# CHAPTER 4

# An assessment of biodiversity surrogacy options in the Northern Province of South Africa

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**Abstract**

Because of the inadequacy of existing data on the distribution of biodiversity, surrogate measures for regional biodiversity have long been used in conservation area selection. These measures include species and environmental surrogate measures, which include vegetation types and land systems and classes. However, the assumed relationship between these surrogate measures and regional biodiversity has seldom been demonstrated. This study uses both species and environmental surrogates of vegetation and landtypes in selecting important areas for biodiversity conservation in the Northern Province of South Africa. The success of these measures in capturing known regional biodiversity is evaluated, as well as their success at identifying important areas containing threatened, rare and endemic non-target biodiversity features. The spatial congruence of the areas identified using different surrogate measures was also assessed. A combined approach to reserve selection using both species and environmental measures was also applied and the areas identified were evaluated in terms of their efficient representation of regional biodiversity. There is a trade-off between success at representing non-target biodiversity features (especially rare, threatened and endemic features) and land-use efficiency. Combined approaches have similar levels of success in representing regional biodiversity, although landtype based ones are more land-use inefficient. The trade-off between efficiency and representation suggests that many of the important conservation areas identified will rely on off-reserve management rather than formal protection. Furthermore, results suggest that recommended national conservation targets of 10% are inadequate

**Introduction**

The need to conserve the world's remaining biodiversity is widely recognised, as human impacts threaten an extinction event likely to rival previous mass extinctions of the geological past (Wilson, 1988; UNEP, 1995; Pimm & Raven, 2000). The resources available for the conservation of biodiversity are limited and there is therefore a need to identify priority areas for conservation swiftly and cost-effectively. Several systematic approaches to the identification of conservation areas in which all known regional biodiversity is protected have been suggested (Kirkpatrick, 1983; Margules *et al.*, 1988; Pressey & Nicholls, 1989a; Bedward *et al.*, 1992; Nicholls & Margules, 1993; Margules *et al.*, 1994; Underhill, 1994; Freitag *et al.*, 1996; Church *et al.*, 1996; Csuti *et al.*, 1997; Margules & Pressey, 2000). These approaches, however, require extensive information on the distribution and taxonomy of species. Often regions under evaluation have inadequate databases on species distribution due to poor quality biological survey data and inconsistent basic taxonomy (Haila & Margules, 1996). Conservation area selection techniques must then rely on substitute or "surrogate" measures of biodiversity (Belbin, 1993; Prendergast *et al.*, 1993; Pressey, 1994; Margules & Redhead, 1995; Pressey & Logan, 1995; Balmford, 1998; Howard *et al.*, 1998; Reid, 1998; Pressey *et al.*, 2000).

These surrogate measures include the species surrogate measures of richness, endemism, rarity and complementarity of indicator groups (Margules *et al.*, 1988; Rebelo & Siegfried, 1992; Nicholls & Margules, 1993; Prendergast *et al.*, 1993; Pressey *et al.*, 1993; Margules *et al.*, 1994; Lombard, 1995; Williams *et al.*, 1996; Flather *et al.*, 1997; Howard *et al.*, 1998; Lawton, 1998; van Jaarsveld *et al.*, 1998), higher taxa such as genera or families (Gaston & Williams, 1993; Williams & Gaston, 1994; Williams *et al.*, 1994), or the environmental surrogate measures of vegetation types, land systems or classes and environmental domains (Noss, 1987; Purdie *et al.*, 1986; Belbin, 1993; Pressey, 1994; Pressey & Logan, 1994; Margules & Redhead, 1995; Pressey & Logan, 1995; Faith & Walker, 1996; Wessels *et al.*, 1999; Fairbanks & Benn, 2000; Pressey *et al.*, 2000; Cowling & Heijnis, (In Press)). These environmental surrogate classes are derived from information on vegetation types, soil properties, remote sensing data, climatic data and terrain data (Austin & Margules, 1986; Margules & Redhead, 1995).

Although the need for surrogate measures is widely recognised, there is still no consensus as to which measures are the most applicable. It has also been argued that this assumed relationship between surrogate measures and regional biodiversity be demonstrated before it is put into practice in conservation planning (Pressey, 1994; Williams & Humphries, 1996; Wessels *et al.*, 1999). The aforementioned species surrogate measures have been widely used (Prendergast *et al.*, 1993; Launer & Murphy, 1994; Williams *et al.*, 1996; Freitag *et al.*, 1997; Kerr, 1997), but have several shortcomings including: a lack of correlation between these surrogate measures and regional biodiversity (Chapters 2 and 3) (Rebelo & Siegfried, 1992; Prendergast *et al.*, 1993; Gaston & Williams, 1993; Margules *et al.*, 1994; Williams & Gaston, 1994; Margules & Redhead, 1995; Faith & Walker, 1996; Gaston, 1996) as well as a lack of coincidence between priority conservation areas selected using various species surrogate measures involving different taxa (Chapters 2 and 3) (Lombard *et al.*, 1995; Prendergast *et al.*, 1993; Howard *et al.*, 1998; van Jaarsveld *et al.*, 1998; Mace *et al.*, 2000). This finding suggests that complementary conservation networks selected to represent specific taxa are unlikely to be representative of all biodiversity.

When considering the usefulness of environmental surrogates, Faith and Walker (1996) argue that, if correctly measured, environmental variation should indicate organismal diversity. Thus different environmental classes are assumed to contain different species assemblages. Therefore the protection of these classes should ensure that all or most species within the region will also be protected (Belbin, 1993). The representativeness of conservation area networks has been assessed using various environmental attributes (Scott *et al.*, 1987; Faith & Norris, 1989; Pressey & Nicholls, 1989b; Belbin, 1993; Margules *et al.*, 1994; Pressey & Logan, 1995). However, as Pressey (1994) points out, the assumed relationship between environmental classes and species distribution and abundance is unclear and seldom investigated. In addition, certain species, especially rare species confined to small patches of habitat which are not recognised as distinct environmental classes, may "fall through the coarse-filter" when using broad-scale environmental classes (Noss, 1983; Bedward *et al.*, 1992; Panzer & Schwartz, 1998).

Nevertheless, environmental surrogates have compelling practical advantages, as information on their distribution is cheaper and easier to acquire than detailed species distribution data. Margules and Redhead (1995) also point out that by representing environmental classes some unknown species and known species with unknown distributions may be represented. The shortcomings of species distribution data and the limitations of environmental surrogate measures in the selection of priority conservation areas suggest that perhaps a combination of the two approaches in conservation planning may be advisable.

This study aims to compare the more traditional species based approach to conservation area selection with site selection based on representing specific target levels of environmental surrogate classes within the Northern Province of South Africa. In other words, conservation areas in which all species known to occur regionally are represented at least once will be compared with conservation areas in which specific levels of vegetation and landtypes are represented.

