

f) Percentage viable populations

Ultimately, the objective is to determine the number of species for which viable populations are included at various degrees of broad scale surrogate selection. Using the PARI algorithm, the mean number of individuals and percentages of species included in repeated analyses was determined. Population sizes of both 100 and 500 individuals were chosen as being possible minimum viable population sizes. Species with fewer than 100 and 500 individuals respectively, were excluded from these analyses. Therefore, for comparative purposes the percentage of species for which viable populations were included are given, and not the number of species. This percentage is calculated as the number of species that reached 100 (or 500) individuals in a given selected area divided by the number of species consisting of at least 100 (or 500) individuals. Considering the fact that the same linear trend is exhibited at all three grain sizes and across all four land classification systems, these analyses were limited to six of the 12 scale combinations - the finest and broadest grain sizes, intersected respectively with the vegetation type, landscape and land type classification systems. Only these results are displayed and discussed.

g) Effectiveness of surrogates for sampling regional biodiversity

It has also been argued that the predictive relationship between surrogates and the target elements (e.g. species) should preferably be demonstrated, and not just assumed (Pressey, 1994; Williams and Humphries, 1996). Thus the question arises as to whether different taxa show similar patterns in relation to broad-scale surrogates, i.e., whether different broad scale surrogates systematically differ in their ability to represent unsurveyed species. The data for the Kruger Park had to be extrapolated to the rest of the Savanna biome where species representation of various surrogates at a broader scale using existing presence/absence data of 7 taxa (mammals, birds, butterflies, termites, antlions, buprestid beetles and scarab beetles) was evaluated. Since these binary data are only available at a quarter degree grid square scale, and the landscape, land type and land system data only exists for the KNP, these analyses were just performed for the 25km² grid square cell layer intersected with the vegetation type data. Only grid cells for the Savanna biome of South Africa were used, since the KNP lies in this biome, and a true reflection would not be

obtained if data were to be extrapolated to the whole country, encompassing all other biomes. All grid cells covering the Savanna biome were extracted from a database for the entire country, and these were used to select for increasing percentages of the biome. All areas currently protected were preselected, and areas were systematically added to this existing reserve network using the PAR algorithm with preselection (selection rules in Appendix C). The numbers of unique species per taxon included at each percentage vegetation type selection were calculated as well as the percentage that this number comprise of the total number of species per taxon found in the Savanna biome.

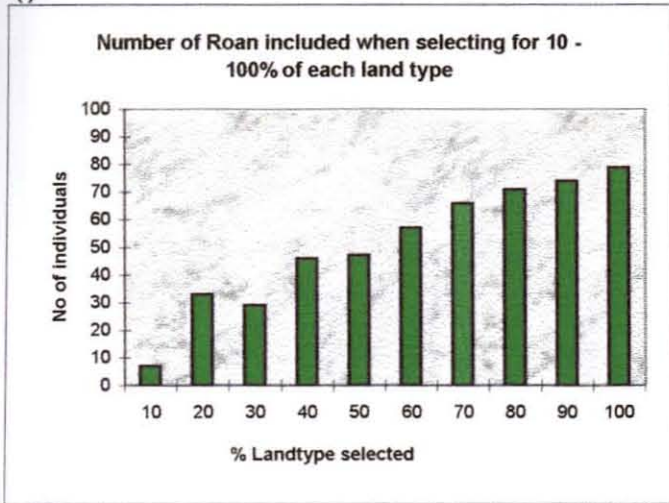
3. RESULTS

The PAR algorithm, that selects a specified percentage of a surrogate, generated outputs that can be spatially interpreted. For each spatial configuration of grid cells generated by the PAR algorithm, the number of individuals per species occurring in these grid cells was determined.

