	28	42	22	28	42	44	34.1	37
145	24	30	32	55	30	32	35	34.0	36
89	35	21	44	15	22	41	43	31.6	35
25	17	22	29	24	23	51	52	31.1	34
58	2	45	19	35	53	29	34	31.0	33
178	9	46	38	42	49	8	24	30.9	32
34	44	23	37	45	21	17	28	30.7	31
77	38	20	31	20	19	40	42	30.0	30
69	22	25	16	41	27	36	38	29.3	29
138	13	38	46	17	38	22	30	29.1	28
181	16	47	33	21	45	10	26	28.3	27
87	42	26	9	18	25	54	22	28.0	26
177	54	29	10	25	29	23	17	26.7	25
67	53	32	11	23	32	19	15	26.4	24
147	19	35	13	33	37	26	18	25.9	23
24	5	19	35	27	17	35	37	25.0	22
194	10	36	28	10	36	34	20	24.9	21

187	27	17	36	16	18	9	25	21.1	20
149	25	33	12	6	33	30	8	21.0	19
20	12	18	7	39	20	31	19	20.9	18
12	1	11	24	28	10	33	36	20.4	17
188	21	13	26	26	13	6	23	18.3	16
27	7	9	20	52	5	16	14	17.6	15
190	32	14	23	9	14	15	13	17.1	14
52	14	16	15	19	16	12	27	17.0	13
29	20	7	27	37	3	13	11	16.9	12
192	8	15	6	34	15	20	16	16.3	11
191	50	4	17	8	8	4	9	14.3	10
11	11	8	30	11	7	14	12	13.3	9
204	34	3	18	14	2	11	10	13.1	8
137	4	24	8	5	26	18	6	13.0	7
13	3	6	3	40	4	25	7	12.6	6
214	49	1	14	7	1	1	1	10.6	5
205	47	5	2	2	9	5	4	10.6	4
213	26	10	4	3	11	3	3	8.6	3
124	15	12	5	4	12	7	5	8.6	2
39	6	2	1	1	6	2	2	2.9	1

Grid cells with high priority ranks have a combination of high suitabilities for a large number of alternate land-uses, large road-effect zones and low levels of current natural land-cover extent. Appendix 1 provides the raw values used for these rank calculations in Table 5. Grid cells of high priority are concentrated in the central and southern regions (Figure 5). These areas are currently largely cultivated, urbanised and degraded (Figure 1) and are also suitable to most forms of land-use (Figure 2).

Discussion

Future land-use scenarios

The Northern Province is a largely untransformed area with over 70% of the region still covered by natural vegetation. When this is compared with other regions, where only 34% (Hokitika, New Zealand; Awimbo *et al.*, 1996), 8% (Bega Valley, New South Wales; Keith, 1995) or as little as 7% natural vegetation remains (Western Australian wheatbelt; Saunders *et al.*, 1993), the biodiversity in the province does not appear to be in the dire situation prevailing elsewhere. However, this low level of transformation within the province is no reason for complacence. First, this estimate gives no indication of how intact or fragmented that remaining vegetation is; some of the natural pieces of land left may have lost their ability to sustain biodiversity and ecological processes. This would depend on the susceptibility of individual species to extirpation, local scale landscape patterns, the nature and environmental impact of interspersed alternative land-uses, the impact of e.g. agricultural or forestry practices on hydrological processes and soil properties, and degradation within natural areas (Saunders *et al.*, 1993; Scholtz & Chown, 1993; Freemark, 1995; Allan *et al.*, 1997; White *et al.*, 1997; Brokaw, 1998; van Jaarsveld *et al.*, 1998a; Joubert, 1998; Seymour, 1998).

Second, the fact that the land is as yet undeveloped is not due to its unsuitability for alternate land-uses. As illustrated by the results there are substantial tracts of land suitable for a variety of largely destructive land-uses. Almost 80% of the province can be used for some form of afforestation, cultivation and mining or quarrying. With increasing population sizes and their associated resource and land-use demands those areas currently under some form of cultivation, forestry or other land-use are likely to increase. South Africa has already witnessed an increase of 50.5 and 7.5% in areas under afforestation and cultivation, respectively, since the mid-1980's up to the 1994 National Land-cover database estimates (Fairbanks *et al.*, 2000).