As Pressey and Logan (1995) argue, assessments of conservation area coverage using environmental classes are scale dependent and influenced by the definition of the various environmental classes. Broad scale classes are relatively heterogenous (Scott *et al.*, 1989), thus selection of these coarse classes is still likely to miss much variation. Fine-scale classes are more homogenous and should therefore lead to a better representation of the environmental variation within a network of conservation areas. This study will also examine the influence of mapping scale on the selection of sites based on the coarse environmental classes of vegetation types, as well as the fine scale classes of landtypes.

Finally a set of conservation areas will be selected and evaluated using a combination of species distribution data and environmental surrogates. This combined approach to conservation area selection is similar to that used by Bull *et al.* (1993) in Margules and Redhead (1995) and Lombard *et al.* (1997). The former study identifies a set of sites, referred to as seed points (which include the location of rare or threatened species, existing conservation areas or rest areas for migratory species). Grid cells were then added until a predetermined proportion of each environmental class was contained within the conservation area network. The present study uses known localities of vertebrate, invertebrate and vascular plant species as seed points and then adds grid cells until a predetermined percent of all vegetation types or landtypes are represented within the network. In addition to this, grid cells with specified representations of these vegetation and landtypes will be used as an initial set of sites to which grid cells will be added until all known species within the region occur at least once in the protected areas.

## Methods

The study area comprises the Northern Province of South Africa (see Figure 1 in Chapter 1).

*Species based approach*

This part of the study incorporates 2060 species with 61329 unique distribution records for invertebrate, vertebrate and vascular plant species. Selection units are quarter degree or 15' x 15' grid cells (n = 215) with an average area of 700 km$^2$ (Table 1).

<u>Species distribution databases</u>

The species data used includes databases on the distribution of taxa that are frequently used as biodiversity indicators, namely mammals, birds, vascular plants and butterflies. These taxa have a relatively sound taxonomy, are well surveyed within the study area and their distribution data are fairly recent (Table 1) (Harrison, 1992; Freitag & van Jaarsveld, 1995; Freitag *et al.*, 1998; Muller, 1999.). Additional data on the distribution of invertebrate species including buprestid beetles, scarab beetles, termites and neuropterans are also included in the analyses, although these taxa are less well known taxonomically, have older distribution records and are less well surveyed within the study area (Table 1) (Freitag & Mansell, 1997; Muller *et al.*, 1997; Hull *et al.*, 1998; Koch, *et al.*, 2000). Because of the large size of the vascular plant dataset (78% of all species) and the disproportionate effect it has on the resultant conservation area networks (43 additional grids cells out of a possible 215 required to protect all plant species), it was decided to exclude all plants not endemic to the study area. The species distribution data used in this chapter were later updated with the removal and addition of some species due to taxonomic changes as well as the discovery of vagrant and exotic species, this explains the slight differences that exist between this database and the ones used in the other chapters.

**Table 1:** A description of the species distribution databases used in the analyses

| Taxon | Species | Records | Grids | Survey date |
|---|---|---|---|---|
| Mammals (Mammalia) | 182 | 4207 | 170 | 1980-1995 |
| Birds (Aves) | 575 | 49427 | 214 | 1980-1992 |
| Vascular plants (Plantae) | 5711 | 42055 | 215 | 1900-1996 |
| Subgroup: Endemic plants | 472 | 2694 | 215 | 1900-1996 |
| Butterflies (Hesperioidea & Papilionoidea) | 328 | 2062 | 84 | 1905-1980 |
| Buprestid beetles (Buprestidae) | 247 | 977 | 119 | 1900-1996 |
| Scarab beetles (Scarabaeinae) | 218 | 1372 | 124 | 1900-1992 |
| Termites (Isoptera) | 16 | 464 | 160 | 1972-1980 |
| Neuropterans (Myrmeleontidae) | 22 | 126 | 41 | 1900-1996 |
| *Combined databases* | | | | |
| All taxa | 7299 | 100690 | 215 | |
| All taxa (excluding non-endemic plants) | 2060 | 61329 | 215 | |

Conservation area selection procedures

A rarity-based conservation area selection algorithm based on that of Nicholls and Margules (1993) was applied. This iterative algorithm begins by selecting grids cells containing unique occurrences of species and proceeds from there in a step wise fashion selecting the grids containing the next most rarest species until all species are represented at least once within the conservation area network. Ties between grid cells are resolved by applying the principles of adjacency of grid cells and complementarity of species content within grid cells respectively.

*Environmental surrogacy approach*

The environmental surrogates of vegetation types and landtypes were used in the present study.

Vegetation types

Low and Rebelo (1996) define a vegetation type as: "a coherent array of communities which share common species (or abundances of species), possess a similar vegetation structure (vertical profile), and share the same set of ecological processes". Vegetation data for the Northern Province were extracted from the national-scale vegetation map of South Africa (Low & Rebelo, 1996). The Northern Province is covered by three biomes (Forest, Grassland and Savanna) and fifteen vegetation types of which Mixed Bushveld, Mopane Bushveld and Sweet Bushveld are the most dominant (see Table 1 in Chapter 1).

Landtypes

Pedosystems are areas with uniform terrain and soil patterns (MacVicar *et al.*, 1974; Land Type Survey Staff, 1986) and are similar to land systems (Christian & Steward 1968; Lawrence *et al.*, 1993), which have been extensively used as environmental surrogates during conservation area evaluation at broad regional scales in Australia (Purdie *et al.*, 1986; Pressey & Nicholls, 1989b; Pressey & Tully, 1994). Climate zones (mapped at 1:250000 scale) have been superimposed upon pedosystem maps to arrive at maps of landtypes covering the majority of South Africa (MacVicar *et al.*, 1974; Land Type Survey Staff, 1986). A landtype therefore delineates an area at 1:250000 scale which displays a marked degree of uniformity with respect to terrain form, soil pattern and climate (MacVicar *et al.*, 1974; Land Type Survey Staff, 1986). Landtype data for the Northern Province were prepared by the Institute for Soil, Climate and Water (ISCW) of the Agricultural Research Council (ARC). A total of 676 different landtypes occur within the study area. Due to the large size of this database as well as the sensitive nature of the data, the landtypes are represented as numeric codes and therefore no specific references can be made to or conclusions drawn about specific landtypes in the present study.

Conservation area selection procedures

The vegetation map and landtypes of the Northern Province were respectively overlaid with the aforementioned 15' x 15' grid cells. The areas of various vegetation and landtypes within each grid cell (n = 215) were subsequently calculated using ArcInfo.