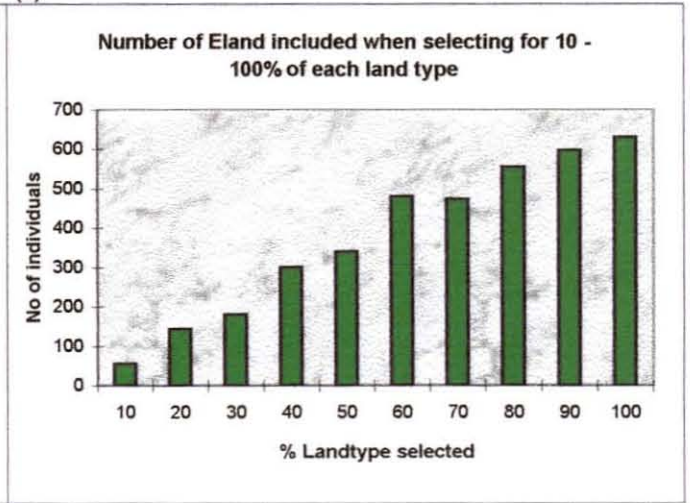
Number of individuals

When selecting for increasing percentages of a land classification system, a perceptible, but not statistical, linear relationship between the percentage land classification (surrogate) and the number of individuals occurring in that area was found. This held true for all species, at all three grain sizes, across all four land classification scales and across all four years examined (e.g. Figure 1 (i - iv)). Figure 1 illustrates this pattern for 1992 for species ranging from low density, rare species (Roan antelope) to species occurring at very high densities (Impala) in the KNP. It can be seen that population size does not considerably influence the observed linearity. The PARI algorithm was applied on the land type classification to establish whether changing the starting point of the algorithm and subsequent selection rules will have an influence on this apparent linearity that exists between the percentage surrogate selected and number of individuals occurring in these areas. No difference was found between the results obtained from the PAR and PARI algorithms.

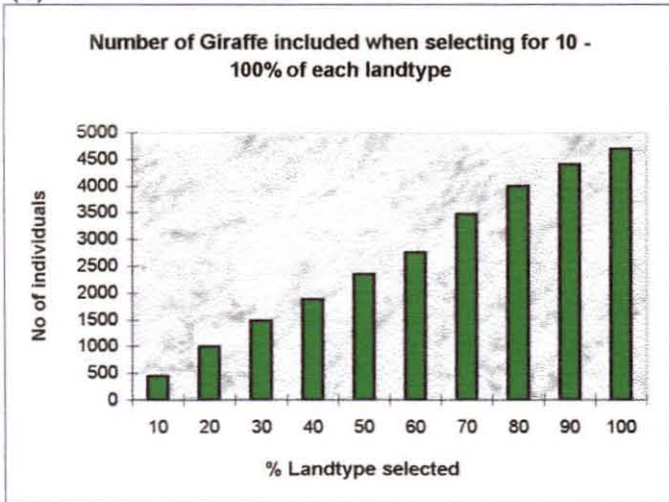
(i)



(ii)



(iii)



(iv)

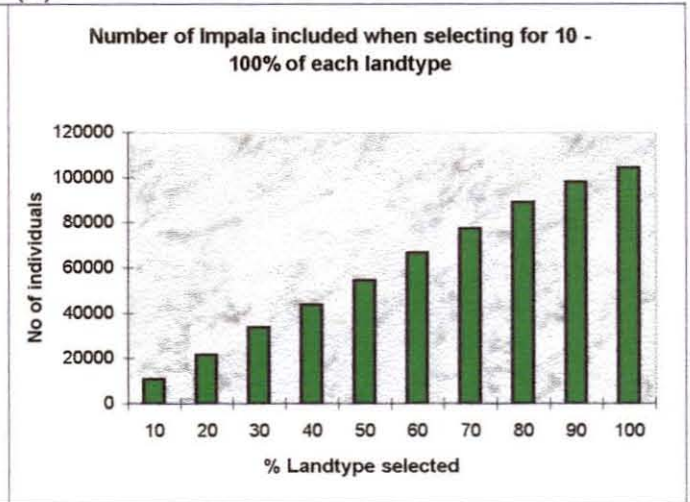


Figure 1: Number of individuals included at different degrees of land type selection for four species (1992 data) Species densities range from 79 individuals (Roan) to 104 300 (Impala).

Percentage individuals

Since species occur at different densities across the landscape, the proportion of total individuals sampled (percentage of individuals) was also assessed. Again, the same linear trend was evident. Consequently, to conserve, for example, 50% of a given species, 50% of the area of each land type is needed (Figure 2 (i - iv)). Combined data for all 12 species are provided for each of the four years (Figure 3) for the land type classification system intersected with the 4km² grid cell layer (finest spatial configuration).