<u>Forestry</u>

The Northern Province is part of the major commercial forestry area in South Africa and the current levels of afforestation (0.81%) could increase substantially with the use of specialised species (Thompson, 1995; Fairbanks, 1997). With almost 75% of the province being suitable for forestry, as well as the fact that the forestry sector has been identified as one of the sectors that can provide additional employment and financial resources in South Africa, the potential impact of forestry on regional biodiversity is cause for concern. The South African Reconstruction and Development Program (RDP) strategy identifies the forest sector as an important element of local natural resources development that can contribute to creating better living environments and economic opportunity. The forest and forest products industry is a major employer and of great importance to the South African labour market. It is estimated that about 200000 to 260000 people are employed in the forest and wood processing industries. An estimated 120000 people are employed in those industries which use wood as a primary input (DWAF, 1996). In addition, there are those employed by the smaller primary converters such as in making poles, matches and charcoal.

Industrial forestry began in the last quarter of the nineteenth century and has proved to be highly profitable in the use of natural resources, although it comes at an environmental and social cost (DWAF, 1996). By 1994, industrial forests in South Africa had grown to about 1,45 million hectares. Of the planted areas, 56% was pines, 32% was eucalyptus and 11% was wattle. New afforestation has increased the total area of plantation by about 17000 ha per year recently (DWAF, 1996). This has been supported by past Government policy to expand the plantations, and by the need for wood for the pulp and paper sector. New afforestation has slowed down, however, with very few permits having been issued in the last year (DWAF, 1996).

Potential productivity of these forests is relatively high by world standards, which satisfies over 90% of domestic demand and provides for a surplus for export, largely as pulp, paper, wood chips and other products. The forest products industries, i.e. all those industries using wood and wood products as raw material, constitute a significant part of the South African economy, contributing about 7,4% to the output of the country's manufacturing sector in 1993/94 (DWAF, 1996). They earned about R1,28 billion in net foreign exchange from total export earnings of about R3,6 billion in 1994/95. Their relative contribution to the economy has grown steadily in the past 20 years. The many jobs involved in these industries mean that over one million mainly rural people depend on this industry directly (DWAF, 1996).

Cultivation

Cultivated land has steadily increased in South Africa since the turn of the century from approximately three percent in 1911 to eight percent in 1981 and finally to 12.11% in 1994 (Scotney *et al.*, 1988; Fairbanks *et al.*, 2000). Agriculture is an important primary component in the South African economy as well as for the community. Not only is agriculture often the major factor in rural economic growth and development, but the necessary programmes to support agriculture play a distinctive role in broadening the economic and social options of rural and urban people, and consequently in improving their quality of life (NDA, 1995). The contribution of primary agriculture to the South African GDP declined from a level of 12% in 1960 to approximately 5% in 1990. Since 1994 this contribution has varied between 3 and 4% of the GDP. This relative decline in the nominal contribution to GDP does not imply that the agricultural GDP has declined in real terms, but that there was a faster growth in other sectors. In 1998 the contribution of primary agriculture to the GDP amounted to R21 607 million, which represented 3,2% of GDP (NDA, 2000). It should be added that with strong linkages to the rest of the economy, the "agro-industrial" complex is estimated to contribute at least 15% of the GDP (NDA, 2000).

In their review of agricultural production for 1999/2000 the National Directorate of Agriculture (NDA, 2000) state that South Africa has for some time been one of the few countries in the world that are net exporters of agricultural produce. In the period 1994 to 1998 the agricultural contribution to total export values was in the order of 8 to 10%. The agricultural share in total imports varied between 6 and 7% during the same period. Exports exceeded the value of imports during this period by percentages which varied between 19 (1995) and more than 60 (1998). Agriculture has also long been the sector with the largest formal wage employment in the South African economy. In 1970 30,6% of the economically active population was employed in the agricultural sector. Even though this percentage declined to 13,2% in 1994, it still represented 1,28 million jobs. With only 3,3 million workers in the rural areas of South Africa, this means that agriculture provided for almost 40% of formal employment in rural areas.

