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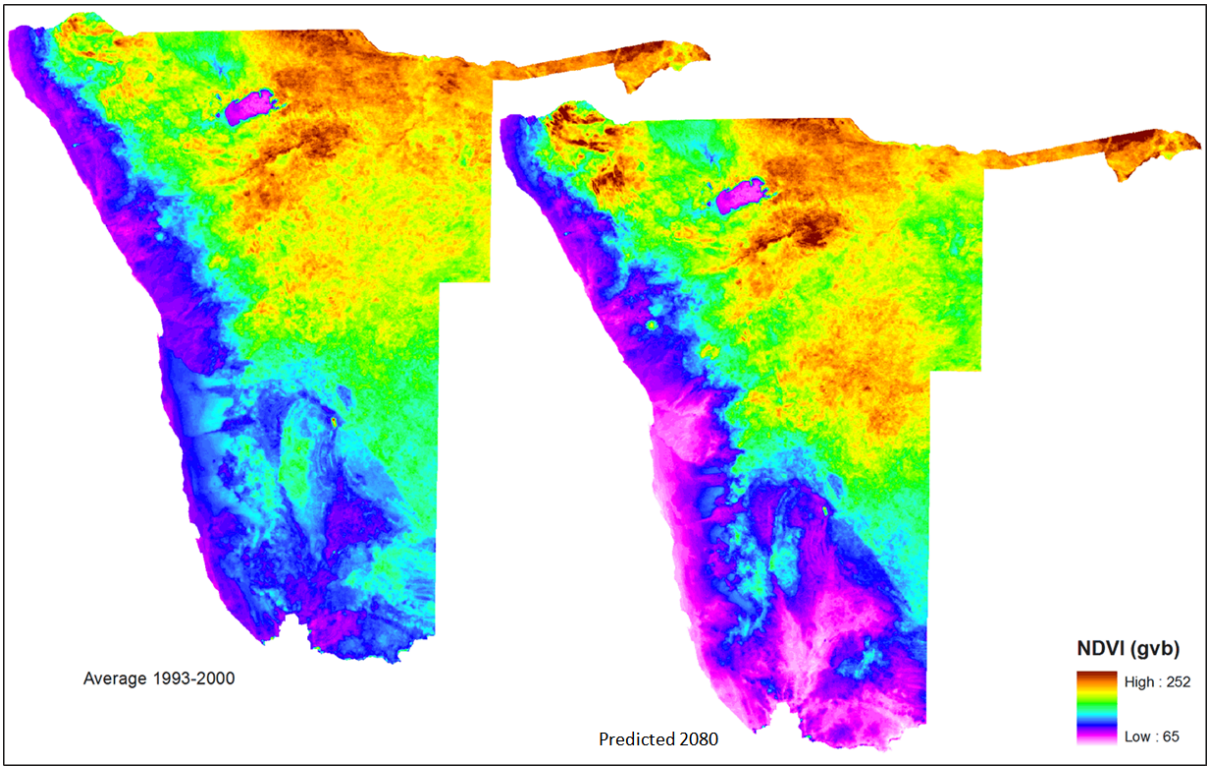
VULNERABILITY OF NAMIBIA'S PROTECTED AREA SYSTEM TO CLIMATE CHANGE: QUANTITATIVE ASSESSMENT OF IMPACTS

(GEF PROJECT ID:)

DR PHILIP DESMET, DR GUY MIDGLEY & DR. JANE TURPIE

JANUARY 2010



Predicted change in primary productivity across Namibia between 2000 and 2080

Report Title: Vulnerability of Namibia's Protected Area System to Climate Change: Quantitative Assessment of Impacts.

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1 INTRODUCTION

This study provides a quantitative assessment of the impacts of climate change onthe Namibian protected area system (PAS)to fulfil its mandate of conserving the country's biodiversity. The assessment looks at the PAS ability to achieve current protected area conservation targets as well as the ability of the current PAS to adequately conserve biodiversity given the anticipated future changes in the distribution of biodiversity due to climate change. Based on the assessment recommendations are made as to how to spatially adapt the PAS to better fulfil its mandate given the anticipated changes.

Achieving adaptation to the impact of climate change is defined here as "facilitating the continued ability of the PASto meet conservation targets". Conservation targets are used in conservation planning as quantitative interpretations of our conservation goals. A conservation goal for a PAS is usually something along the lines of "protect a representative portion of a country/regions biodiversity". Interpreting this goal as quantitative conservation targets may include targets such as "conserve 10% of each vegetation type" or "represent 3 separate populations of each species within the PAS". Defining conservation targets is optimally performed on the basis of the best available scientific information, expert advice and international best practice. Therefore targets provide a useful means with which to measure the effectiveness of a PAS in terms of meeting its mandateboth in the present and under future conditions, and for our purposes here provide a quantitative measure of the ability of the PAS to "buffer" the impacts of climate change by continuing to meet these targets.

Determining whether a PAS has the ability to meet conservation targets now and into the future is limited by the availability of suitable data. Data are not only required on the current distribution of biodiversity, but more importantly are also required for the projected future distribution of biodiversity. For this study two excellent data sources were sourced, processed and utilized:

1. A vegetation-basedAdaptiveDynamic GlobalVegetation Model(aDGVM) dataset for southern Africa created by Scheiter and Higgins (2009) that predicts changes in 2080 in vegetation structure and biomass production over the sub-continent; and,

2. Aspecies-based model dataset created by Broennimann *et al.* (2006) that projects the changes in 2080 in species distribution for 975 endemic southern African plant species.

This study is divided into two parts. The first explores how well the existing PAS meets current conservation targets, or is representative of Namibia's biodiversity. The second part of this study looks at how well the current PAS meets conservation targets given the anticipated changes in biodiversity distribution due to climate change. For both the current and future scenarios spatial options and constraints for improving the representation of biodiversity (i.e. meeting conservation targets) are explored and quantified with a view to reviewing the development vision for the Namibian PAS.

The basic methodology followed in this study assesses gaps in the PAS (i.e. how well does the PAS achieve conservation targets) in both the current and predicted future biodiversity state, and them uses MARXAN conservation planing software to explore spatial options for addressing these gaps.

2 METHODS

2.1 DATA SETS

To perform the assessment four groups of data were collated (seeAppendix 1: Input Data):

1. Data on the current and future distribution of biodiversity:
    a. Current Namibian vegetation types
    b. Current agricultural land-types based on broad soil and rainfall groups

c. Current modelled distribution of species at quarter degree square based on PRECIS herbarium records (approximately 18km raster grid).
d. Steep, south-facing mountain slopes that act as local-scale climate change refugia for species. Calculated from the SRTM digital elevation model
e. Predicted (2080) modelled species distribution based on PRECIS quarter degree square herbarium records and the HadCM3 General Circulation Model B2 IPCC SRES climate change projections (approximately 18km raster grid).
f. Predicted (2080) average annual plant production interpolated from modelled biomass production using the ECHAM5 IPCC (2007) SRES A1B climate change projections (1km raster grid)

2. The current extent of the PAS including all protected area status categories.
3. Context information that informs which areas have little or no biodiversity value and can be excluded from the analysis as making no contribution to achieving targets (e.g. urban areas, croplands and other transformed areas)
4. Context information that gives an indication of the relative "cost" of including additional areas into the PAS (e.g. distance to urban areas or likelihood that areas will be required for other land-uses such as cropping agriculture or mining).

Spatial data were sourced from the Atlas of Namibia[1] the South African Biodiversity Institute (SANBI) and from this project.

2.2 Conservation Targets

Namibia does not have an explicit PAS target, i.e. the amount of land the government wishes to formally set aside for biodiversity conservation. In order to evaluate the biodiversity representivity of the PAS we set conservation targets (viz. protected area targets) for the features included in this analysis based on current international guidelines (Langhammer *et al.* 2007) and approaches elsewhere in the region (Driver *et al.* 2003, Driver *et al.* 2004).These were 15% of the original extent of all vegetation types and agricultural land types, 50% of the original extent of south-facing slopes (which are assumed to act as refugia in arid landscapes), and 10% of the area of occupied by each species (using occurrence in planning unit as a surrogate) (Table 1).

In addition, because of the relative unreliability of species distribution projections, we introduce primary production (PP) as a novel target in this study in order to evaluate the performance of the PAS under climate change (Table 1). We set the target as either being equal to the sum of primary production in the PAS at present, or as being equal to the proportion of regional PP held in the PAS at present. The rational for this is that primary production is expected to change over much of the existing PAS. Adjusting the PAS to maintain current levels of primary productivity is assumed to maintain the same level of abundance of wild plant and animal populations because of its relationship to carrying capacity (e.g. Desmet, 2004; Berliner and Desmet, 2008). Note that this does not necessarily look after species who are narrow in their habitat requirements or less able to shift their distributions.

[1] http://www.met.gov.na/programmes/infocom/infocom/atlas.htm

TABLE 1 SUMMARY OF TARGETS USED IN FOUR GAP ASSESSMENT SCENARIOS. THE CURRENT SCENARIO LOOKS AT THE CURRENT REPRESENTIVITY OF THE PAS. FUTURE 1 LOOKS AT THE CURRENT PAS MEETING TARGETS FOR THE FUTURE PREDICTED DISTRIBUTION OF SPECIES. FUTURE 2 ASSESSES THE ABILITY OF THE CURRENT PAS TO MAINTIAN THE CURRENT PP LEVELS BASED ON THE FUTURE PREDICTED PP. FUTURE 3 ASSESS THE ABILITY OF THE CURRENT PAS TO REPRESENT AN EQUAL PROPORTION (40%) OF EACH REGIONS FUTURE PREDICTED PP.

Biodiversity Feature Group	Current	Future1	Future2	Future3
Vegetation types	15% of original extent	-	-	
Agricultural land-types	15% of original extent	-	-	
South-facing slopes	50% of original extent	-	-	
Species	10% of current occurrences[1]	10% of 2080 occurrences	-	
Primary Production			Sum of PAS in 2009	Equal proportion of eco-region PP in 2080

1: Species were recorded only as present/absent in a planning unit therefore 10% of occurrences implies 10% of planning units in which species was recorded.