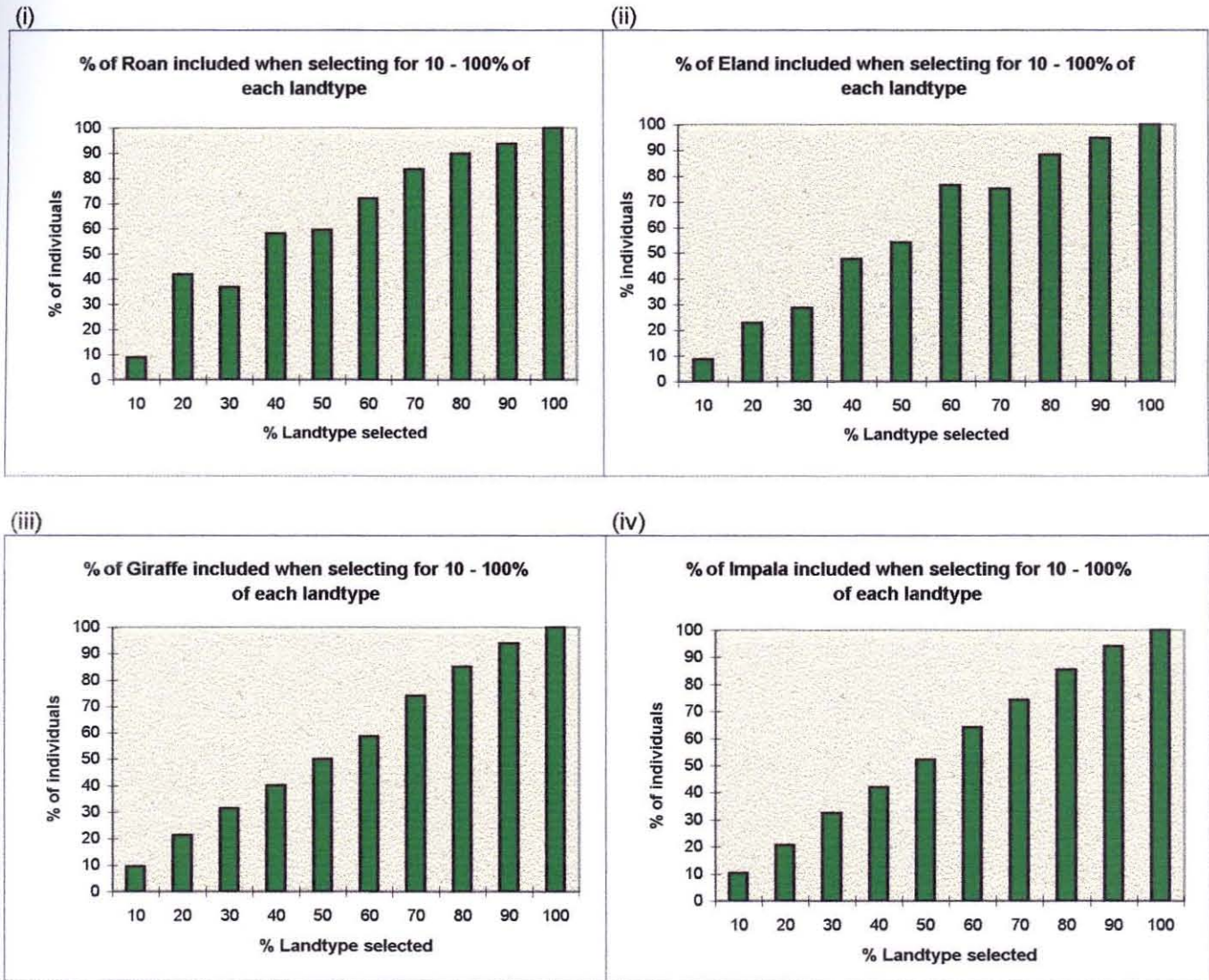


Figure 2: Percentage individuals included at different degrees of land type selection for four species (1992 data). Species densities range from 79 individuals (Roan) to 104 300 (Impala).

Kendall's coefficient of variation was used to establish whether the small difference observed between the data sets is statistically significant, since this will indicate whether environmental variation (measured by rainfall) influences species distribution patterns. If a strong significant association is found between the four data sets, it will be an indication that the influence of environmental variation upon species abundance and distribution patterns is negligible - there will be little difference in the number of individuals selected in all four years and these figures will be statistically correlated.