Forestry and cultivation scenarios

The Northern Province has large areas of mostly untransformed arable land as illustrated in this study. However, as evidenced by the results there is a lot of overlap between areas suitable for forestry and cultivation. Suitable agricultural land is limited due to scarce water resources and suitable land of high agricultural potential. There is also an increased demand for land by non-agricultural land-uses including residential and industrial development. In addition to this economic development and national food security depend on the availability of productive and fertile agricultural land. The White Paper on Agriculture (NDA, 1995) therefore states that it is imperative for agriculture to utilise these two resources to ensure the sustainable production of agricultural products. Thus South Africa's productive agricultural land should be retained for agricultural use and the use of agricultural land for other purposes should be minimised. This trade-off and land-use decision making with respects to these two large land-uses of forestry and agriculture will depend on the policies and economics of the day.

Limiting factors for the further expansion of forestry and cultivation within the province include the low rainfall and new water laws (DWAF, 1996). The aridity of the province has up till now limited the afforested areas to the moist escarpment and mountain regions (see Figure 4 in Chapter 1) and the commercial cultivated areas to the same areas as well as the Springbok flats. However the development of specialised species with higher levels of drought and frost resistance has increased the afforestable areas within the province (Figure 2) (Fairbanks, 1997). In opposition to this expansion, the South African National Water Act (Act 36 of 1998) now includes a section on stream flow reduction activities. This allows for the regulation of land-based activities that reduce stream flow. These activities include the use of land for afforestation which has been or is being established for commercial purposes. Other activities including the cultivation of any particular crop or other vegetation can also be declared to be a stream flow reduction activity. Therefore although the areas under forestry and cultivation will in all likelihood be more intensively farmed and expanded in South Africa in order to meet the needs of expanding future generations, the aridity of the province as well as the water laws will in probability constrain this expansion. Stream flow reductions and failure of irrigation schemes all contribute to the fact that these two forms of land-use will not expand and may in fact recede.

Alternate land-uses

The province's wide variety of mineral and dimension stone wealth is clear, as well as the potential implications this would have for regional biodiversity. However this wealth and impact may be underestimated within the current study due to the limited number of areas that have been explored within the province. Many mineral regions and provinces within the study area remain unexplored (Wilson & Anhaeusser, 1998). Finally the impacts of roads on the biodiversity appears to be consistent with levels of impacts found in the rest of the country at approximately 5% of the region being impacted (Addendum I). Although these road-effect zones are useful ways to approximate the threats facing regions due to road infrastructure they may not be the best indicators and more work is required on determining the impacts of roads on biodiversity. As Stoms (2000) points out, many aspects of roads affect biodiversity: road width, traffic volume, traffic speed, vehicle miles travelled, road network structure or its spatial configuration, management of the right-of-way, noise levels, light disturbance, and chemical pollution. Most of these factors vary over daily, weekly and annual cycles, which may interfere with critical behavioural periods such as breeding or migration. As such, the road-effect zone can represent only a first order approximation attempt to capture more of the multi-dimensional nature of road network effects

Impacts of future land-uses

Although all of these land-uses pose a threat to regional biodiversity through land-use transformation and alteration and were treated as equally important threats, it is important to note that the types and magnitude of the impacts they have on biodiversity will differ widely. Both afforestation and cultivation, the main threats to biodiversity within the province, are monocultures usually planted on a large scale. However their impacts on biodiversity structure and function are very different. Afforestation involves the replacement of natural vegetation such as grassland or woodland, as well as ancient communities rich in species (DWAF, 1996). Fundamental habitat changes of this kind obviously impact upon biodiversity (Allan *et al.*, 1997). This is especially the case for transformation of areas that were open grassland or woodland areas (like those in the Northern Province) to closed-canopy plantations of alien trees resulting in large-scale habitat changes. Afforestation also has biological implications and has important impacts on regional biodiversity including decreases and changes in species community diversity (Armstrong &

van Hensbergen, 1994; 1995; 1996; 1997; Armstrong *et al.*, 1998) especially of globally and regionally threatened species (Allan *et al.*, 1997). The disruption of natural ecological processes of normally open grasslands and woodlands e.g. fire regimes, species movements, hydrological and nutrient cycles, is also enormous (Richardson & van Wilgen, 1986; Saunders *et al.*, 1991).