2.3 PLANNING UNITS

The planning domain (viz. Namibia) was divided into 10788 equal-size 9x9km or 18000ha conservation planning units (PU). The minimum size of the PU was limited by the scale of the species input data. Species were originally modelled at an approximately 18x18km grid cell size and it was not possible to down-scale this information without going back to the original modelling process. Therefore a compromise had to be made between using smaller planning units that are more suited to the level of conservation decision making (i.e. cadastre-level or below, ca. 500-2000ha) versus a planning unit that better matched the spatial resolution of the input data. Each species model grid cell comprised exactly 4 planning units and it was assumed that a species was equally likely to occur in each planning unit if it was encountered in the corresponding model grid cell. We acknowledge that this is not necessarily valid especially for endemic species that tend to be restricted to particular habitats and are not encountered equally throughout the landscape or a QDS in which they are recorded.

PU cost was the same for the current and future scenarios. This is a potentially problematic assumption as the relative PU cost is likely to change in future given expected changes in population size and patterns of land-use (e.g. urban expansion, abandonment of agricultural areas). Given the time constraints of this project preparing future PU cost scenarios was not conducted.

PUs that were more than 40% transformed were excluded form from the analysis. For future scenarios PUs excluded due to urban areas were expanded by one PU to take into account likely expansion in major urban areas between now and 2080. In total for current scenarios there were 61 or 0.56% of sites excluded vs. 223 or 2.07% of sites for the future scenarios.

2.4 PROTECTED AREA SYSTEM

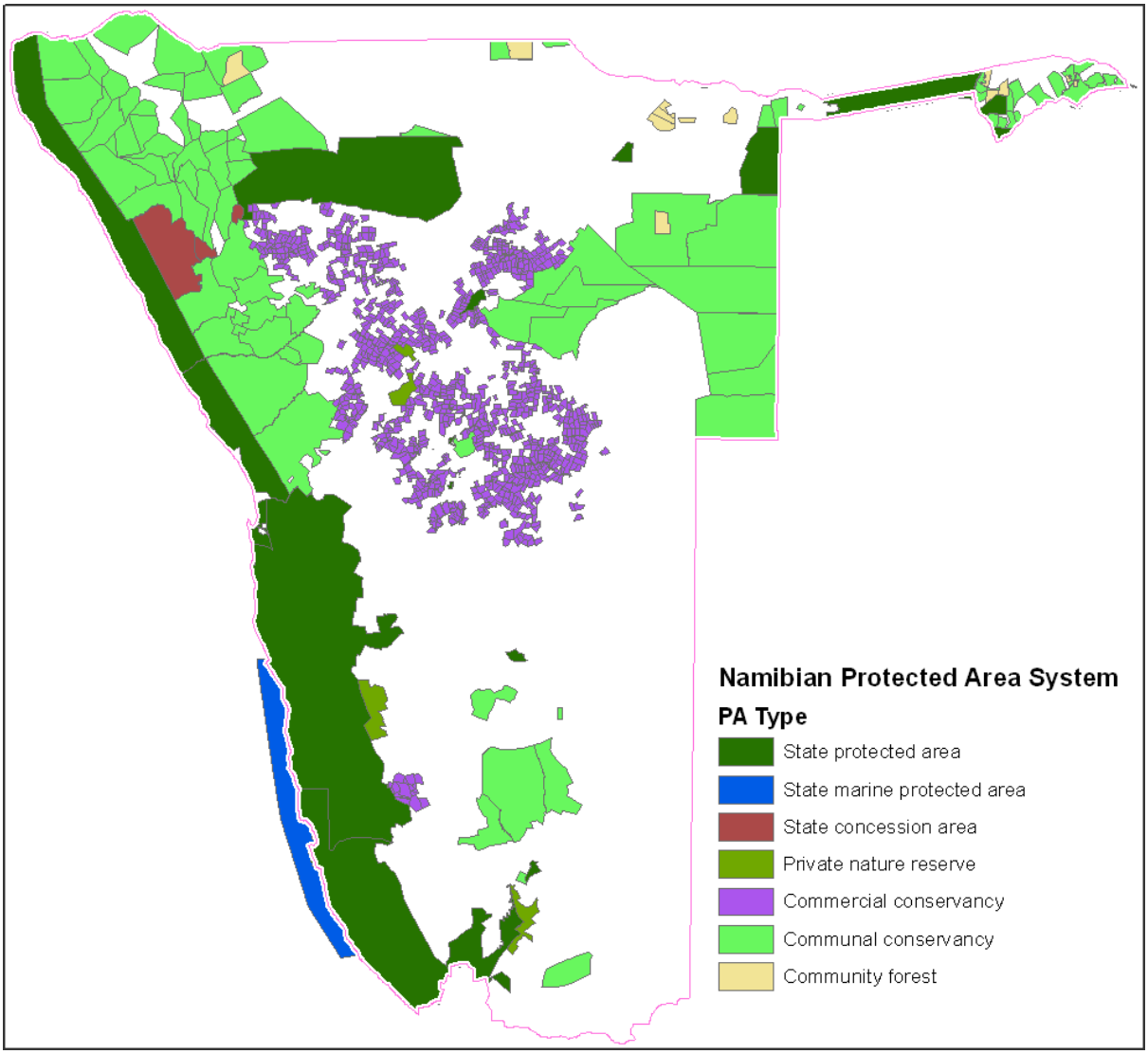
For the purposes of this analysis all categories of current and establishing protected areas were considered as contributing towards achieving targets. The PAS covers 45% of the country or approximately 37 147 714ha (Figure 1), but only 39% of this comprises state-owned protected areas (Table 2). The objective of this exercise was not to compare the relative contribution of the state vs. private components of the PAS towards achieving targets. With nearly 60% of the PAS comprising privately/communally owned conservancies clearly

conservancies play a major conservation role in Namibia. Assessing the conservation management effectiveness of conservancies is a topic for another discussion.

TABLE 2 A SUMMARY OF THE PROPORTIONAL COMPOSITION (% OF TOTAL PAS AREA) OF PA CATEGORIES AND OWNERSHIP TYPES MAKING-UP THE NAMIBIAN PAS.

PA Category	Ownership				Total
	Emerging	Gazetted	Private	State	
Commercial conservancy	0	0	13.4	0	**13.4**
Communal conservancy	10.1	35.8	0	0	**45.8**
Community forest	0	1.1	0	0	**1.1**
Private nature reserve	0	0	1	0	**1**
Protected area	0.3	36.6	0	0	**36.9**
State concession area	0	0	0	1.8	**1.8**
Total	**10.3**	**73.4**	**14.5**	**1.8**	**100**

FIGURE 1 THE EXTENT OF PROTECTED AREAS IN NAMIBIA.



2.5 ECO-REGIONS

For the purposes of the primary productivity analysis the country was divided into 12 broad bio-climatic eco-regions based on biomes and basic geo-morphological regions. The rationale for this subdivision was to provide a coarse national-level stratification of the country with which to test the representivity of the PAS in terms of capturing an equal proportion of each region's PP.

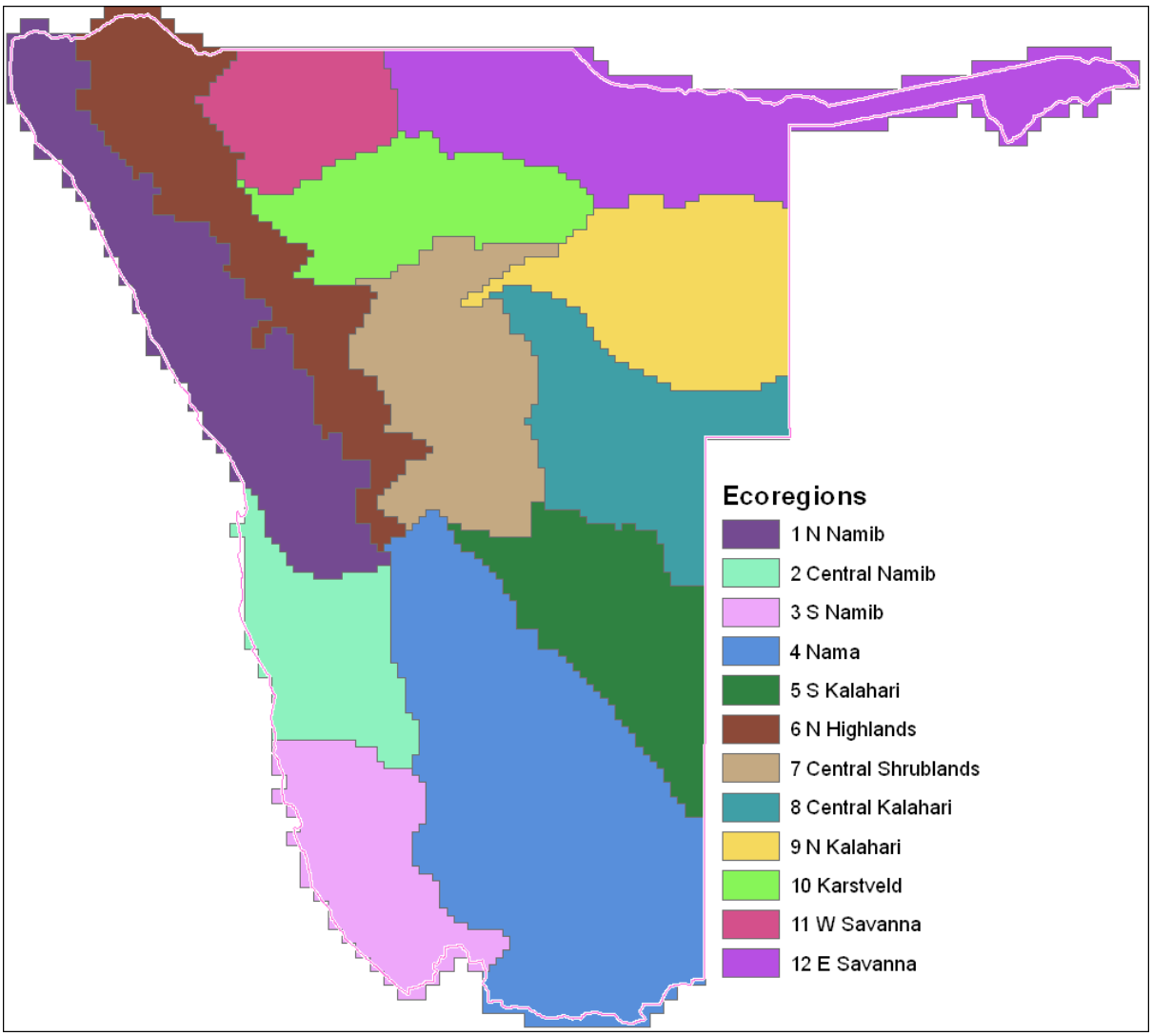


FIGURE 2 BROAD ECOREGIONS USED TO SUMMARISE PP DATA IN THIS ANALYSIS.