A percentage representation approach similar to that used by Pressey and Nicholls (1989b), and Pressey and Tully (1994) was applied; this approach attempts to sample a nominated percentage area (5-50%) of each vegetation and landtype. The algorithm initially selects the feature covering the smallest total area and thus conforms to the rarity-based algorithm of Margules *et al.* (1988). An over representation constraint rule was designed to restrict overshooting initial target representation levels, as is often the case in conservation area selection procedures (Bedward *et al.*, 1992; Nicholls & Margules, 1993; Wessels *et al.*, 1999). The adjacency constraint rule was also included to resolve ties and ensure larger contiguous areas where possible (Nicholls & Margules, 1993; Lombard *et al.*, 1995; Freitag *et al.*, 1996; Willis *et al.*, 1996).

*Comparison of the species based and surrogacy approaches*

The conservation area network selected by the species based approach was evaluated in terms of the percentage of each vegetation and landtype it contained. Similarly, the percentages of total species captured within the conservation areas selected to represent target levels of the vegetation and landtype classes were also calculated. In addition to this the spatial congruence or overlap of the conservation areas selected by both species and environmental surrogate based approaches was compared using measures of proportional overlap (Chapter 2 and 3) (Prendergast *et al.*, 1993; Lombard *et al.*, 1995)

$$\textit{Proportional overlap} = N_c / N_s \times 100$$

where: $N_c$ is the number of common sites in a pair of conservation area networks and $N_s$ is the number of sites in the smallest network containing data for both groups. Thus the measure of proportional overlap measures spatial overlap as a proportion of the maximum overlap possible (Chapter 2 and 3). Finally the success of the conservation area networks based on species and environmental surrogates in representing rare, threatened and endemic species and environmental features was evaluated (Chapter 3).

*Combined approach*

The present study uses two combined approaches. The first, similar to that of Bull *et al.* (1993) *in* Margules & Redhead (1995), preselects a set of grids cells (seed points) required to represent all species at least once. From here it then calculates the percentage of each vegetation or landtype already represented in the preselected seed points and then adds on grids cells necessary to ensure that the target levels of each vegetation and landtype representation (5-50%) are reached. This approach will be termed the species-first combined approach. The second approach, or surrogate-first combined approach, preselects a set of grid cells required to represent specified levels of the surrogate classes of vegetation and landtypes (5-50%). The species represented within these preselected grid cells are counted and then grid cells containing the unrepresented species are selected until all species within the database are contained at least once within the set of sites.

These two approaches were then evaluated in terms of efficient representation of regional biodiversity, i.e. maximum biodiversity representation at minimum cost in terms of land required. This efficiency was determined for the species-first approach by calculating the number of additional grid cells required to represent the target levels of the surrogate classes after preselection of the seed points. Similarly, efficiency of the surrogate-first approach was calculated as the number of additional grid cells needed to represent all species at least once after preselection of grid cells containing target levels of the environmental surrogate classes.

*The influence of scale*

The above mentioned analyses use both the environmental surrogates of vegetation types (a broad scale surrogate) and landtypes (a finer scale surrogate). Because the scale and definition of environmental classes can influence the results of studies of this nature (Pressey & Logan, 1995), the effects of the different scales of resolution of these two classes are investigated throughout the present study.

**Results**

*Species based approach*

The species-based conservation area selection algorithm required 116 grid cells (54%) to represent all 2060 species once, more than all conservation areas based on vegetation types, but less than landtype based areas (Figure 1). This conservation area network represents an average of 59% of the 15 vegetation types within the Northern Province (Table 2). Nearly all vegetation types are well represented, with the majority having between 70-80% of their areas represented in the species-based networks. Most lie above a 40% representation with the exception of the Kalahari Plains Thorn Bushveld which is not represented at all and the Lebombo Arid Mountain Bushveld which has only 12.5% of its area represented (Table 2). On average 60% of each of the landtypes are represented in this conservation area network. The majority of landtypes are either not represented at all (0%) or fully represented (100%), the remainder appear to be evenly distributed between all percentage representation classes (Figure 2). Of the 676 landtypes within the Northern Province 134 (20%) are less than 10% represented, while 256 (38%) are more than 90% represented (Figure 2).

*Environmental surrogacy approach*

Figure 3 illustrates the increase in the percentage species captured in conservation areas selected to represent increasing levels of vegetation and landtypes. More than 50% of all species are captured by areas selected to represent vegetation types, however more than 50% of the vegetation type must be selected before 80% of the species are captured, requiring over 45% of the available land area. Areas selected to protect nominated levels of finer-scale landtypes appear to capture more species than areas