Most industrial forests in South Africa were established in grassland ecosystems on naturally acid soils which are prone to loss of mineral nutrients. Where mineral nutrients in the wood are exported by harvesting, or if the forest litter is not effectively recycled, the already acid soils lose fertility. The combination of acidification and forestry effects has been found to be comparable to areas affected by 'acid rain' to the worst degree in industrialised countries (DWAF, 1996). The loss of nutrients is worsened by the increasing acidity of rainfall over much of the region, caused principally by industrial pollution. Afforestation also has serious water budget economic and sociological implications in South Africa as well as in other regions of the world (Macdonald, 1989; National Water Act, (Act 36 of 1998)). An example of these broader-scale effects is the impact on water in rivers which flow through protected areas, such as the Kruger National Park. This, together with other factors such as irrigation abstraction and prolonged droughts, have jeopardised aquatic ecosystems (DWAF, 1996). The forestry and forest products industries also have other environmental impacts which must be recognised and managed. Sawmills, mining timber mills, pulp and paper mills generate waste and water- and airborne emissions which are environmentally harmful and often offensive to neighbouring people.

The impacts of agriculture are argued to be less far-reaching and threatening to biodiversity. Structural changes are relatively minor in comparison, water demands are less, and landscapes fragmented by areas under cultivation still allow for dispersal of plant and animal species (Freemark, 1995). There are however some impacts that must be considered and managed within cultivated areas. Cultivated areas do disrupt natural ecosystems and their processes (DEAT, 1996). Agro-pesticides and herbicides have been shown to have negative impacts on various animal species (Freemark, 1995). The intensification and abandonment of traditional farming methods have also resulted in declines in biodiversity (Suárez *et al.*, 1997). Hinsley *et al.* (1998) point out that abandonment of fields can result in plant species invasion and subsequent biodiversity declines.

Mining, although its impacts are felt on a finer spatial scale, can result in drastic habitat changes through mine dumps, pollution of ground and surface water, ground and air pollution, alien plant invasions, erosion and topsoil and vegetation losses. The ecological effects of roads mentioned previously are indications of the far reaching impacts of roads on biodiversity. Therefore it is important that although all of these land-uses were considered to be equally important in threatening biodiversity, any conservation or land-use planning initiative within the province would have to consider the differing impacts of these land-uses.

Another form of land-cover threat in the province, one that is not easily mapped or predicted in studies such as this one, is land degradation (Scholtz & Chown, 1993; Hoffman, 1999). Land degradation refers to the loss of primary production of natural vegetation in an area. This includes all regions with very low vegetation cover in comparison with the surrounding natural vegetation cover and are typically associated with subsistence level farming and rural population centres, where wood-resource removal, overgrazing and subsequent soil erosion are excessive (Thompson, 1996). South Africa's natural resources are being degraded at an alarming rate (Newby & Wessels, 1997; Hoffman *et al.*, 1999). Soil erosion, as a consequence of overgrazing and improper cultivation, is considered to be one of the most serious environmental problems facing South Africa (Newby & Wessels, 1997; Hoffmann *et al.*, 1999). It is postulated that between 50 and 87% of natural rangeland is in a poor to critical condition (Newby & Wessels, 1997), while an estimated 150 million tons of sediment are transported annually by South African rivers (DEA, 1992).