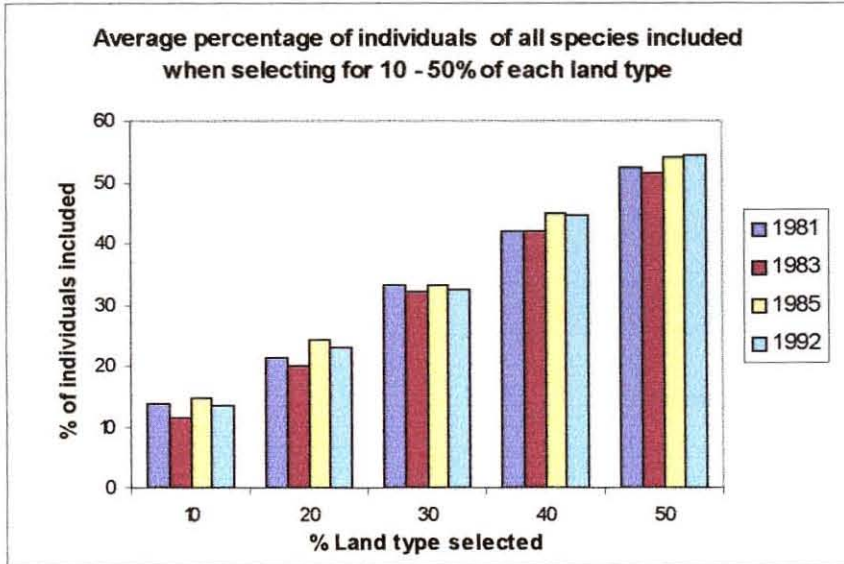


Figure 3: The average percentage of individuals of all 12 species combined, included at increasing percentages land type selection

If, however, a strong significant concordance is not obtained, it would suggest that differences exist in either the distribution patterns of the species or in the densities at which they occur across the landscape under different environmental conditions. The concordance between the data sets in Figure 3 was found to be significant, though not strong with $p < 0.05$ and W-values ranging between 0.6 and 0.75. This indicates that the concordance might be unsatisfactory as an indication of potential association between the four years.

Percentage viable populations

The mean number of individuals and percentages of species included in repeated analyses was determined. Population sizes of both 100 (Figure 4 (i - iv)) and 500 (Figure 5 (i - iv)) individuals were chosen as being possible minimum viable population sizes. Results for six of the 12 scale combinations are displayed in Figures 4 and 5.

From Figure 4 it can be seen that irrespective of the scale combination used, at 40% surrogate selection all species have viable populations being conserved, where a viable population consists of 100 individuals, except for the 1992 data set in Figure 4 (i). This