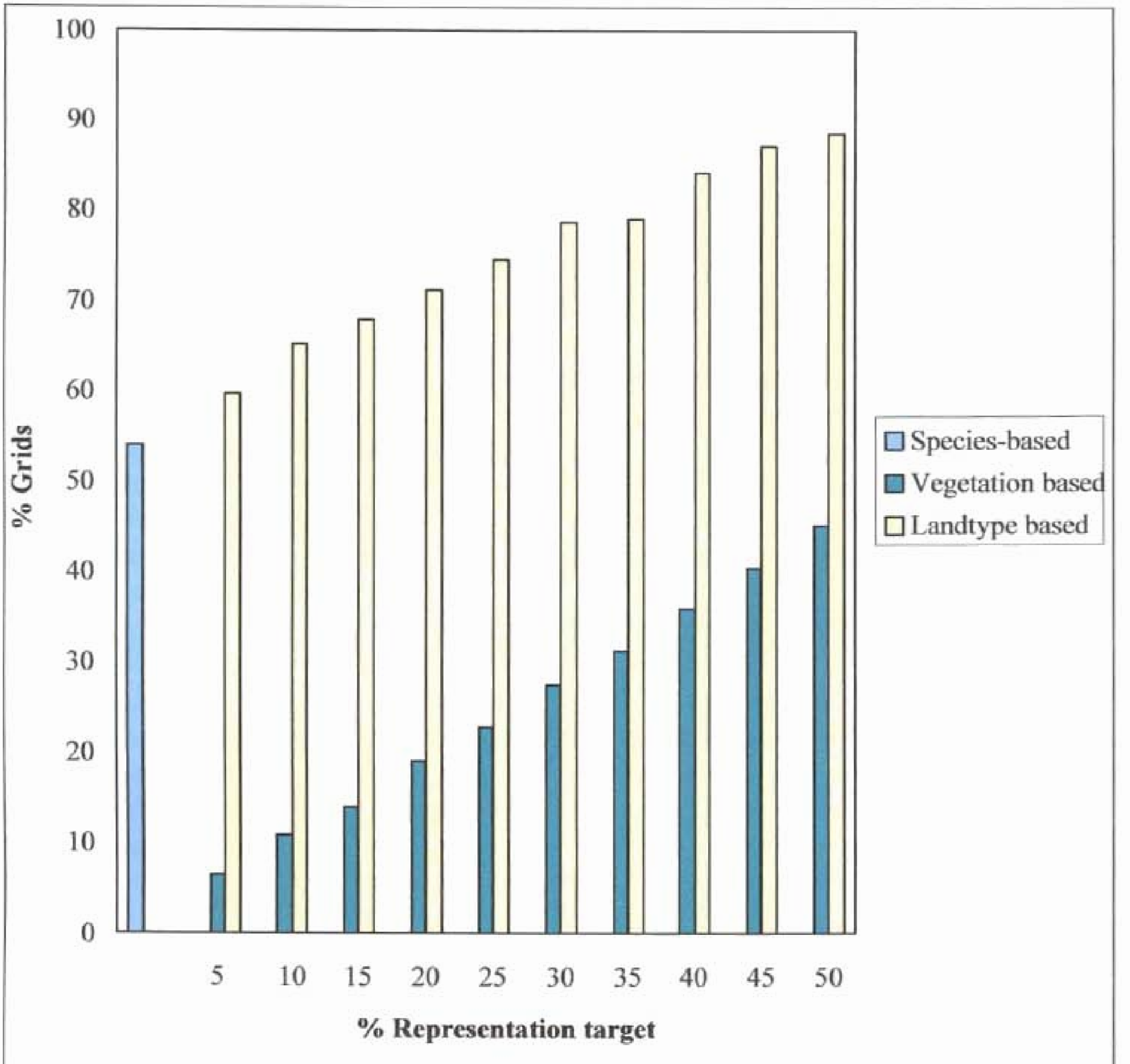



**Figure 1:** Relative efficiencies of conservation area selection procedures measured as the percentage grid cells required.

**Table 2:** Percentage of each vegetation type represented in grid cells selected by species-based approach.

| Vegetation type | % Represented |
|---|---|
| Afromontane Forest | 98.22 |
| Clay Thorn Bushveld | 40.53 |
| Kalahari Plains Thorn Bushveld | 0.00 |
| Lebombo Arid Mountain Bushveld | 12.58 |
| Mixed Bushveld | 49.30 |
| Mixed Lowveld Bushveld | 61.16 |
| Moist Sandy Highveld Grassland | 74.15 |
| Mopane Bushveld | 54.25 |
| Mopane Shrubveld | 77.66 |
| North-eastern Mountain Grassland | 85.97 |
| Sour Lowveld Bushveld | 79.76 |
| Soutpansberg Arid Mountain Bushveld | 77.65 |
| Sweet Bushveld | 34.84 |
| Sweet Lowveld Bushveld | 86.94 |
| Waterberg Moist Mountain Bushveld | 56.11 |

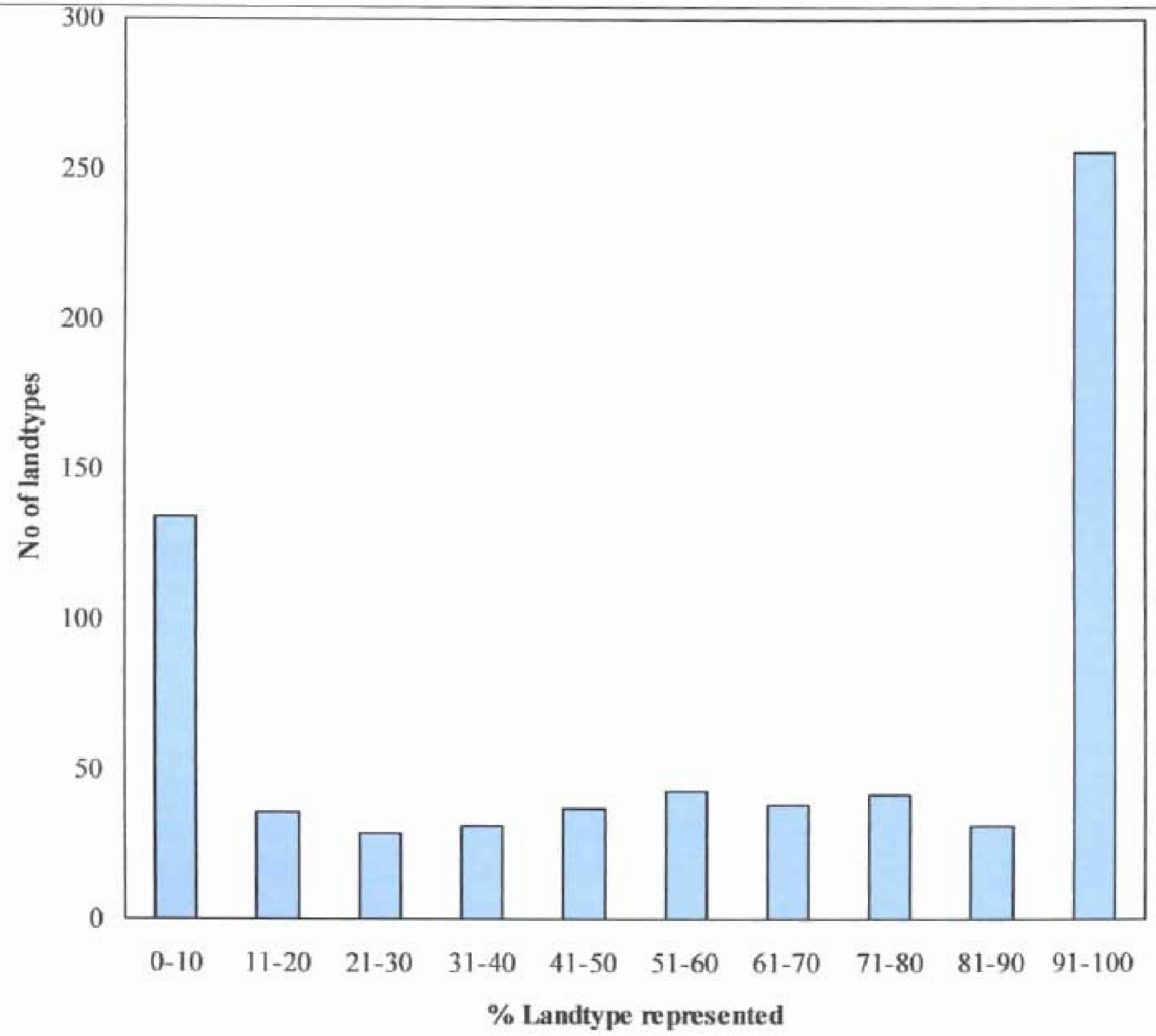



**Figure 2:** Number of landtypes falling into representation classes in a conservation area network based on species data.