The Northern Province is made particularly vulnerable to degradation by two factors. First, its high levels of aridity make it vulnerable to the loss of natural vegetation and subsequently to soil degradation which in essence makes the degradation process irreversible and permanent (desertification) (Newby & Wessels, 1997). Second, a large proportion of the human population in the Province is rural and leads a subsistence level lifestyle. Through fuel wood harvesting and domestic livestock grazing on areas particularly susceptible to degradation, thereby exacerbating the process. Other land-uses within the area include commercial domestic and wildlife livestock ranching (land-uses considered to be more amenable to biodiversity conservation) (Pressey, 1992). However, if not managed these land-uses can also degrade this sensitive land (Newby & Wessels, 1997). Therefore, although various acts, laws and permit systems regulate some of the land-use impacts in an area, something must be done to address the ongoing land degradation. Because as Lewis and Berry (1988), and James (1991) predict: if the current rate of degradation continues and sustainable utilisation is not achieved, all attempts at socially and economically uplifting South Africa's people are doomed to fail.

Land-use planning

Generally, the use of land in South Africa has been poorly planned, with resultant inefficiencies, inequities, and environmental degradation. Although the most glaring consequences arise from the apartheid policies as applied in the former homelands, effects are evident throughout the rest of the country (DWAF, 1996). Some consequences of inadequate land-use planning are seen in land disputes, the conflicts over water resources, a concern over the loss of land suited to crop cultivation and the loss of habitats for native species. It is obvious from the discussion above that there are several factors that must be taken into consideration during land-use planning. The economic and social implications of various land-uses, are just two of the considerations that must be taken in this decision-making process. The impacts of these land-uses on biodiversity are substantial and often irreversible. As signatories to the Convention on Biological Diversity South Africa is compelled to review the impact of land-use changes on biodiversity and seek changes where necessary. This study therefore provides an important first step towards achieving this goal in that it highlights areas of extreme importance to biodiversity conservation.

At a broad-scale the results illustrate that similar to the findings in Addendum I most of the vegetation types of South Africa are not under large threats at present. However, the Clay Thorn Bushveld and Mixed Lowveld Bushveld are threatened due to high levels of transformation within South Africa as well as within the province and require conservation attention. The fact that these vegetation types and many of the others face large future threats due to high levels of suitability for various land-uses is important and highlights their conservation needs and should be considered in any land-use plan for the area. The Clay Thorn Bushveld as well as the forest and grassland vegetation types are almost entirely suitable for some form of land-use development. This has very important implications for biodiversity conservation.

The grassland biome is an endangered biome in South Africa requiring urgent conservation attention. It is the most productive agricultural area, hosts most of the human population of South Africa, is very rich in minerals (especially coal and gold) and also includes most of the areas suitable to forestry. It is also one of the most important biomes in terms of its biodiversity content due to high levels of species endemism, rarity and richness (Allan *et al.*, 1997; van Jaarsveld *et al.*, 1998a)

Indigenous subtropical forest is the smallest biome represented in southern Africa, covering less than 0.25% of the total land area (Low & Rebelo, 1996), yet it supports a high proportion of the region's floral and faunal diversity (e.g., 14% of all terrestrial birds and mammals; Geldenhuys & MacDevette 1989). The importance of conserving forest biodiversity in southern Africa is widely recognised (e.g., Cooper, 1985; Geldenhuys & MacDevette, 1989; Lawes *et al.*, In Press). However, it is evident that the forest biome is under increasing and harmful anthropogenic pressure (Cunningham, 1989; Geldenhuys & Macdevette, 1989). Macdonald (1989) estimates that approximately 42.5% of the forest biome in South Africa has already been transformed, mostly in the recent past. These results therefore emphasise that the identification of conservation areas in the forest and grassland biome within the region is an issue of immediate concern.

Similarly most of the regions identified as important to biodiversity conservation (hotspots, complementary networks etc.) due to their biodiversity composition are currently not largely threatened by alternate land-uses, but may well become so in the near future due to high levels of suitability to especially forestry. In both the White Papers for forestry and agriculture (NDA, 1995; DWAF, 1996) it is widely acknowledged that demands for both forestry and agricultural products will increase in the future as populations increase, therefore these suitable areas must be seen as real potential threats to areas important to biodiversity.