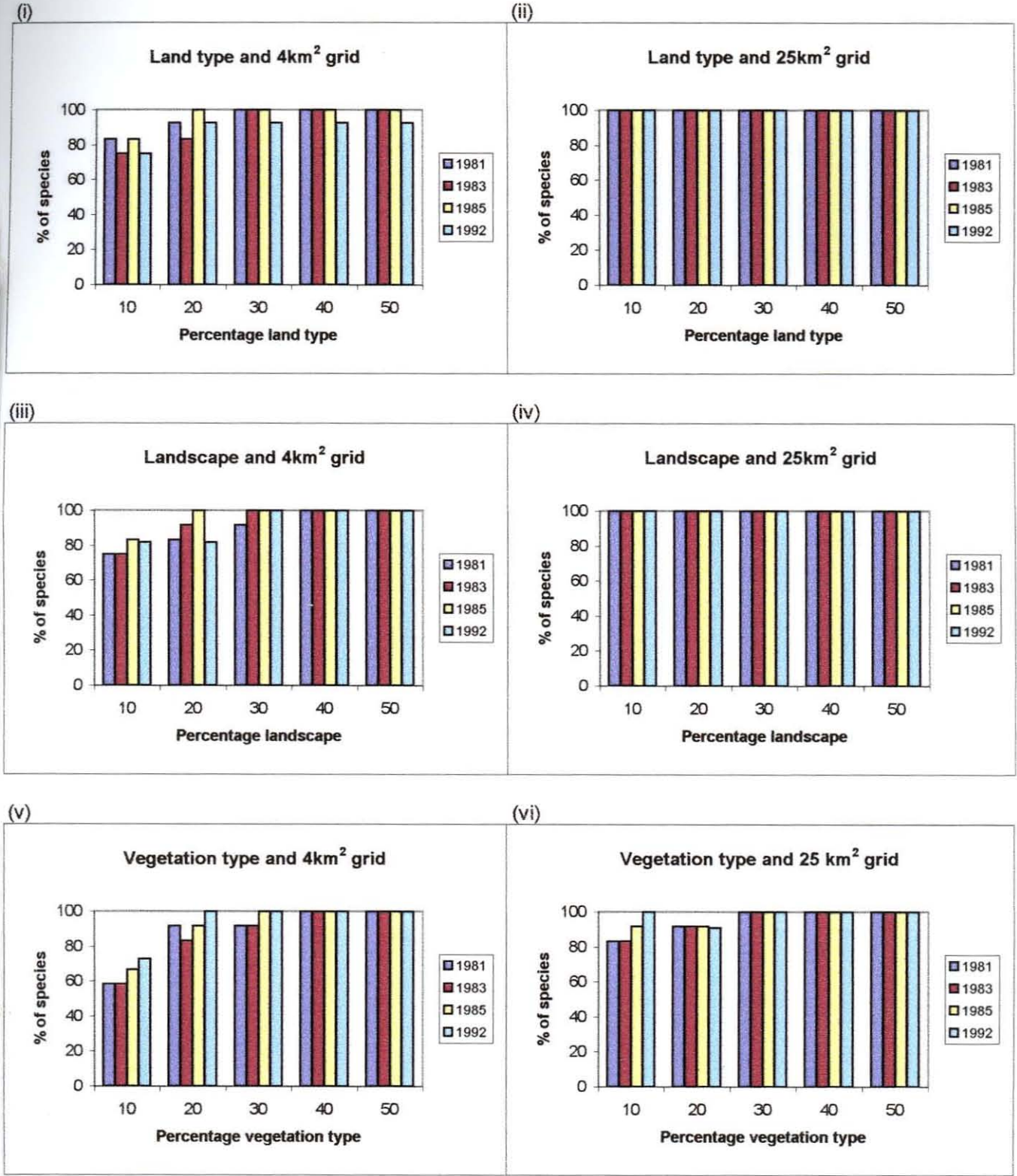


Figure 4: Percentage of species for which viable populations (100 individuals) are included at different degrees of broad scale surrogate selection