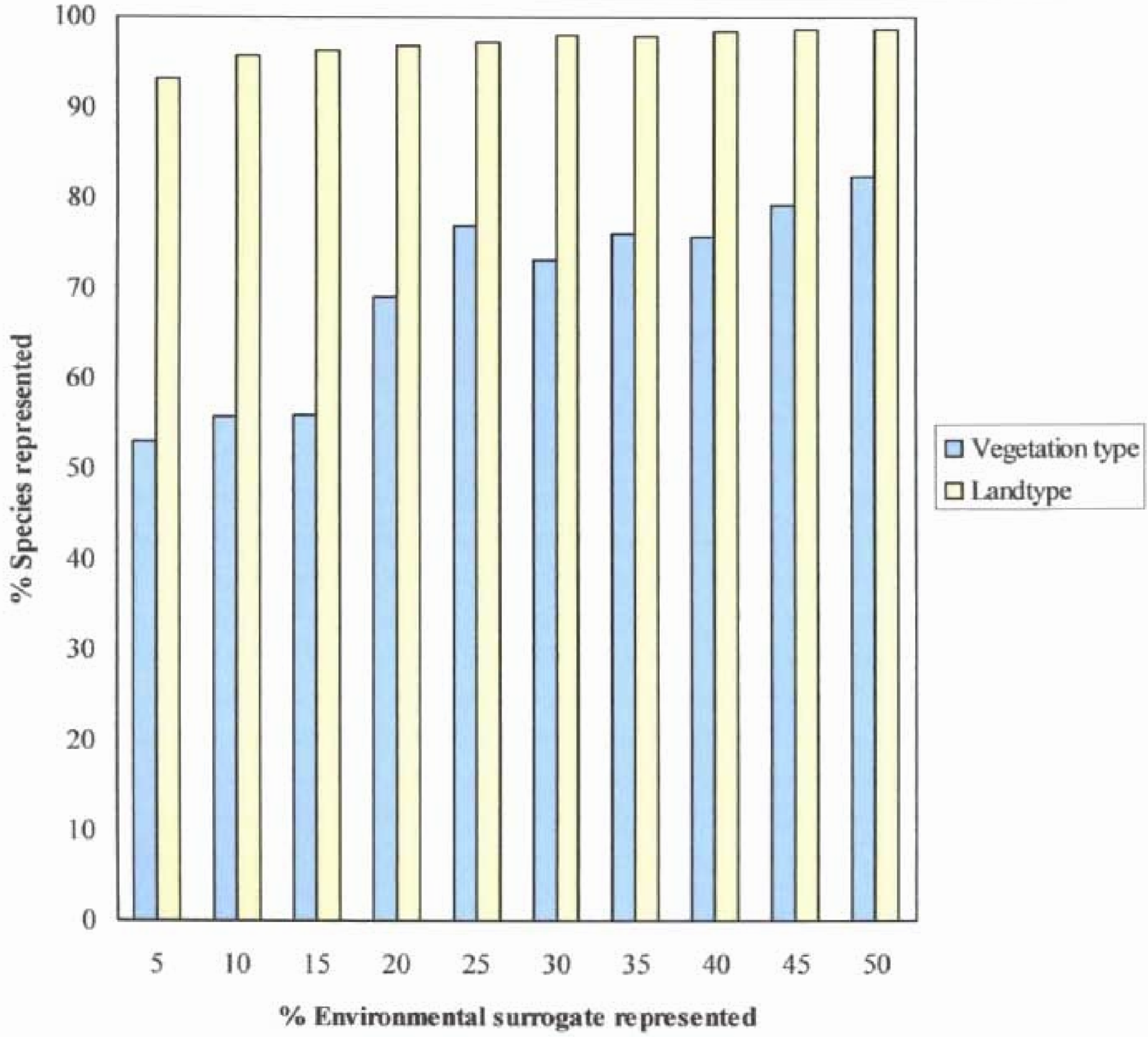



**Figure 3:** Percentage species represented in conservation area networks based on vegetation and landtype representations.

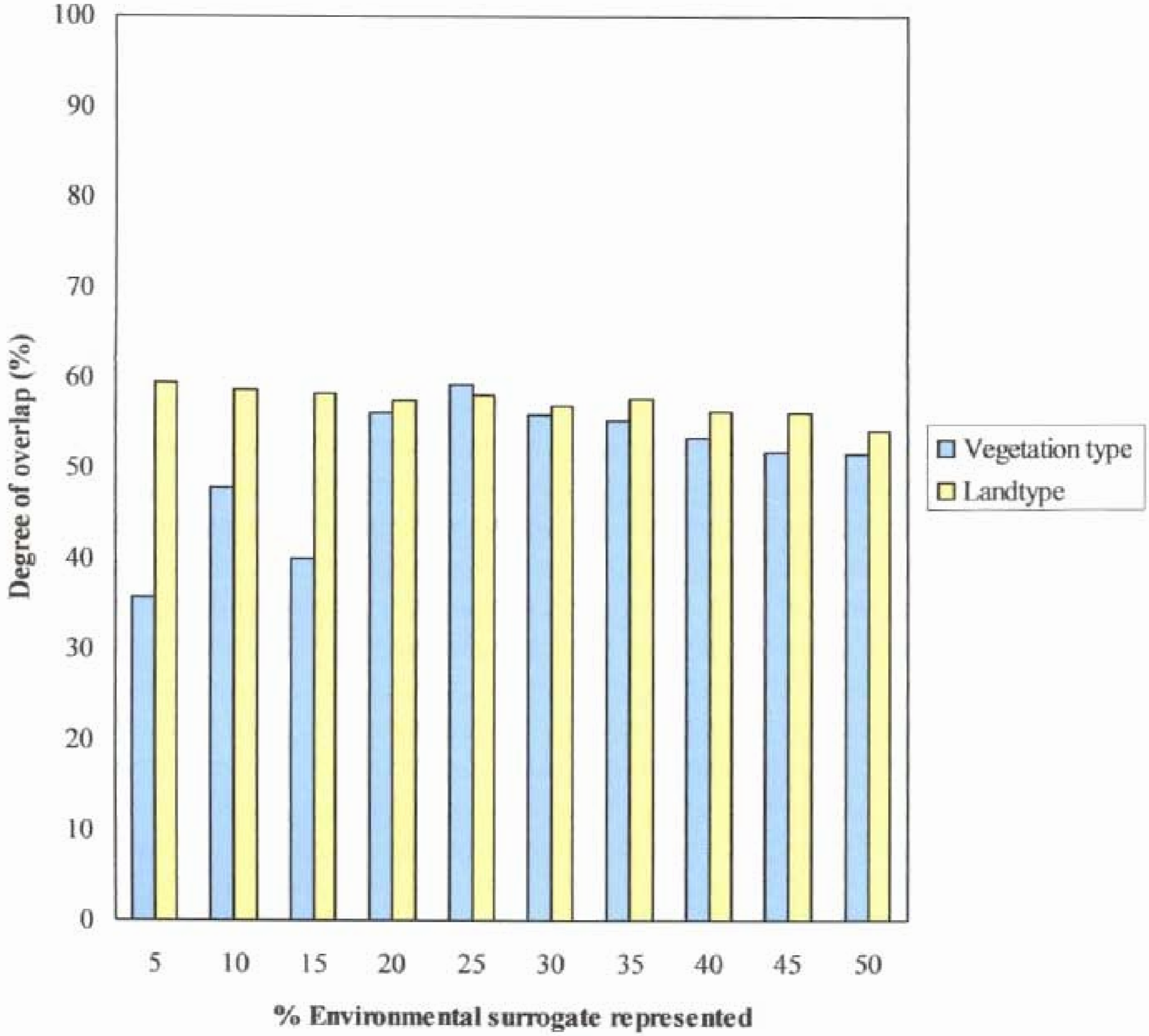



**Figure 4:** Degree of proportional overlap between conservation area networks based on species distribution data, and vegetation and landtype representations.