2.6 SOFTWARE

The spatial options assessment was conducted using MARXAN conservation planning decision support software (Ball and Possingham, 2000; Possingham *et al.,* 2000) with the CLUZ extension for ArcView 3 GIS (Smith 2004).

MARXAN is software that delivers decision support for reserve system design (Ball and Possingham 2000; Possingham et al 2000). The basic idea behind a reserve design problem is that a conservation planner has a large number of potential sites (or planning units) from which to select new conservation areas. They may wish to devise a reserve system which is made up of a selection of these planning units which will solve a problem that includes several ecological, social and economic criteria and principles. MARXAN is primarily intended to solve a particular class of reserve design problem known as the 'minimum set problem', where the goal is to achieve some minimum representation of biodiversity features (i.e. achieve targets) for the lowest possible cost. The rationale is that less costly or socially disruptive reserve networks are more likely to be implemented. Furthermore, meeting a set of targets for all conservation features provides a solid platform for expanding a

reserve system in the future; reserve systems biased to habitats of high commercial value are often hard to expand. In minimum set problems the elements of biodiversity that you wish to conserve are entered as constraints to solutions of the problem (Possingham et al 2000). Given reasonably comprehensive data on species, habitats and/or other relevant biodiversity features, MARXAN aims to identify the reserve system (a combination of planning units [PUs]) that will meet user-defined biodiversity targets for the minimum cost (Ball and Possingham 2000; Possingham et al 2000).

The key variables in determining aMARXAN solution are:

1. Conservation targets (see Section 2.2)
2. PU cost–or the cost of selecting a particular planning unit. The cost used in MARXAN can be the monetary value of a PU or any relative social, economic or ecological measure of costs, or combination thereof.
3. Boundary Length Modifier (BLM) –a weighting factor that promotes the selection of more compact solution or a more desirable solution comprising a reserve network of a few large contiguous reserves rather than many small scattered reserves. The boundary length is the sum of exterior boundaries of a reserve solution. BLM is a function of the total number of *available* planning units (i.e. total boundary length), and is not influencedby PU cost, conservation targets or number of features. A more fragmented reserve network will have a greater overall boundary length. It is this boundary length, plus a weighting on its importance (the BLM or boundary length modifier) relative to the other components of the objective (cost and meeting targets), that can be included in the objective function.
   For the purposes of this analysis we chose to limit the influence of boundary length by setting a constant BLM for all current or future scenarios (0.16 for current and 0.15 for future – bearing in mind that the number of excluded sites differs for current (61 sites) vs. future (223 sites) scenarios). This BLM represents an optimised BLM calculated following the methodology suggested by Fisher et al. in Ardron et al. (2008). Note that this BLM creates for a "hungry algorithm" promotes a larger continuous rather than smaller fragmented PAS.

2.7 Area Requirement Scenarios

Eleven PAS expansion scenarios were explored using the MARXAN software (Table 3). The objective of the spatial analyses was to determine (1) where outstanding targets could be achieved; and, (2) the approximate additional area required by the PAS in order to achieve these targets.

TABLE 3A SUMMARY OF THE PAS CURRENT AND FUTURE AREA REQUIREMENTS SCENARIOS BASED ON DIFFERENT TARGET SETS (TABLE 1) AND ADJACENCY (BLM) CONTSTRAINTS.

Scenario	Parameters	Description
1	Current, no BLM	Absolute minimum number of sites required to meet current outstanding targets
2	Current, BLM	Minimum number of sites required to (1) meet outstanding targets, and (2) create a contiguous PAS. This is a more real-world scenario as real-world reserve establishment is rarely spatially efficient relative to meeting targets.
3	Future1 (species), no BLM	Absolute minimum number of sites required to meet future outstanding species targets. Targets based on 10%of future distribution of species
4	Future1 (species), half optimal BLM	As above but two levels of an adjacency factor (BLM) is introduced to force a more compact reserve scenario
5	Future1 (species), optimal BLM	

Scenario	Parameters	Description
6	Future2 (PP), no BLM	Minimum number of sites required to maintain existing levels of PP within the current PAS.
7	Future2 (PP), half optimal BLM	As above but two levels of an adjacency factor (BLM) is introduced to force a more compact reserve scenario
8	Future2 (PP), optimal BLM	
9	Future3 (PP), no BLM	The minimum number of sites required to represent a given proportion of PP (40%) in the PAS within each region.
10	Future3 (PP), half optimal BLM	As above but two levels of an adjacency factor (BLM) is introduced to force a more compact reserve scenario
11	Future3 (PP), optimal BLM	

3 Results and Discussion

3.1 Gap Assessment and Options for creating a fully representative PAS

As a proportion of the country Namibia probably has one of the largest PAS of any country globally. Approximately 45% of the country falls under some form of conservation management (Table 2, Figure 1).Only 2% of biodiversity features targeted are not represented within the PAS at all, and a total of 5% fall short of their target (Figure 3, Table 4). We can conclude that currently the Namibian PAS is representative of the majority of the country's biodiversity.

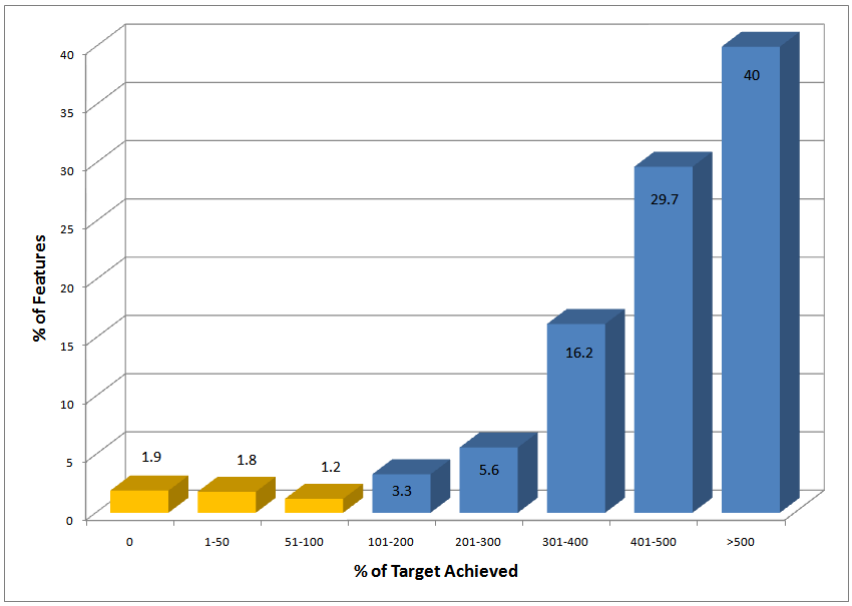


FIGURE 3: THE PERCENTAGE OF CURRENT TARGETS ACHIEVED BY THE PAS FOR THE 1045 FEATURES USED IN THE GAP ASSESSMENT.

There are some notable gaps in the PAS (Figure 4):

1. In the north of the country targets for the vegetation and land-types of the Cuvelai drainage system cannot be achieved. Based on the land-cover data available this ecosystem has been almost entirely transformed and there is less natural vegetation remaining than the target set (i.e. the ecosystem is greater than 85% transformed). This is the only highly transformed or "critically endangered" landscape in Namibia.

2. The south of the country especially the SE (Nama Karoo and Orange River valley) is the most poorly represented in the PAS and consequently the area where most outstanding targets are to be met.

TABLE 4 THE BREAKDOWN PER FEATURE GROUP OF CURRENT TARGETS ACHIEVED BY THE PAS.

	Number of Features		
Feature Group	**Target NOT Achieved**	**Target Achieved**	**Total**
Vegetation Types	27	74	101
Land Types	18	51	69
Species	2	854	856
South Slopes	5	14	19
Total number of features	**52**	**993**	**1045**

Addressing these gaps in the PAS will require two strategies (Figure 5):

1. Expansion and consolidation of existing reserves particularly in the north where this strategy can meet all targets.
2. Creation of new reserves particularly in the SE Kalahari, Nama Karoo and eastern Orange River valley regions.

Note that the "selected sites" in Figure 5 are attempting to achieve two objectives – (1) reduce the overall boundary length of the PAS; and, (2) achieve all outstanding targets. Placing less emphasis on creating a contiguous PAS would mean that far fewer sites would be selected in the north of the country, however, this would have limited impact on areas in the south especially groups of selected sites that are not adjacent to existing protected areas. These sites will still be required as they are selected primarily to meet outstanding targets.The "optimised" PAS expansion scenario depicted in Figure 5 requires adding another 1527 additional sites to the PAS, roughly 12 million hectares, or expanding the current PAS by 30% in order to meet current targets for all biodiversity features.

The PAS currently captures 42.5% of the country's primary productivity (Table 5). At this point the primary productivity (PP) value has not been related to actual carrying capacity although this is possible (e.g. Desmet, 2004; Berliner and Desmet, 2008). What this value does provide though is a future target for the PAS. One climate adaptation strategy that can be implemented with the PAS is to maintain the total primary productivity of the PAS at current levels through PAS expansion so as to maintain existing animal population sizes. The spatial implications of this PAS adaptation strategy are explored in Section 3.4.