Finally this study makes a contribution to land-use planning especially conservation planning. These land-use threats to biodiversity, both current and future, are real and serious (Soulé, 1991; Sala *et al.*, 2000). One method of addressing these threats is through the conservation of biodiversity within areas that are protected from these land-use impacts (Margules & Pressey, 2000). However, with the limited resources on hand for conservation area establishment it is obvious that first, not all areas identified as being important to biodiversity conservation will be protected immediately, and second many of these areas may well have to rely on off-reserve management rather than formal protection (Pressey & Logan, 1997, Cowling *et al.*, 1999). The techniques highlighted within this study provide a useful way of deciding which of these areas should receive some form of protection first. The combined conservation area selection algorithm identified grid cells that are arguably all important to effective biodiversity conservation within the province, but by looking at the threats facing those areas one can form an idea of the conservation urgency of some of them. Thus the use of not only the current levels of threat facing biodiversity, but also the incorporation of future threats within the region, allows for effective and efficient conservation planning. One can decide which of the areas if they were to remain unprotected would either lose all the biodiversity or become transformed due to a high land-use suitability and would subsequently lose their biodiversity at some later stage.

Conclusion

Sustainable development calls for development that meets the needs of current generations without compromising the needs of future ones (WCED, 1987). This implies improving the quality of life for humans while living within the carrying capacity of the environment (IUCN, 1991). Often though the reality of the situation is that the primary focus is on development with conservation concerns acting as a constraint. However, effective sustainability will only be attainable when a compromise between these two seemingly mutually exclusive forms of land-use can be attained. Regional sustainability will depend on both effective land allocations for alternative and often-competing land-uses and also management of these areas to satisfy multiple goals (Faith & Walker, 1996). We feel this study brings us closer to the goal of regional sustainability in that it acknowledges the need for expansion of current land-use practices, as well as investigating their potential spatial extent and implications for regional biodiversity (at a broad-scale). Finally it admits that the delay between conservation planning and implementation is often lengthy. By ranking the areas of crucial biodiversity importance in order of the number and degree of threat they do and will face, biodiversity losses can be minimised.

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Appendix 1: Percentage area currently transformed, suitable for alternate land-uses and impacted on by road-effects within each of the grid cells selected by the combined algorithm.

Grid cell	Transformed	Suitable	Cultivated	Rainfed	Irrigated	Mining	Dimension	Mineral	Road-effect	Forest	Eucalyptus	E.c.	E.t.	E.u.	E.n.	E.s.	Pine	P.c.	P.t.	P.p	Wattle
11	7	7	5	0	5	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0
12	2	13	3	0	3	1	0	1	4	5	5	4	2	0	0	0	0	0	0	0	0
13	3	4	0	0	0	2	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0
20	7	47	0	0	0	2	0	2	4	44	44	43	16	0	0	0	0	0	0	0	0
24	4	49	7	1	6	1	1	0	5	40	40	33	21	0	0	0	0	0	0	0	2
25	10	73	4	4	0	1	0	1	13	70	70	52	44	5	0	8	0	0	0	0	12
27	4	8	1	0	1	5	4	1	2	0	0	0	0	0	0	0	0	0	0	0	0
29	11	7	4	0	4	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
32	29	87	14	14	0	4	0	4	3	86	86	47	59	33	3	36	19	19	2	5	23
33	49	98	33	33	0	1	0	1	3	97	97	29	63	68	0	69	55	55	37	7	16
34	49	76	7	0	7	3	0	3	2	68	68	59	38	7	0	8	1	1	0	0	0
39	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	9	39	0	0	0	0	0	0	1	39	39	39	36	0	0	0	0	0	0	0	0
58	2	100	1	0	1	1	0	1	3	99	99	99	11	0	0	0	0	0	0	0	0
67	66	91	0	0	0	1	0	1	2	90	90	90	29	0	0	0	0	0	0	0	0
69	13	79	0	0	0	2	0	2	5	77	77	77	0	0	0	0	0	0	0	0	0
77	30	52	6	2	4	0	0	0	6	43	43	43	12	0	0	0	0	0	0	0	2
83	23	81	2	2	0	5	0	4	13	75	75	72	29	2	0	3	0	0	0	0	3
87	47	79	0	0	0	0	0	0	14	75	75	75	0	0	0	0	0	0	0	0	0
89	27	73	15	15	0	0	0	0	6	68	68	58	36	6	0	8	1	1	0	0	6
91	56	95	48	48	0	1	0	1	9	94	94	47	21	22	39	45	35	34	24	28	53