The landtype based conservation areas capture species well, representing over 90% of species within the region when just five percent of the landtypes being represented. However this comes at a high cost to land, requiring almost 60% of the land area. Although the number of species increases with increasing levels in surrogate representation, this increase requires a disproportionate increase in land area. An increase of 30% in species represented by the vegetation based areas (from 52-82%) requires an almost 40% increase in land (from 7-45%). While a five percent increase (from 93-98%) in species captured by landtype based conservation areas requires an almost 30% (from 59-88%) increase in land area.

*Comparison of approaches*

The success at which each of the species and environmental surrogate approaches represent non-target biodiversity features (species, vegetation and landtypes) is varied. Species-bases approaches represent relatively high levels of vegetation types and landtypes, while environmental surrogate approaches also represent species well, but at a high cost to land. The spatial configurations of these different sets of conservation areas, compared using measures of proportional overlap (Figure 4), demonstrate a relatively low degree of overlap and suggest that areas of conservation importance to species do not necessarily coincide with areas identified for the efficient representation of vegetation and landtypes.

Figure 5 illustrates the success with which the environmental surrogate based approaches capture species important to effective conservation, i.e. rare and endemic species. Landtype based conservation areas are very effective at representing rare and endemic species, representing between 89 and 98% of all rare and endemic species identified. While the vegetation based areas are not as effective, especially at low levels of vegetation types representation, only representing over 50% of the rare and endemic species when more than 20% of each vegetation types is represented. Once all vegetation types are 50% represented, still more than 30% of these important species are excluded.

*Combined approach*

Figure 6 illustrates the results of the species and environmental surrogate first approaches. In the species first approach (Figures. 6a & 6b) there is a general increase in the number of additional grid cells required as the percentage of vegetation and landtypes represented increase. The number of additional grid cells required to protect a specified percentage of landtypes (Figure 6b) is more than that required to protect the same level of vegetation types (Figure 6a). Figures 6c and 6d show the number of grid cells required for the surrogate-first approach based on vegetation and landtypes respectively. More additional grid cells are required to protect all species when vegetation types (Figure 6c) are pre-selected than when landtypes are pre-selected (Figure 6d). However, the vegetation types require fewer initial grid cells than the landtypes, thus the vegetation type based approach uses fewer grid cells in total for this surrogate-first approach. As both vegetation and landtype based approaches tend towards a 50% level of representation, so the number of additional grid cells required decreases.