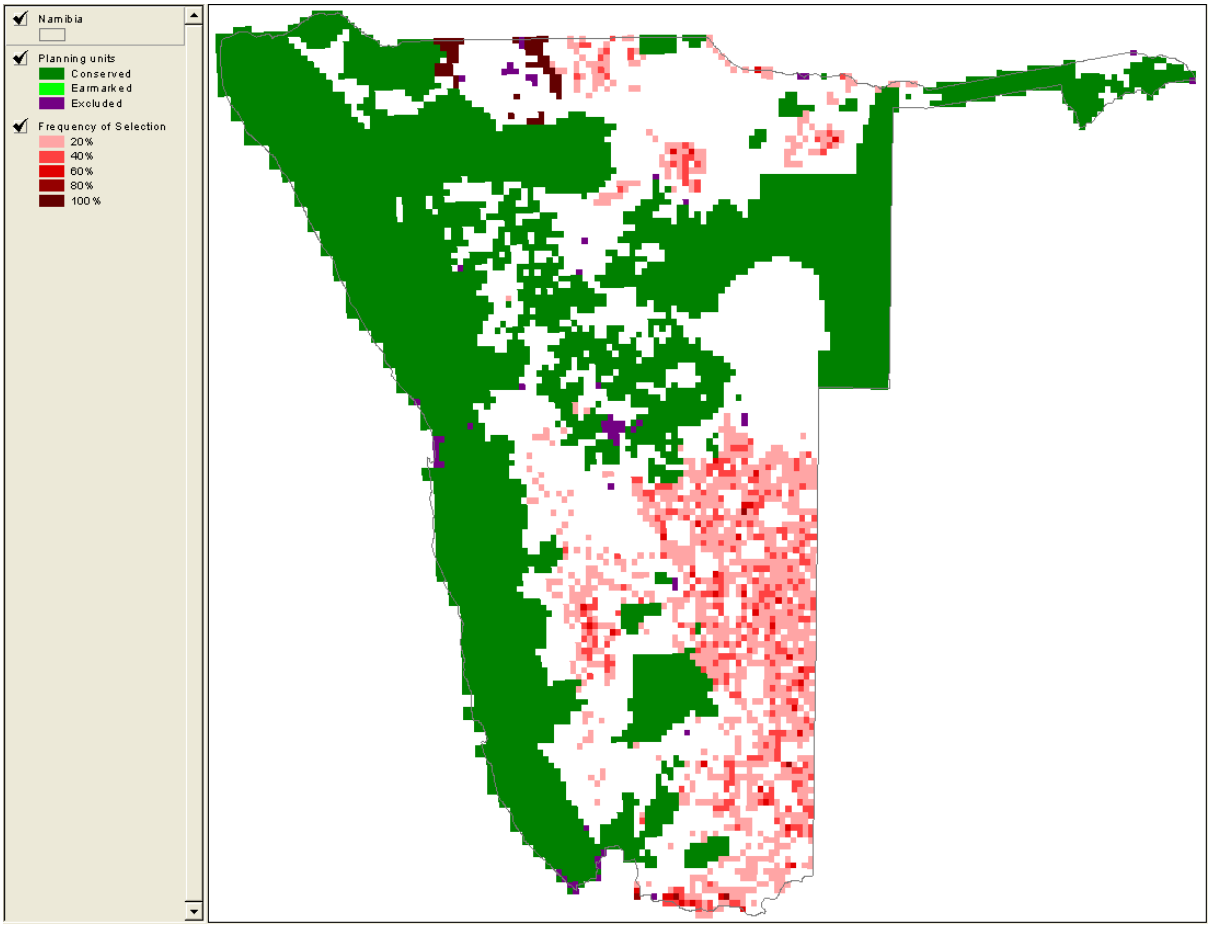
Although the PAS captures a significant proportion of national PP, an equal proportional representation of each region's PP is not achieved (Table 5). Another CC adaptation strategy might be to ensure that an equal proportion of each regions PP is captured in the PAS (Future 3 scenario, Table 1). The significance of this target on future development options for the PAS is explored in Section 3.4.

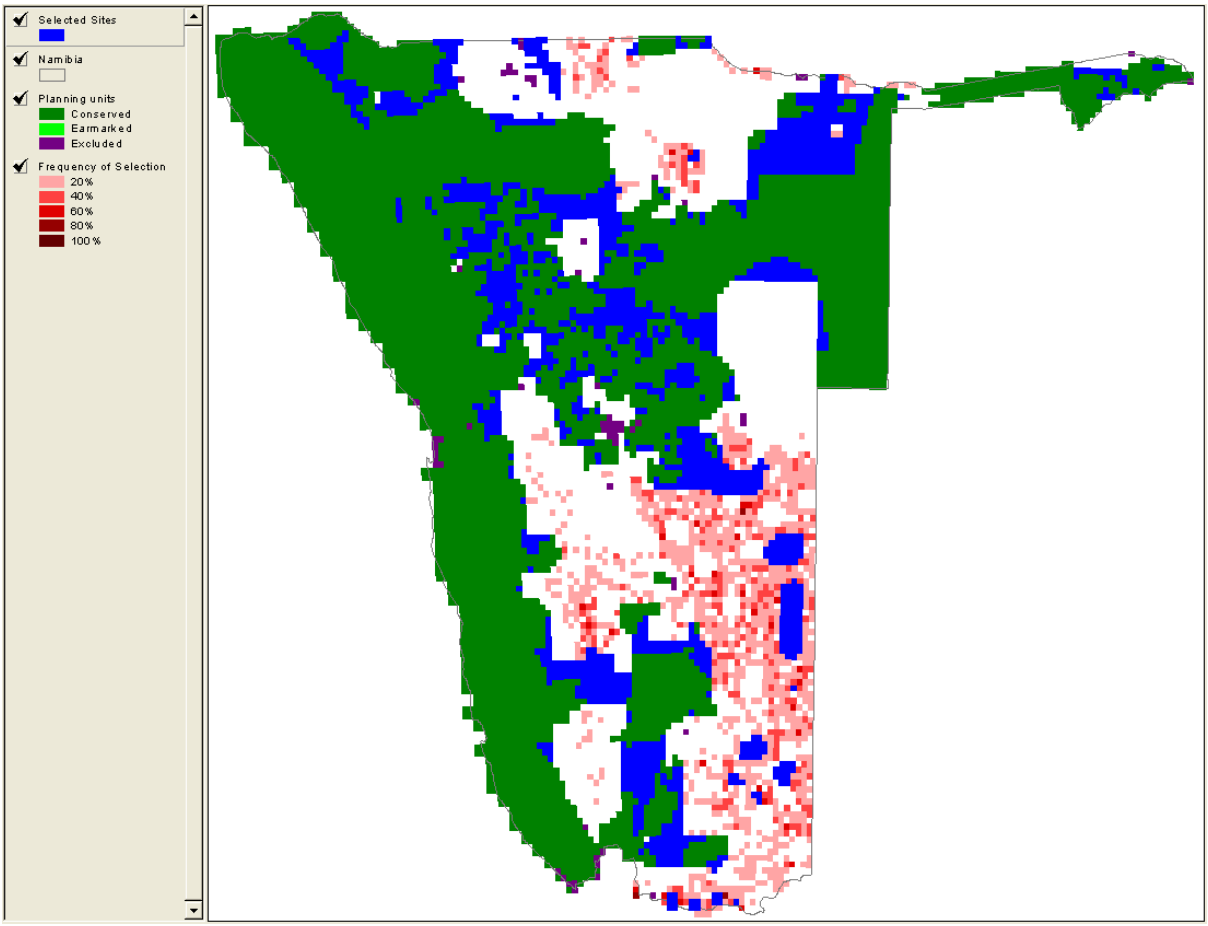
TABLE 5 THE PROPORTION OF REGIONAL PRIMARY PRODUCTION REPRESENTED IN THE PAS.

REGION	OUTSIDE	PAS
1 N Namib	11.46	88.54
2 Central Namib	26.86	73.14
3 S Namib	21.23	78.77
4 Nama	87.97	12.03
5 S Kalahari	99	1
6 N Highlands	35.35	64.65
7 Central Shrublands	55.83	44.17
8 Central Kalahari	68.33	31.67
9 N Kalahari	28.53	71.47
10 Karstveld	58.95	41.05
11 W Savanna	56.1	43.9
12 E Savanna	76.7	23.3
Total	**57.5**	**42.5**

FIGURE 4 (FOLLOWING PAGE, TOP): THE MARXAN SELECTION FREQUENCY OF SITES MEETING ALL BIODIVERSITY TARGETS IN THE PRESENT CLIMATE USING TARGET AND COST ONLY.

FIGURE 5 (FOLLOWING PAGE, BOTTOM): THE MINIMUM SET OF SITES SELECTED (BLUE) TO MEET ALL BIODIVERSITY TARGETS IN THE PRESENT CLIMATE AS WELL AS MIMINUM COST AND BOUNDARY LENGTH.


Namibia
Planning units
Conserved
Earmarked
Excluded
Frequency of Selection
20%
40%
60%
80%
100%


Selected Sites
Namibia
Planning units
Conserved
Earmarked
Excluded
Frequency of Selection
20%
40%
60%
80%
100%