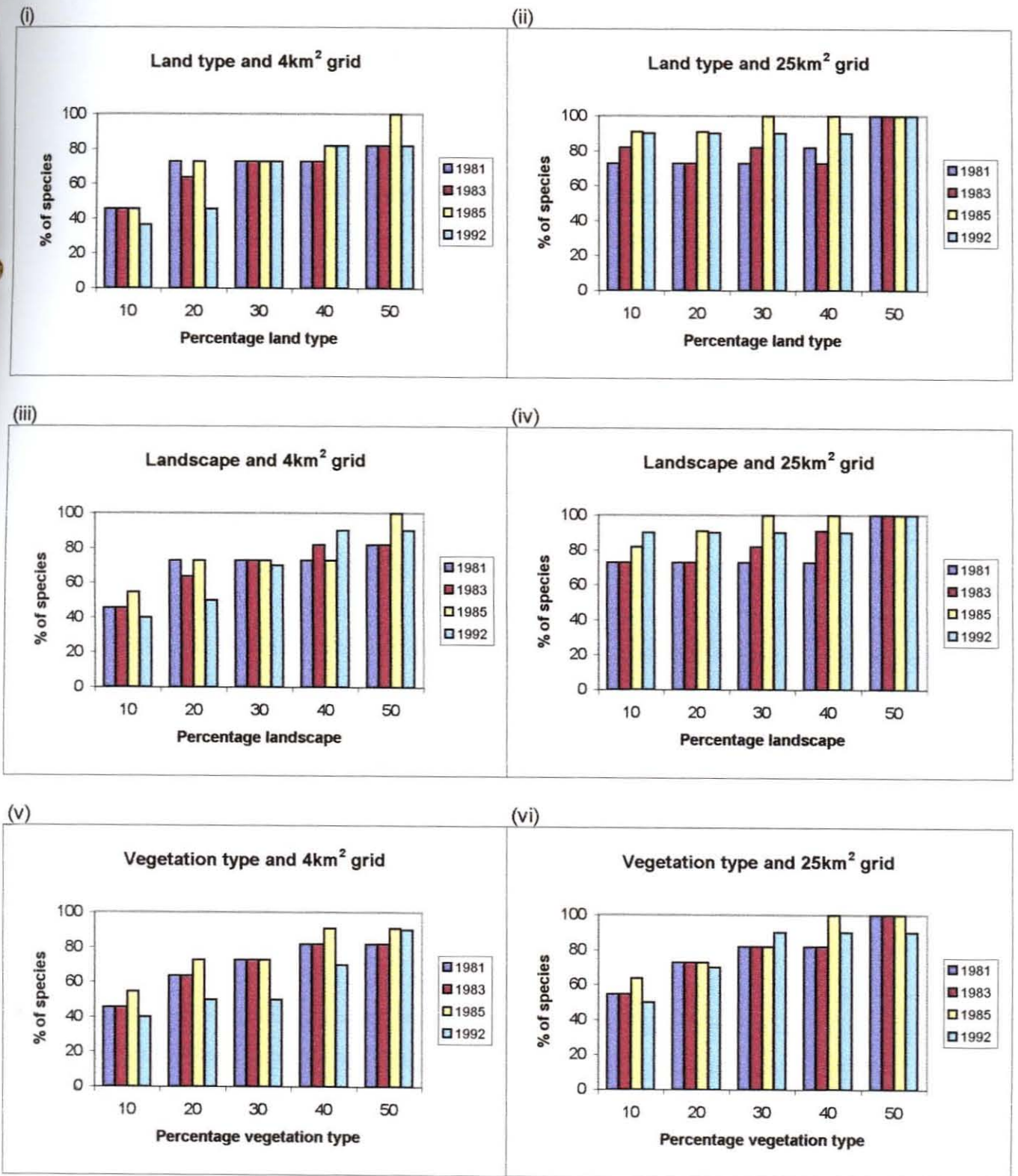


Figure 5: Percentage of species for which viable populations (500 individuals) are included at different degrees of broad scale surrogate selection

can be ascribed to the fact that the rainfall of the 1991/92 climatic year is the lowest in the recorded history of the KNP (Zambatis & Biggs, 1995), and species numbers and densities were therefore very low during the 1992 census. The results obtained when the 25km² grid cell network is intersected with the land type and landscape classification systems respectively (Figure 4 (ii) and (iv)) can be expected due to the way in which the area-selection algorithm works: the larger 25km² grid cells increases incidental over-representation of smaller scaled land classification units, since these cells are large relative to the total size of the study area (only 50 25km² grid cells in the KNP) and therefore the selected cells often contain untargeted replication of classification units. Consequently, when the algorithm selects for the specified percentage of each classification unit, a much larger area is thus actually selected and therefore larger numbers of individuals are fortuitously included in these over-represented areas than would be otherwise expected. This effect is less prominent when the vegetation type classification is used (Figure 4 (vi)), since this is a much broader scaled classification system (seven vegetation types vs. 35 landscapes and 56 land types) and the vegetation types fit into the large grid cells with less areas of unselected vegetation types being selected and therefore fewer individuals are incidentally included. When the 4km² grid cell network is used, fewer individuals are included because the smaller classification units fit more neatly into these cells and incidental overrepresentation of units are minimised. The smallest number of species are adequately represented in Figure 4 (v), due the above mentioned factors.

A much lower percentage of the species under consideration will have viable populations conserved in the selected areas when a criterion of 500 individuals per species is used to define a viable population (Figure 5 (i – vi)). Once again when the 25km² grid cell network is used, over-representation of species can be observed in Figure 5 (ii) and (v) when this network is intersected with the land type and landscape classification respectively. This effect is less profound when the vegetation type classification is intersected with these larger 25km² grid cells (Figure 5 (vi)). In Figure 5 (i - iii) it can be seen that fewer species achieve viable population numbers in the selected areas, when land types, landscapes and vegetation types are intersected with the 4km² grid cell

network. This can be expected, since the classification units fit more neatly into these smaller grid cells and little overrepresentation of land area will occur. Consequently fewer individuals will be over-represented. From Figure 4 and 5, it can thus be seen that scale indeed influences the results obtained in the present study, and that the right choice of scale is exceedingly important when conducting biodiversity surveys.

Vegetation type as a surrogate of Savanna biodiversity

The percentages of unique species per taxon included through the selection of increasing percentages of vegetation types in the Savanna biome are displayed in Table 2. The numbers of species represented through the percentages are given in brackets. From these numbers it is clear that the invertebrate databases comprise very little species - especially the databases for antlions and termites.

Table 2: The percentage (and number) of unique species per taxon, occurring in the Savanna biome, at each percentage vegetation type selection.

% Veg type	Antlions	Birds	Buprestid beetles	Butterflies	Mammals	Scarab beetles	Termites
10	17.9 (5)	85.5 (603)	52.5 (53)	59.4 (285)	66.5 (169)	42.1 (158)	69.6 (16)
20	46.4 (13)	86.3 (607)	55.5 (56)	58.5 (281)	72.1 (183)	42.1 (158)	87.0 (20)
30	57.1 (16)	89.9 (632)	65.4 (66)	75.6 (363)	82.3 (209)	67.2 (252)	91.3 (21)
40	71.4 (20)	90.9 (639)	69.3 (70)	76.7 (368)	83.9 (213)	71.7 (269)	87.0 (20)
50	75 (21)	91.3 (642)	71.3 (72)	79.0 (379)	85.8 (218)	77.6 (291)	87.0 (20)

From Table 2 it can be seen that the antlion and termite databases comprise very few species, but that considerable percentages of these species are included through the vegetation type selection, except for antlions at the 10% selection level where only 5 species (17.9%) are represented. Generally, substantial proportions of all species are represented in the selected areas - even at the 10% level.