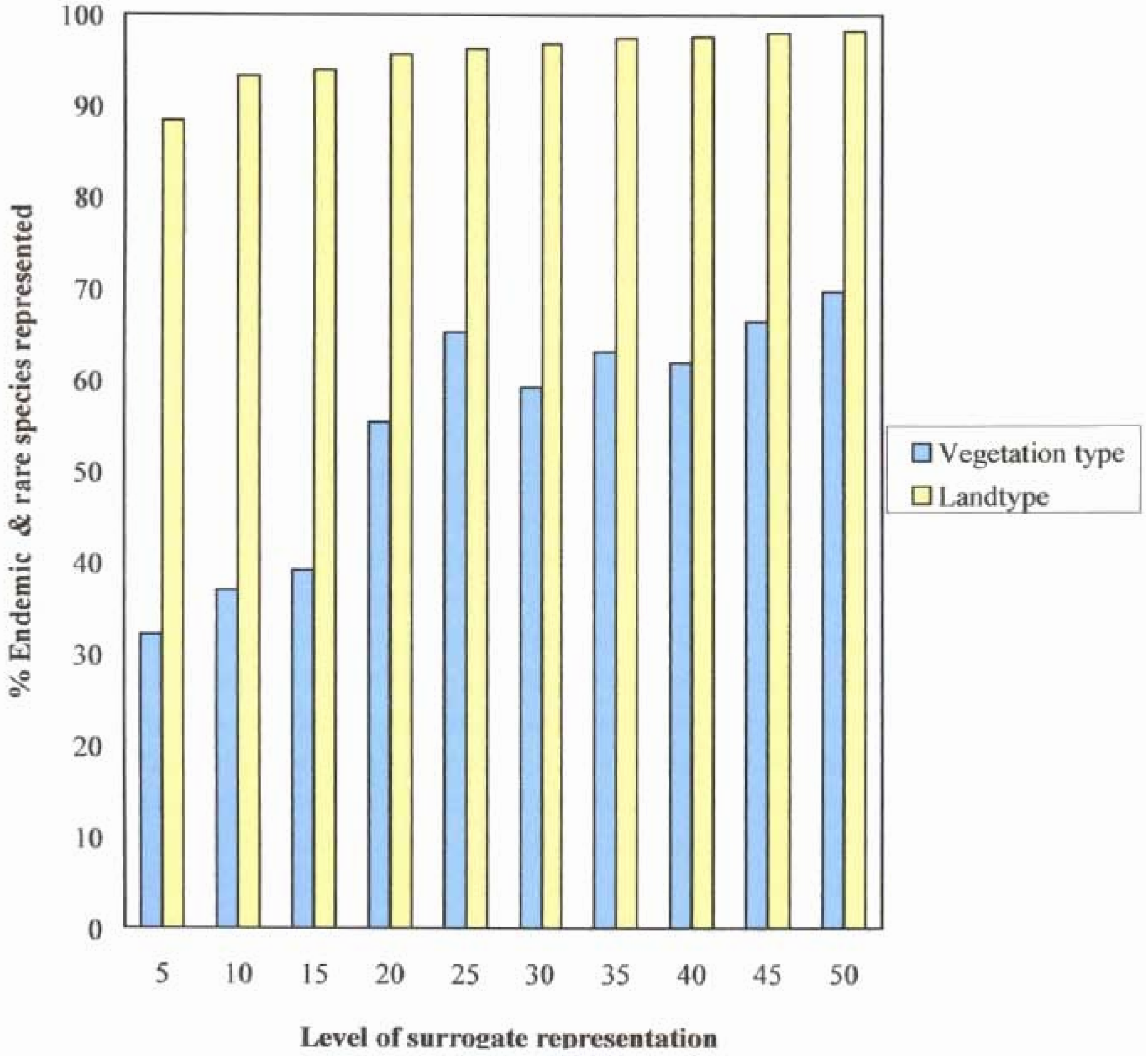



**Figure 5:** Percentage rare and endemic species captured by vegetation type and landtype based conservation areas.

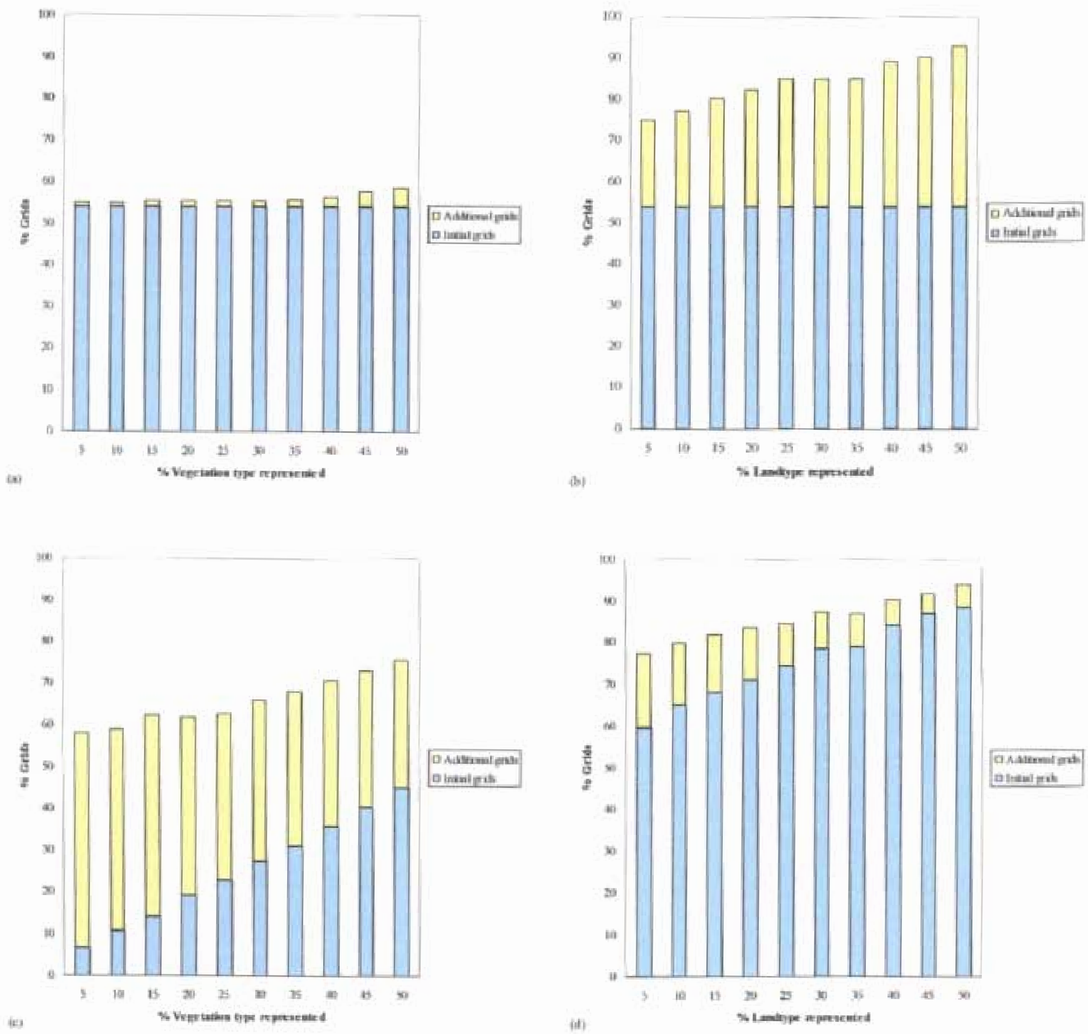


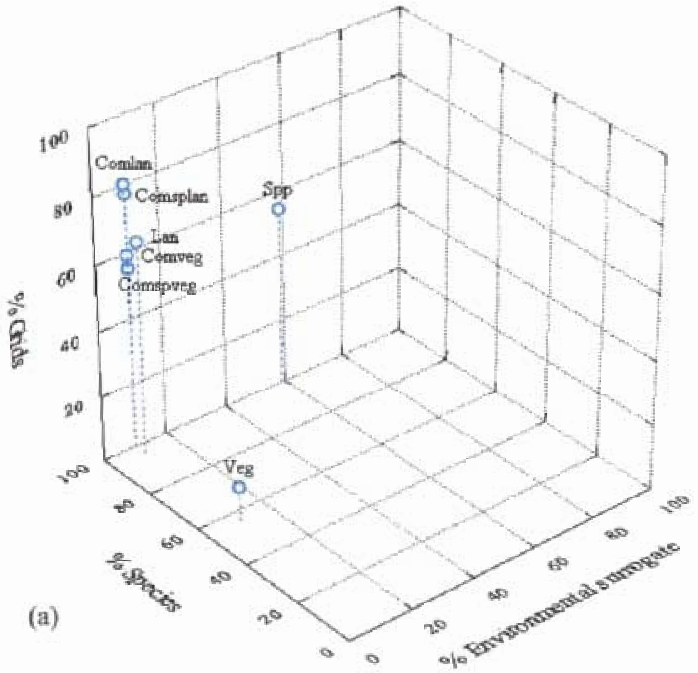

**Figure 6:** Percentage of initial and additional grid cells required to represent: (a) a required percentage of each vegetation type; and (b) landtype using a species first approach to conservation area selection; and (c) all species using a vegetation type first; and (d) landtype first approach to conservation area selection.

**Discussion**

Although many studies using surrogate measures of biodiversity in an attempt to identify areas important to the conservation of regional biodiversity have been conducted, they have made little attempt to test whether a relationship exits between these surrogate classes and biodiversity within the area (Pressey & Nicholls, 1989b; Bedward *et al.*, 1992; Pressey & Tully, 1994). Many authors have actually questioned the existence of such a relationship and recommend that it be demonstrated before being applied in conservation planning decision making (Landres *et al.*, 1988; Bedward *et al.*, 1992; Pressey, 1994; Wessels *et al.*, 1999). This study highlights various aspects of this assumed relationship. First, it is once again evident from the results that support for the use of species or environmental measures as surrogates for regional biodiversity will depend on the assessment techniques used (Chapter 3), with measures of proportional overlap showing little support while levels of non-target feature representation provide more support for surrogate measures.