3.2 CHANGES IN BIODIVERSITY DISTRIBUTION UNDER CLIMATE CHANGE

3.2.1 PRIMARY PRODUCTION

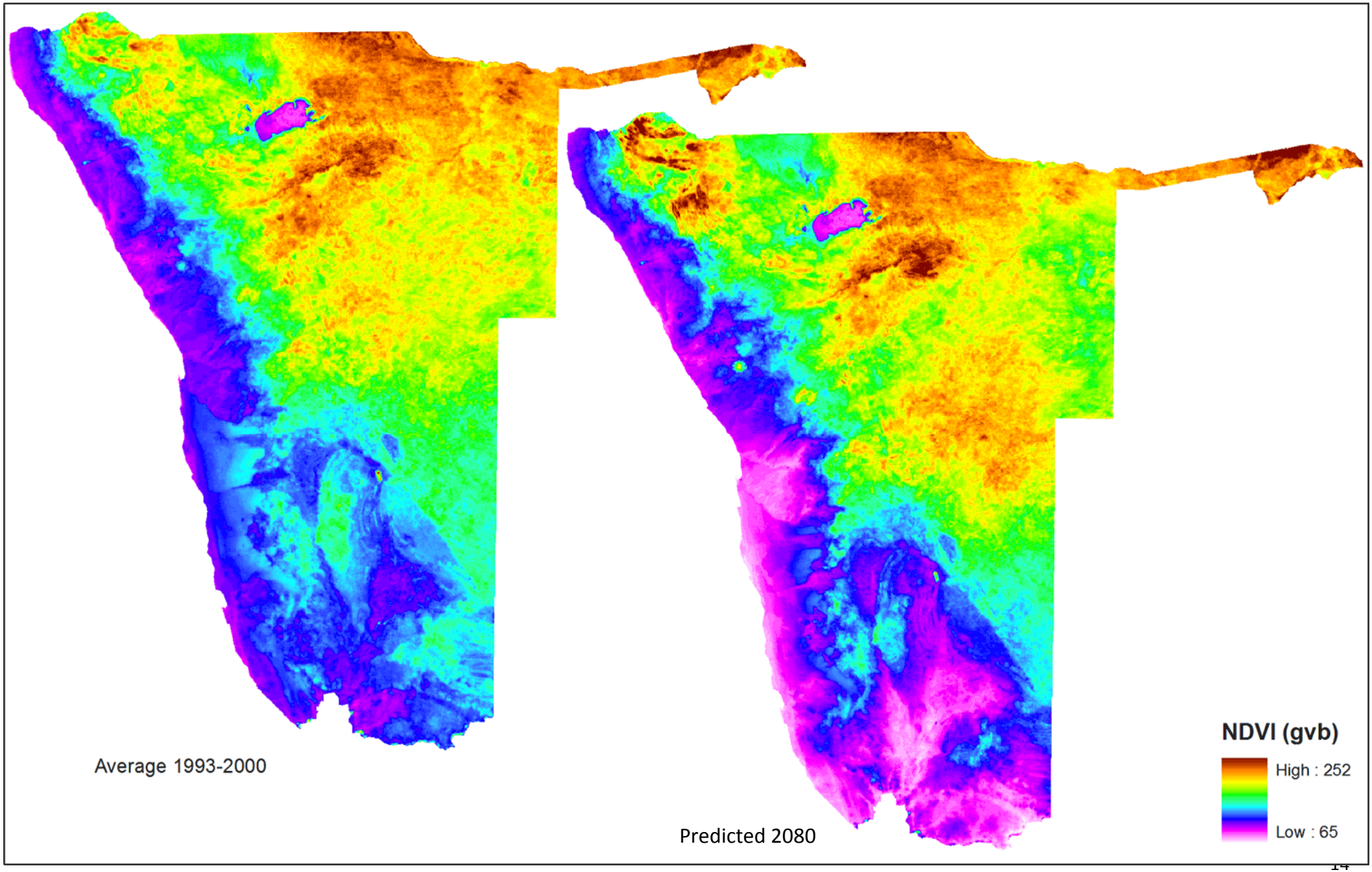
Based on the observed current and future predicted PP the national total PP is predicted to decrease by 4.5%. For the PAS the decrease is similarand predicted to be 4.4%. In arid areas (<500-600mm rain per annum) PP is directly correlated with the numbers of livestock or game that can be kept on the land. Therefore it is possible to quantify in monetary terms the impact of CC on industries dependent on primary production (stock and game farming, protected areas, fuel wood harvesting) as well as the rural and national economies.

However, change is not equal across the country (Figure 6 and Figure 7). Summer rainfall areas are expected to increase by as much as 30% especially high-lying areas such as the Kaokoveld (northern escarpment) and central plateau. In contrast, winter and winter/summer ecotone rainfall areas in the south are expected to decrease by as much as 40% particularly in the Central/southern Namib, Succulent Karoo and Nama Karoo. For the PAS (Table 6 and Figure 2) this change will have significant impacts on the abilities of protected areas in the Central and Southern Namib and Nama eco-region (change >-15%) whereas elsewhere in the currently summer rainfall areas change is expected to be less severe (-5% to +5%).

TABLE 6 THE PERCENTAGE CHANGE IN PAS TOTAL PRIMARY PRODUCTION (RELATIVE UNITS)SUMMARISED PER ECO-REGION.

Region	PP2000	PP2080	% Change
N Namib	8148187	7966627	-2.2
Central Namib	3634438	3021807	-16.9
S Namib	3801814	3261031	-14.2
Nama	2187823	1799096	-17.8
S Kalahari	82439	86176	4.5
N Highlands	6953828	7165227	3
Central Shrublands	5031922	4908301	-2.5
Central Kalahari	3165280	3213166	1.5
N Kalahari	8112039	7552630	-6.9
Karstveld	3457586	3424461	-1
W Savanna	2456772	2446857	-0.4
E Savanna	3927390	3847292	-2
Total for PAS	50959518	48692671	-4.4

FIGURE 6(FOLLOWING PAGE) PREDICTED CHANGES IN PLANTPRIMARY PRODUCTION (BASED ON MODELLED PP) BETWEEN 2000 AND 2080.


Average 1993-2000
Predicted 2080
NDVI (gvb)
High : 252
Low : 65

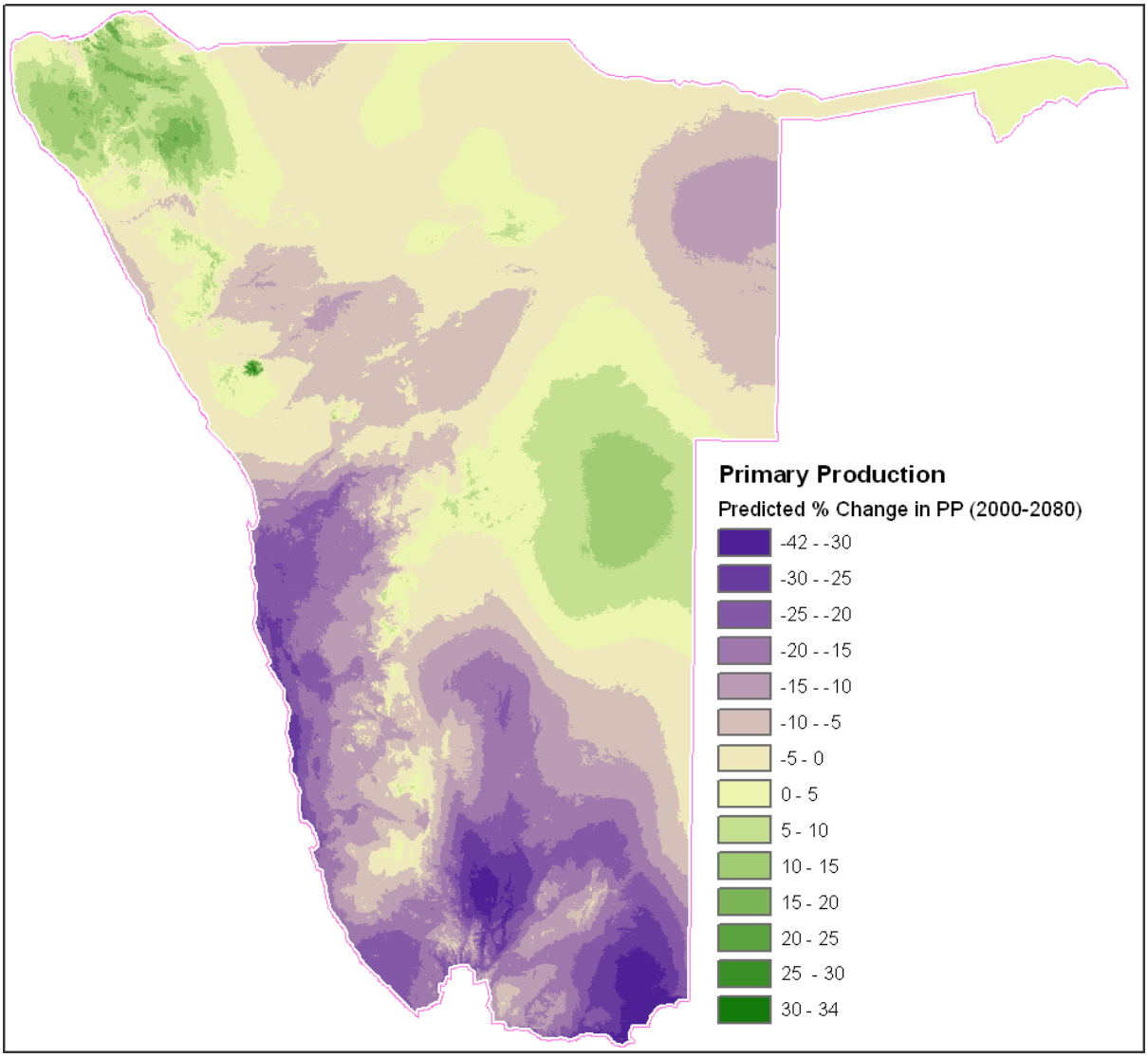


FIGURE 7 THE PREDICTED PRECENTAGE CHANGE IN PRIMARY PRODUCTION BETWEEN 2000 AND 2080.

3.2.2 SPECIES RANGE SHIFTS

The outputs from the species distribution modelling are reported in detail in Midgley *et al.* (2005). Below we summarise the results briefly to provide a context for the PAS analysis.

At the individual species range-level the predictions in terms of changes in overall range size are mixed – 52% of species modelled are expected to have range contractions, 41% range increases and 7% to go extinct from Namibia.

At the vegetation type or ecosystem-level these predicted changes in species rangesshow anapparent inverse pattern to what the primary production model is predicting. The areas expected to experience the greatest reduction in PP (south and south west) are predicted to see the greatest increase in total species numbers as well as the lowest proportion of species loss. While this gain in species diversity in areas most affected by CC is perhaps contrary to what might be expected, it may be related to the fact that Namibia is rich in species adapted to warm, dry conditions. With an expansion of such conditions and of low NPP into the future, this rich group of arid-adapted species is modelled to expand their range and migrate into regions that are warming and drying.