4. DISCUSSION

Mathematically, the linear relationship between the area selected and the number (or percentage) of individuals occurring in that area will be expected when dealing with an area where individuals are either homogeneously (as in the KNP) or randomly distributed. According to Bayes theorem (Martin, 1967; Hartigan, 1983), when any number of individuals are randomly distributed across a landscape, and an area is randomly selected, (though a fixed percentage is selected each time) the relationship between area and number of individuals will always be linear. See Chapter 4 for further discussion and explanation of the concept of fixed percentage surrogate selection, and the implications that this has in terms of number of individuals selected. It is important to note here that if the conservation issue is about representing all species, a fixed percentage rule might be considered. If, however, one would want to conserve viable populations, and thereby secure the species' future, the fixed percentage rule appears to be inappropriate.

Slight differences in the distribution of individuals between years with high rainfall and years with low rainfall were found. These results suggest that there is a difference in the spatial distribution pattern of herbivore species in response to habitat quality changes at the scales investigated here. In a study correlating animal distribution patterns to the availability of water, it was found that patterns differed between years with a high rainfall figure and years with comparatively low rainfall figures (Redfern, pers. comm.). Furthermore, when we tested for significant differences in species numbers across the four years (Chapter 2) it was found that environmental variation influences the distribution patterns of the large herbivore species investigated here. In the light of this, we can deduce that these data sets are statistically significantly correlated, but that this association (based on W values) is too small to be biologically meaningful at the scales used in this study. Hence, we can conclude that environmental variation marginally influences the distribution patterns of these large herbivore species when the number of individuals occurring in certain areas are compared between four different years. This does, however, not affect the linear relationship between percentage surrogate selection and number and percentage of individuals included, nor does it affect the considerable amount of land needed to fully conserve these species at these scales.

Presence/absence data were used to determine the success of vegetation types as a surrogate for seven different taxa in the Savanna biome of South Africa. These taxa included well-studied taxa such as mammals (Mammalia), birds (Aves) and butterflies (Hesperioidea and Papilionidae) that have been frequently used in the past as biodiversity indicators (Woinarski *et al.*, 1988; Sætersdal *et al.*, 1993, Howard *et al.*, 1998), as well as less well-known taxa, including antlions (Myrmeleontidae), buprestid beetles (Buprestidae), scarabaeoid beetles (Scarabaeoidea) and termites (Isoptera). It has to be noted that all these invertebrate databases are highly subjected to collector bias, low collection effort and taxonomic limitations (Hull *et al.*, 1998) and that the quality of the databases are generally surprisingly and alarmingly poor (Koch *et al.*, in press). The only available data for termites came from an incomplete set of published data from a systematic survey, and only about 20% of antlion species are included in this database (Freitag and Mansell, 1997). The mammal database is fairly complete in the Savanna biome with consistent sampling effort covering most of the area under consideration. The birds, on the other hand, have been surveyed in all grid cells and all species are included (Van Jaarsveld *et al.*, 1998).

According to the World Conservation Union some 10% of each of the world's major biomes should be afforded formal protection by the year 2000 (WRI, 1994; Soulé and Sanjayan, 1998). It was suggested that this should be adequate in protecting most elements of biodiversity. If only 10% of the Earth's ecosystems are protected it will endanger at least half of all terrestrial species and make them vulnerable to anthropogenic extinction in the near future (Soulé and Sanjayan, 1998). Using the Savanna biome of South Africa to evaluate this assertion, we found that at 10% vegetation type selection on average only 55% of all species across the 7 taxa occurring in the Savanna biome are represented in the selected area (Figure 6). When moving on to the 50% selection level, more than 80% of all species are represented at least once. From these analyses it would seem that the vegetation type classification is not a successful surrogate at the scale of investigation, since only little more than half of the total number of species are represented, and this number is not a sufficient conservation effort.