Second, the more effective the conservation area selection techniques are at representing regional biodiversity, the less land-use efficient they become, requiring large tracts of land. This trade-off between the degree of feature representation achieved within surrogate based conservation areas and the amount of land required is a recurrent theme in conservation planning (Chapters 3) (Williams & Humphries, 1996; Pressey & Logan, 1995; Pressey & Logan, 1998; Wessels *et al.*, 1999). Similarly the scale at which the surrogate classes are defined, the number of these classes and the size of the selection units will also influence the outcome and efficiency (Bedward *et al.*, 1992; Nicholls & Margules, 1993; Pressey & Logan, 1995). With larger or more classes (e.g. landtype classes) and selection units often resulting in overrepresentation of regional biodiversity features and a decrease in land-use efficiency. This however is often traded off against an improvement in the persistence of organisms in larger reserves and a smaller need for expensive interventionist management (Pressey & Logan, 1998). The more heterogeneous classes of vegetation types do seem to miss some of the underlying variation in species diversity, which the finer homogenous landtype classes seem to capture. However, it is difficult to make definite conclusions on this aspect of scale due to the difference in total area required by the two approaches, with landtypes requiring much more land to reach the same levels of surrogate representation as vegetation types (Fig. 7).

Figure 7 illustrate this trade off between effective biodiversity representation and efficient land-use for conservation area selection by species and environmental surrogate approaches, both separately and combined. It illustrates the higher land-use requirements when using a surrogate like landtypes which have many classes defined at a finer resolution, as opposed to the vegetation types. The vegetation type approach (Veg) requires little land but achieves low levels of species and environmental surrogates representation, whereas the combined approaches using landtype data (Comsplan and Comlan) represent many species but at a much higher land-use cost.



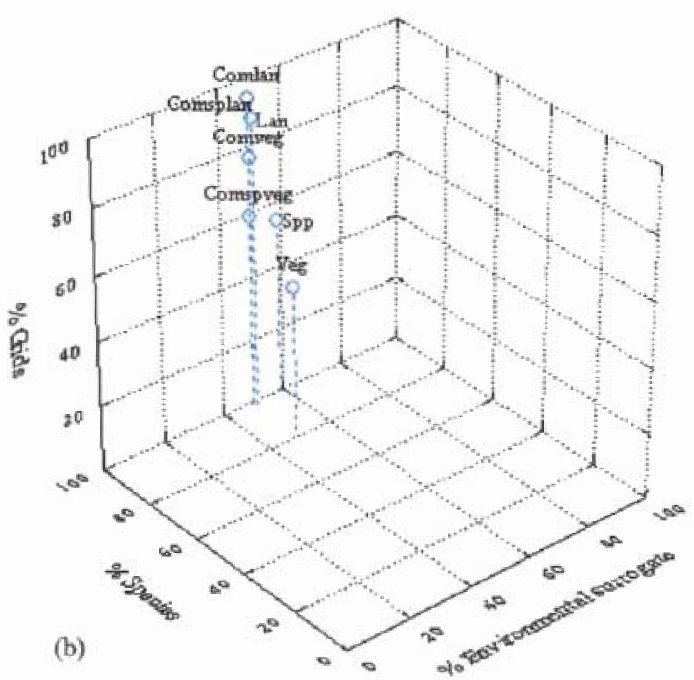




**Figure 7:** Graphical comparison of the efficiencies (% grid cells required) and representativeness (% species and % environmental surrogates represented) of conservation area selection techniques targeting (a) 10%; and (b) 50% surrogate representation. Techniques include: species-based **(Spp)**, vegetation type based **(Veg)**, landtype based **(Lan)**, combined species first with vegetation type targets **(Comspveg)**, combined species first with landtype targets **(Comsplan)**, combined vegetation type first with species targets **(Comveg)**, and combined landtype first with species targets **(Comlan)**.

It appears that both species first and environmental surrogate first combined approaches display similar degrees of success in representing species and environmental surrogates, but that the landtype based ones are more costly in terms of land area. It therefore appears that the species-based approach (Spp) effectively reaches a compromise between representing many species and moderately high levels of environmental surrogates at a lower cost to land. It must however be noted that levels of environmental surrogates represented by the environmental surrogate based techniques in Figure 7 are averages of the representation target levels (5-50%).

Third, although the results appear encouraging for the use of both species and environmental surrogates in conservation area selection in that they capture many non-target biodiversity features, these approaches still exclude some important components of regional biodiversity. As found in Chapter 3 as well as other studies on biodiversity surrogates (Prendergast *et al.*, 1993; Curnutt *et al.*, 1994; Williams *et al.*, 1996; Dobson *et al.*, 1997), many surrogate approaches miss species and other biodiversity features of conservation importance due to high levels of threat, endemism or rarity. The vegetation type approaches miss many rare and endemic species, while the landtype approach selects many more grid cells and misses less of these species. The species-based approach may represent high levels of vegetation and landtypes, however it does exclude some of these totally in the areas identified.

This approach excludes nearly 20% of all the landtypes and although it represents the vegetation types well, the Kalahari Plains Thorn Bushveld it totally excluded and is recognised as one of the most threatened vegetation types in South Africa (see Addendum I). This is an important shortcoming in most current biodiversity surrogate measures and must be highlighted. As Pressey (1994) points out, it is not only the geographic rarity and the increased likelihood of being missed by conservation areas that makes threatened, rare and endemic biodiversity features a conservation priority. Even if some of these features are captured in the coarse-filter surrogate approach they will not necessarily be adequately protected, often requiring additional protection and active management.

Lastly, these results seem to suggest that the 10% protected area coverage recommended by the IUCN (1993) is far from adequate. Protecting 10% of all vegetation types only represents some 50% of the species known to occur in the Northern Province, and excludes almost 65% of all rare and endemic species. Thus this study supports Soulé and Sanjayan (1998) in their review of findings on conservation targets where they illustrate that approximately 50% of the land area would be required to represent and protect most elements of biodiversity. Not only are these politically convenient conservation targets therefore inadequate in preventing a mass extinction of species, they also run the risk of becoming ceilings above which no nation feels the need to protect.

Thus it would appear from the results that the best approach to conservation area selection is one that uses all available forms of data, thereby incorporating more biodiversity components (Lombard *et al.*, 1997; Maddock & Du Plessis, 1999; Maddock & Benn, 2000). Including both species and environmental measures into selection procedures ensures that not only are all facets of biodiversity better represented but that the important aspects of biodiversity; the threatened, endemic and rare features, are also captured. This of course requires much land area and thus perhaps off-reserve management and conservation are the only feasible ways of ensuring that these identified areas are guaranteed some level of protection, even if it is outside of reserves (Pressey & Logan, 1997).

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