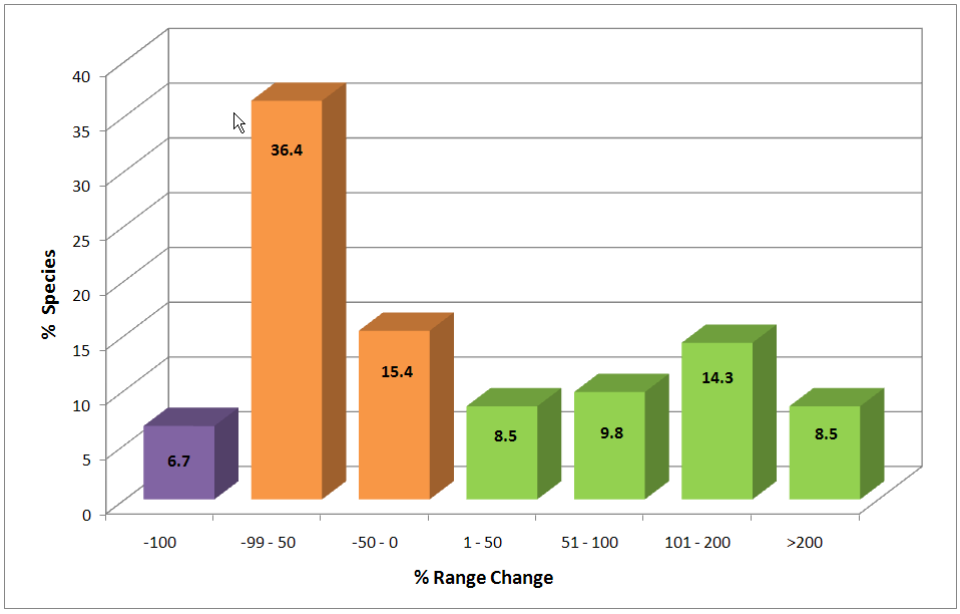


FIGURE 8 A SUMMARY OF THE PERCENTAGE CHANGE IN RANGE SIZE FOR THE 857 PLANTS SPECIES MODELLED BY MIDGLEY *ET AL.*(2005). -100% IMPLIES THAT A SPECIES HAS GONE EXTINCT FROM NAMIBIA.

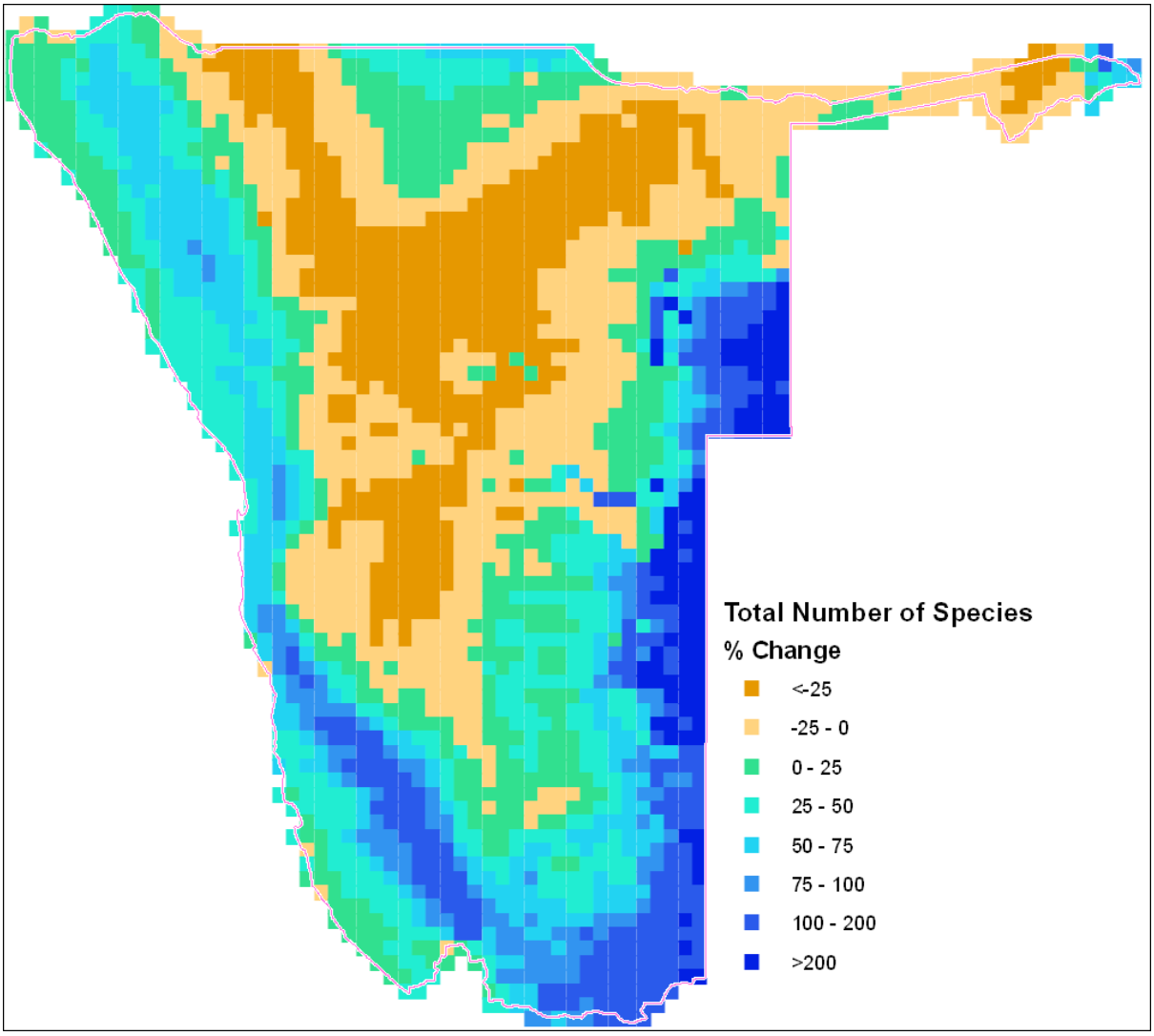


FIGURE 9THE RELATIVE CHANGE IN TOTAL SPECIES NUMBERS ACROSS NAMIBIA 2000-2080 (ORIGINAL DATA FROM MIDELEY *ET AL.* 2005 AND BROENNIMANN*ET AL.* 2006).

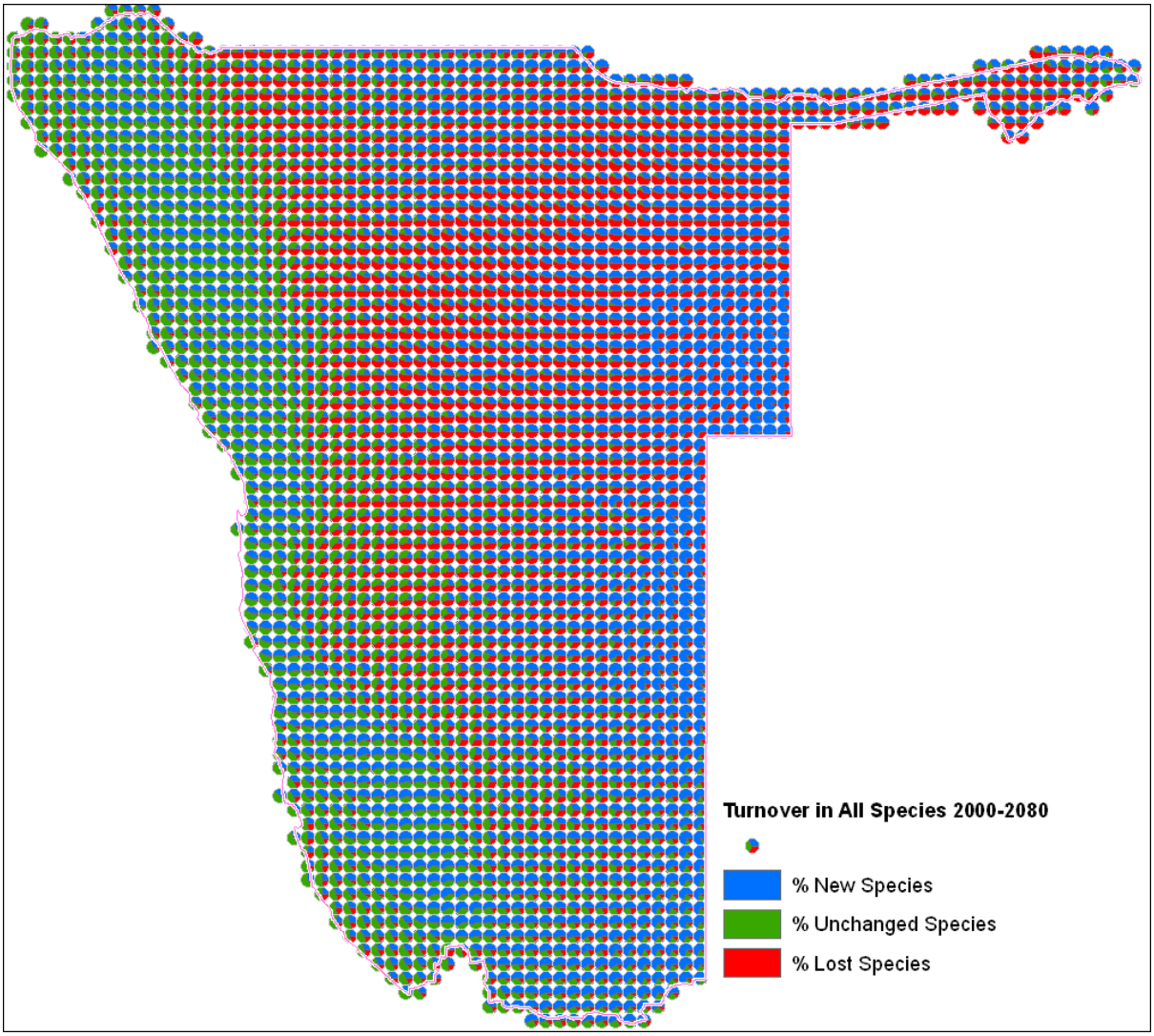


FIGURE 10THE RELATIVE CHANGE IN SPECIES COMPOSITION IN TERMS OF SPECIES GAIN/LOSS FOR THE MODEL PERIOD 2000-2080 (ORIGINAL DATA FROM MIDELEY *ET AL.* 2005 AND BROENNIMANN*ET AL.* 2006).

The assumption made by the species model of rapid migration of these species in response to CC is untested. This raises an important conservation strategy perspective for future consideration – is it possible both practically and cost-wise to assist the migration of desert species to occupy novel ranges? Certainly, effective corridor design at the landscape level is an important first step in such a strategy.

At this stage no analysis in terms of change in vegetation composition (e.g. vegetation structure, palatable species) is attempted due to the limited time available for the project, although with the data available and key inputs from experts this would be possible. Therefore what the impacts of these plant species range changes might be on herbivore communities is unknown.