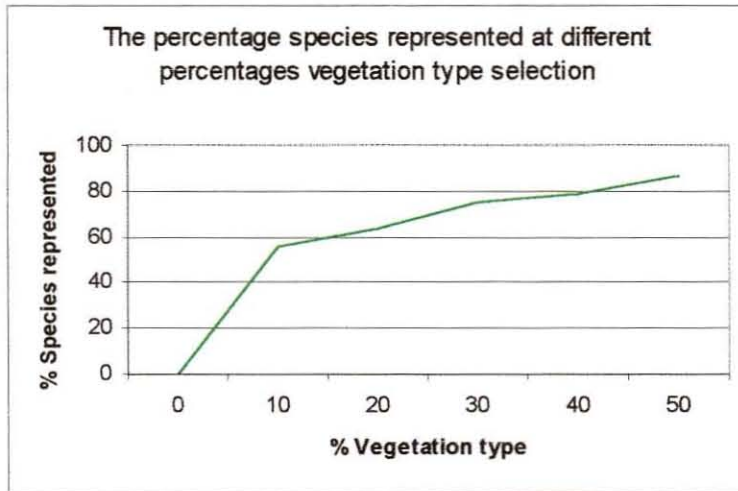


Figure 6: The percentage of 7 faunal species included at increasing percentages vegetation type selection

Furthermore, the concern should not just be to represent all species, but to actually conserve viable populations of species – and thereby secure their future. It was found in the present study that to conserve viable populations of the large herbivore species, 10% of the area is far from adequate, and nearly 50% of each land classification unit is needed to achieve this conservation goal.

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Appendix A

Percentage Area Representation (PAR) algorithm (Wessels *et al.* 1999).

Written by Stefanie Freitag (1996).

Selection rules are as follows:

1. Choose a grid cell containing an occurrence of the smallest (in terms of area) vegetation type. If more than one type is equally small, choose the one which is also "database rarest" (i.e. there are the fewest polygons (records) of that type).
2. If there is a choice of grid cells to represent this type, choose the one containing the biggest area of the type required to bring the representation of the type to the required level, i.e. the site which contains either the smallest percentage area necessary to achieve the required representation, or the one that contributes the largest percentage area of that type - if no one site will achieve the representation target.
3. If there is a choice, select the grid cell that is nearest in space to one that is already selected (adjacency constraint).
4. If there is still a choice, select the grid cell that also contributes the largest area of the next smallest under-represented type.
5. If there is still a choice, select the grid cell that will add the biggest number of under-represented types.
6. If there is still a choice, select the first in the list of types.

Appendix B

Percentage Area Representation algorithm for iterative selections (PARI).

This algorithm was modified, using the previous algorithm (PAR), (Wessels *et al.* 1999), by Heath Hull (1998).

Selection rules are as follows:

1. Select a grid cell at random.
2. If there is only one vegetation type present in the grid cell, select further grids until the required target level is reached - using the methods described for "rule 2" in Appendix A. If there is more than one vegetation type in the grid cell, select all vegetation types present in that grid (one at a time, but in no specific order) by adding further grids until all target levels for these vegetation types are met, using the methods described in Appendix A (rules 2 - 6).
3. Go to the top of the file containing a list of all vegetation types (randomly arranged). Select the vegetation type to be fully represented next by choosing the type occurring at the top of the list.
4. Select all types using the rules described in Appendix A (rules 2 - 6). Each time that a type is fully represented, the next to be represented is the one occurring at the top of the vegetation type list.

All areas of vegetation types that are present in the grid cell chosen, other than the type for which the algorithm was selecting, are subtracted from the areas required to fully represent them, i.e. added to the area represented for these types as well.

Appendix C

Percentage Area Representation algorithm with preselection.

Written by Stefanie Freitag (1996), and modified by Heath Hull (1999).

Selection rules are as follows:

1. Preselect all grid cells currently under protection.
2. Remove these grids from the input database, and store them in the Gridsel file.
3. Determine the size of all vegetation types in the database.
4. Choose a grid cell containing an occurrence of the smallest (in terms of area) vegetation type. If more than one type is equally small, choose the one which is also "database rarest" (i.e. there are the fewest polygons (records) of that type).
5. If there is a choice of grid cells to represent this type, choose the one containing the biggest area of the type required to bring the representation of the type to the required level, i.e. the site which contains either the smallest percentage area necessary to achieve the required representation, or the one that contributes the largest percentage area of that type - if no one site will achieve the representation target.
6. If there is a choice, select the grid cell that is nearest in space to one that is already selected (adjacency constraint).
7. If there is still a choice, select the grid cell that also contributes the largest area of the next smallest under-represented type.
8. If there is still a choice, select the grid cell that will add the biggest number of under-represented types.
9. If there is still a choice, select the first in the list of types.