92	42	100	36	35	1	1	0	1	6	99	99	51	65	43	2	43	32	32	21	15	4
95	60	100	6	6	0	2	0	2	2	99	99	99	32	0	0	0	0	0	0	0	0
102	62	100	70	70	1	0	0	0	10	99	99	12	56	86	11	86	83	82	68	53	11
103	69	100	41	24	22	0	0	0	10	99	99	79	77	14	0	15	3	3	0	0	0
106	10	100	34	24	12	1	1	0	8	99	99	97	43	1	0	2	0	0	0	0	0
124	9	19	0	0	0	0	0	0	1	19	19	19	5	0	0	0	0	0	0	0	0
137	3	78	0	0	0	0	0	0	2	76	72	66	10	0	8	0	0	0	0	0	21
138	8	98	22	16	6	0	0	0	2	97	97	97	62	0	0	0	0	0	0	0	0
141	19	99	19	12	7	4	0	4	6	95	95	95	37	0	0	0	0	0	0	0	0
145	17	87	6	6	0	9	0	9	4	84	84	84	55	0	0	0	0	0	0	0	0
147	11	97	0	0	0	1	0	1	3	96	96	95	1	0	2	0	0	0	0	0	0
149	18	94	0	0	0	0	0	0	3	93	92	77	3	0	27	0	0	0	0	0	8
152	29	98	10	10	0	1	0	0	6	97	97	92	17	0	8	0	0	0	0	0	11
153	34	100	26	26	0	4	0	4	13	99	99	99	43	0	0	0	0	0	0	0	0
157	52	99	27	27	0	4	0	3	16	97	97	97	49	0	0	0	0	0	0	0	0
158	23	99	3	3	0	3	0	2	11	97	97	97	58	0	0	0	0	0	0	0	0
162	14	100	11	11	0	2	0	2	12	99	99	98	0	0	14	0	0	0	0	0	3
163	23	100	1	1	0	5	0	5	13	99	99	99	0	0	0	0	0	0	0	0	0
166	45	100	11	11	0	1	0	1	3	98	98	97	4	0	4	0	0	0	0	0	3
177	67	86	0	0	0	1	0	1	2	84	84	84	1	0	28	0	0	0	0	0	0
178	5	100	9	9	0	2	0	2	1	99	98	59	63	23	5	34	18	17	3	6	45
179	52	100	30	30	0	6	0	6	7	99	99	73	75	18	0	20	16	16	1	2	11
181	9	100	6	6	0	0	0	0	1	99	99	53	72	25	0	29	19	18	1	11	24
185	24	81	14	0	14	1	0	1	7	79	79	75	11	3	0	3	1	1	0	0	0
187	19	42	7	7	0	0	0	0	1	41	41	40	16	0	0	1	0	0	0	0	3
188	12	20	3	3	0	1	0	1	0	20	20	19	11	0	2	0	0	0	0	0	4

190	24	25	3	0	3	0	0	0	2	23	23	11	18	11	0	13	6	6	2	0	0
191	59	2	0	0	0	0	0	0	0	2	2	0	2	2	0	2	2	2	1	0	0
192	4	36	0	0	0	1	0	1	2	34	34	34	0	0	0	0	0	0	0	0	0
194	5	97	4	0	4	0	0	0	5	96	96	96	0	0	0	0	0	0	0	0	0
204	24	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
205	58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
213	18	9	0	0	0	0	0	0	0	8	8	8	0	0	3	0	0	0	0	0	2
214	55	4	0	0	0	0	0	0	0	4	4	3	4	1	0	1	1	1	0	0	0

E.c. = *Eucalyptus camaldulensis*, *E.t.* = *Eucalyptus tereticornis*, *E.u.* = *Eucalyptus urophylla*, *E.n.* = *Eucalyptus nitens*, *E.s.* = *Eucalyptus saligna*.

P.e. = *Pinus elliottii*, *P.p.* = *Pinus patula*, *P.t.* = *Pinus taeda*