3.3 How well does the current PAS meet targets for future species distribution?

Deciding on an approach to setting targets to assess how well the current PAS meets targets for the future distribution of species is not trivial. Should a target be based on the current distribution of species (i.e. the area equivalent of 10% of the current range of each species – Target 1) or relative to the future distribution of species (i.e. the area equivalent of 10% of the future predicted range of each species – Target 2)?This is an

important conceptual conservation planning and policy issue that is not resolved here. For the purposes of this analysisthe future distribution target (Target 2) is used.

Currently the PAS achieves 99.7% of targets for species (854 out of 856 species current targets achieved, Table 4). The current PAS is also effective at achieving future targets for plant species - 848 out of a total of 856 (99%) species future targets are achieved by the current PAS. Mopping-up outstanding future targets, however, is not spatially efficient and would require between a 20-30% expansion of the PAS to meet targets for all species (Table 7). Most of this expansion can be achieved by expanding existing PA's with two notable exceptions – the eastern Orange River Valley and the southern Kalahari/Nama Karoo regions where species priorities are located away from any existing PA.

TABLE 7SUMMARY OF MARXAN MODEL INPUTS AND OUTPUTS FOR THREE PAS EXPANSION OPTION SCENARIOS (3 DEGREES OF COMPACTNESS [BLM]) FOCUSSING ON REPRESENTING 10% OF THE FUTURE PREDICTED RANGE OF EACH PLANT SPECIES (TARGET SCENATIO FUTURE 1, TABLE 1). EACH PU IS 18 000HA.

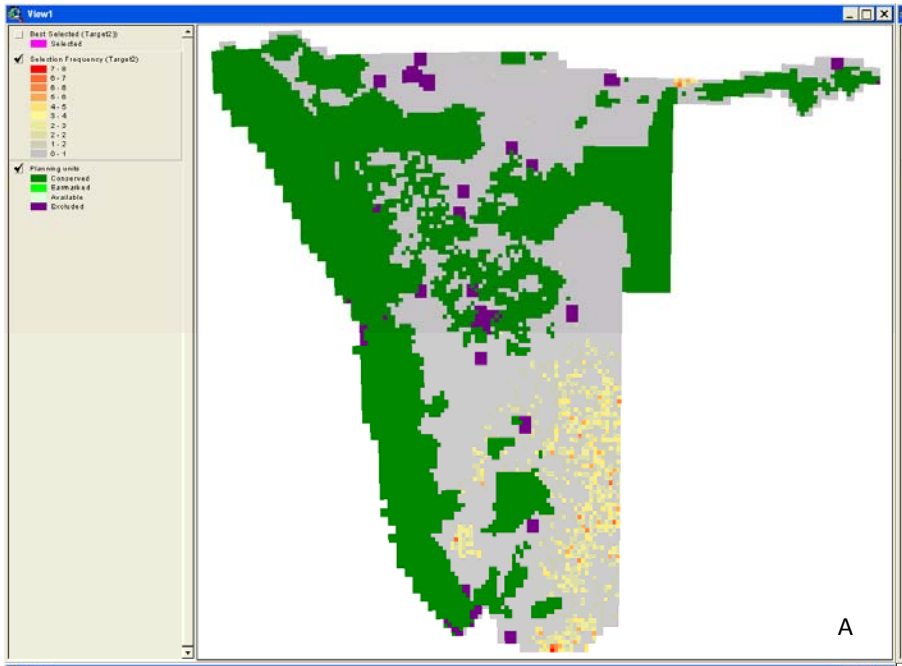
	Input			Output			
Scenario	**Cost**	**BLM**	**Target Scenario**	**Total Cost**	**Total PUs**	**Boundary Length**	**Required Additional Sites**
RUN 3	COST2	ZERO	Future 1	2708360.0	5167	19737454.2	98
RUN 4	COST 2	HALF OPT	Future 1	2831760.0	6205	8550715.6	1136
RUN 5	COST 2	OPT	Future 1	2915960.0	6707	7549047.0	1638

3.4 How well does the current PAS maintain current carrying capacity?

Assessing changes in the PP of the current PAS is done using two target sets. Future target scenario one assumes the PP of the current PAS is adequate and looks simply at options for maintaining current PP levels within the context of the future predicted PP (i.e. create a PAS that maintains the current game carrying capacity, target scenario Future 2, Table 1). From Table 6 the PP for the PAS in three regions is predicted to increase whereas those for other regions particularly in the south are predicted to decrease (i.e. 3 out of 12 future PP targets achieved by the current PAS, Table 8).

The current PAS is not fully representative of Namibia's biodiversity. There are spatial biases with the PAS being well developed in some regions but underdeveloped or non-existent in other regions. A valid conservation goal would be to ensure that an equal proportion of each regions PP is represented with the PAS. Currently the PAS captures 42% of the country's PP (Table 5). Therefore a future target might be to ensure that the PAS captures at least 40% of each eco-region's future PP (Target scenario Future 3, Table 1). Using this target set the current PAS achieves future PP targets for eight of the 12 regions (Table 8), one of the regions, the southern Kalahari, has almost no representation within the PAS.

FIGURE 11 (FOLLOWING PAGE) OUTPUTS FROM THE FUTURE SPECIESMARXAN MODELS SHOWING THE SELECTION FREQUENCY OF SITES FOR 20 MODEL ITERATIONS:
A = RUN3 – NO ADJACENCY REQUIREMENT (I.E. NO BLM). NOTE THAT NO SITE IS SELECTED MORE THAT 10 OR 50% OF MODEL RUNS INDICATING THAT NO SPECIES IS LIMITED TO A SINGLE SITE AND WHERE ADJACENCY IS NOT A REQUIREMENT THERE IS A HIGH DEGREE OF FLEXABILITY AS TO WHERE TO SELECT ADDITIONAL SITES.
B = RUN4 –MODERATE ADJACENCY REQUIREMENT (0.5 OPTIMAL BLM)
C = RUN5 – HIGH ADJACENCY REQUIREMENT (OPTIMAL BLM)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Best Selected (Target2)
Selected
Selection Frequency (Target2)
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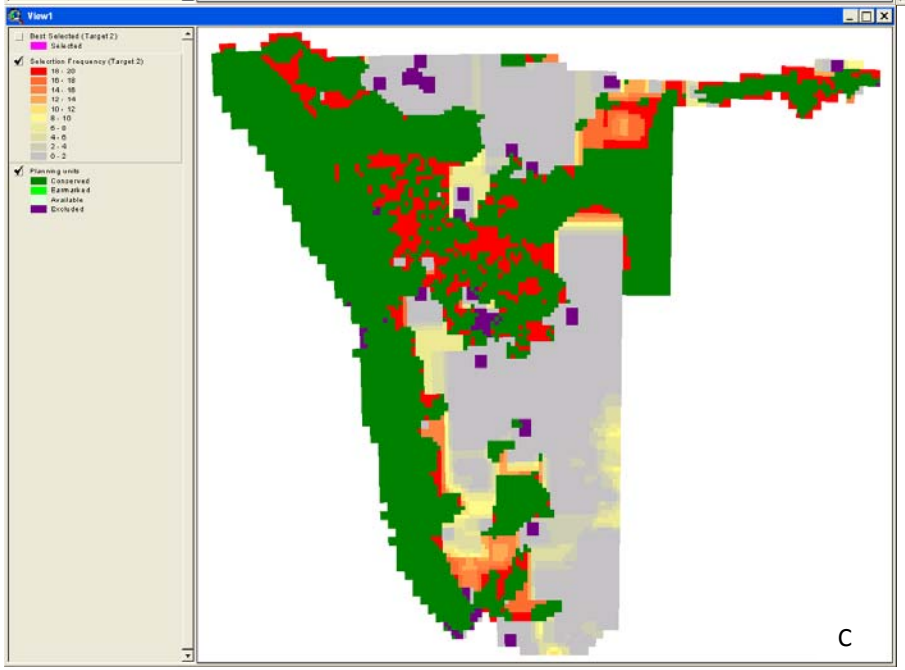
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Planning units
Conserved
Earmarked
Available
Excluded
A

View1
Best Selected (Target 2)
Selected
Selection Frequency (Target 2)
10 - 20
16 - 18
14 - 16
12 - 14
10 - 12
8 - 10
6 - 8
4 - 6
2 - 4
0 - 2
Planning units
Conserved
Earmarked
Available
Excluded
B


View1
Best Selected (Target 2)
Selected
Selection Frequency (Target 2)
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14 - 16
12 - 14
10 - 12
8 - 10
6 - 8
4 - 6
2 - 4
0 - 2
Planning units
Conserved
Earmarked
Available
Excluded
C

TABLE 8 SUMMARY OR PERCENTAGE OF TARGET ACHIEVED FOR THE TWO PRIMARY PRODUCTION TARGET SETS USED IN THE ANALYSIS.

		% Target Achieved	
Id	**Region Name**	**Future 2**	**Future 3**
1	N Namib	97.52	226.71
2	Central Namib	83.37	181.15
3	S Namib	85.6	199.42
4	Nama	82.32	34.39
5	S Kalahari	104.61	3.71
6	N Highlands	102.51	179.14
7	Central Shrublands	97.28	138.76
8	Central Kalahari	101.82	85.15
9	N Kalahari	93.34	181.36
10	Karstveld	99.1	116.83
11	W Savanna	99.24	116.92
12	E Savanna	97.99	65.29

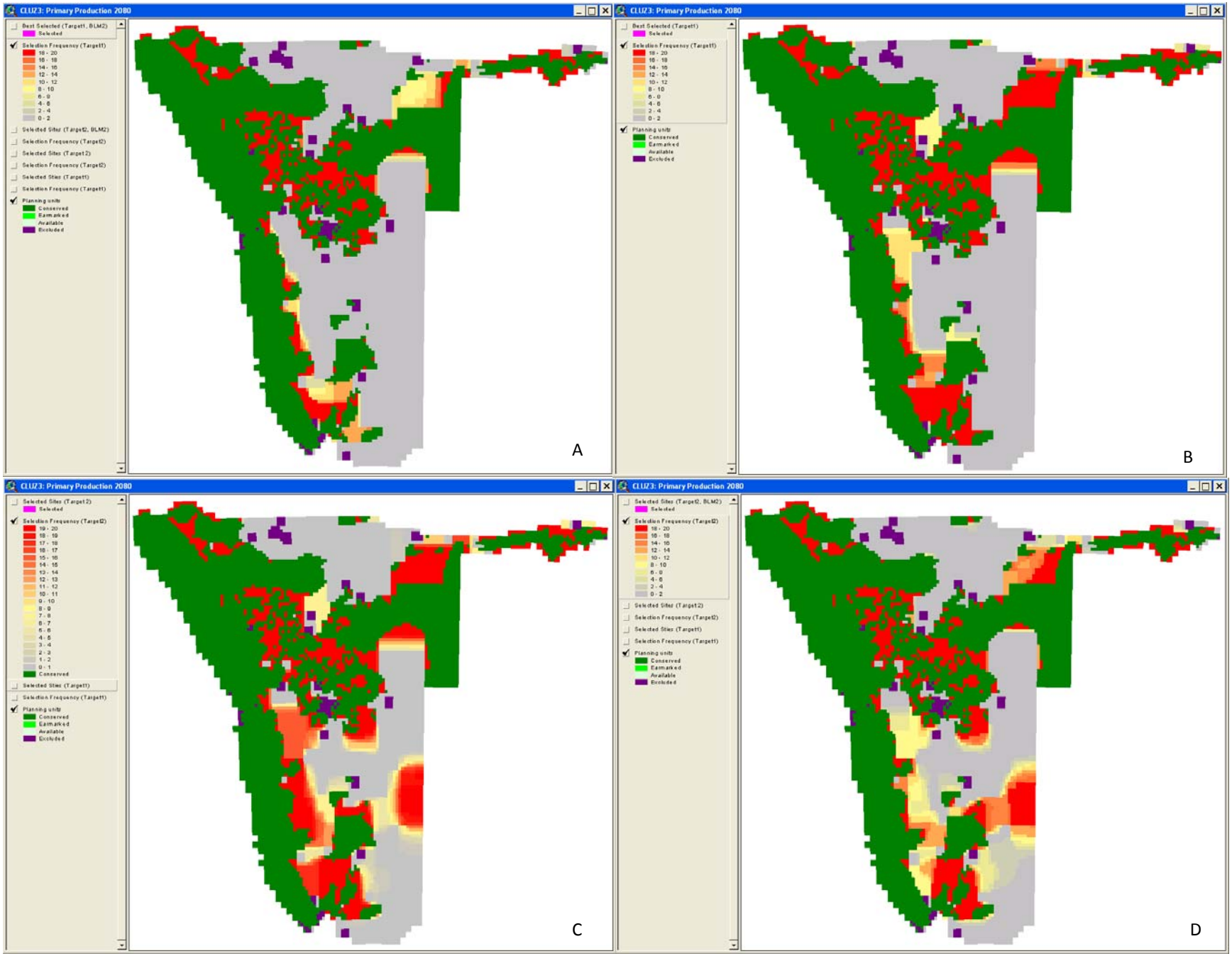
Addressing gaps in the current PAS to achieve future targets in PP would require between a 35-43% increase in the size of the current PAS (Table 9). Most of this expansion could be achieved by expanding and consolidating existing PAs with notable exceptions in the south of the country particularly the southern Kalahari where there are currently no PAs (Figure 12). Consolidation of the PAS into 3 major bioregional corridors would also contribute significantly to the maintenance of macro-ecological climatic gradient corridors. These corridors are the:

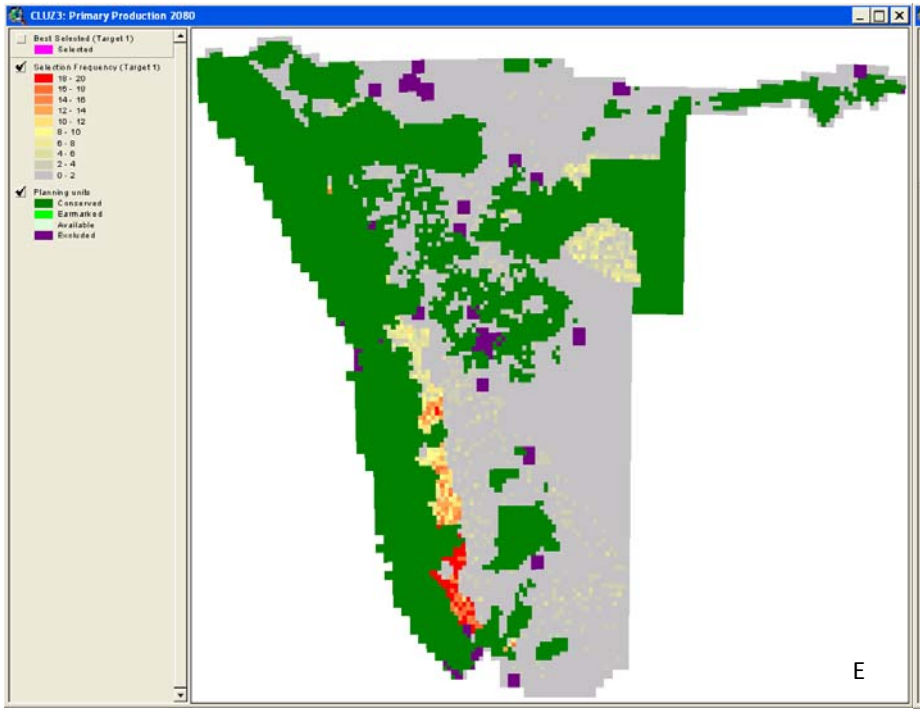
1. North-south escarpment/Namib corridor (existing)
2. West-east Kaokoveld-Caprivi corridor (existing)
3. West-east southern Namib-Kalahari corridor (not existing)

TABLE 9 SUMMARY OF MARXAN MODEL INPUTS AND OUTPUTS FOR SIX PAS EXPANSION OPTION SCENARIOS (TWO TARGET SETS X 3 DEGREES OF COMPACTNESS [BLM]) FOCUSSING ON MAINTAINING CURRENT PP (TARGET SCENARIO FUTURE 2) AND REPRESENTING A FIXED PROPORTION OF FUTURE PP IN EACH REGION (TARGET SCENARIO FUTURE 3). EACH PU IS 18 000HA.

	Input			Output			
Scenario	**Cost**	**BLM**	**Target Scenario**	**Total Cost**	**Total PUs**	**Boundary Length**	**Required Additional Sites**
RUN9	COST2	ZERO	Future 2	27264.7	5347	21568175.4	278
RUN7	COST2	HALF OPT	Future 2	28399.3	6284	7791131.5	1215
RUN 8	COST2	OPT	Future 2	29396.4	6848	6744097.2	1779
RUN10	COST2	ZERO	Future 3	27935.7	6016	36858526.5	947
RUN6	COST2	HALF OPT	Future 3	29165.8	7016	8043213.2	1947
RUN5	COST2	OPT	Future 3	29976.9	7242	7088248.4	2173

FIGURE 12 (FOLLOWING PAGE) OUTPUTS FROM THE FUTURE PP MARXAN MODELS SHOWING THE SELECTION FREQUENCY OF SITES FOR 20 MODEL ITERATIONS:
A = RUN7: MAINTAIN CURRENT PP, MODERATE ADJACENCY REQUIREMENT
B = RUN 8: MAINTAIN CURRENT PP, HIGH ADJACENCY REQUIREMENT
C = RUN6: REPRESENT EQUAL PROPORTION OF FUTURE PP, MODERATE ADJACENCY REQUIREMENT
D = RUN5: REPRESENT EQUAL PROPORTION OF FUTURE PP, HIGH ADJACENCY REQUIREMENT
E = RUN9: MAINTAIN CURRENT PP, NO ADJACENCY REQUIREMENT
F = RUN10: REPRESENT EQUAL PROPORTION OF FUTURE PP, NO ADJACENCY REQUIREMENT


CLUZ3: Primary Production 2080
A
CLUZ3: Primary Production 2080
B
CLUZ3: Primary Production 2080
C
CLUZ3: Primary Production 2080
D


CLUZ3: Primary Production 2080
Best Selected (Target 1)
Selected
Selection Frequency (Target 1)
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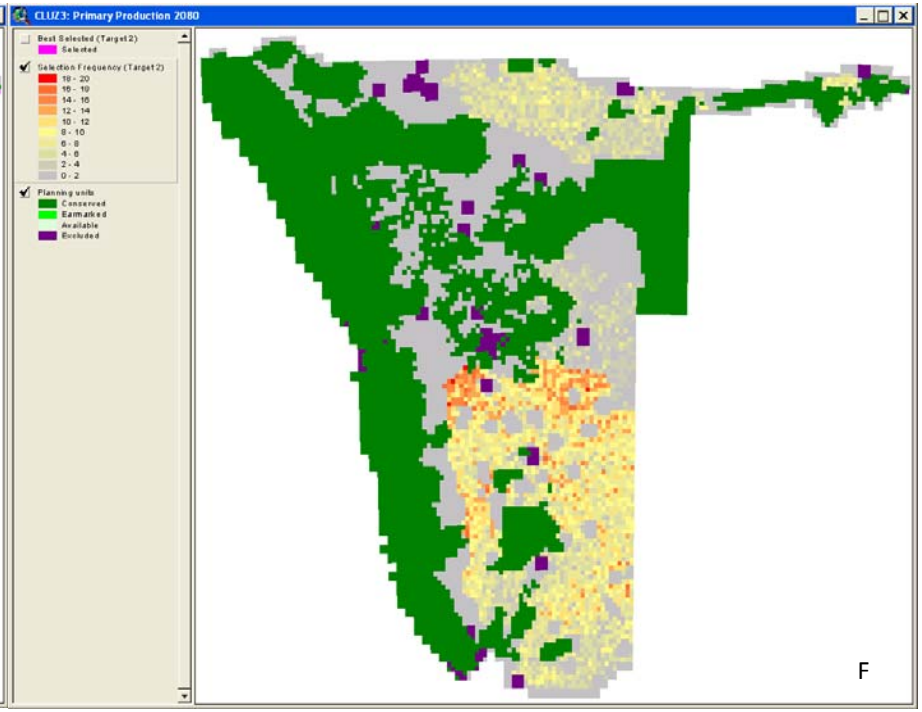
14 - 16
12 - 14
10 - 12
8 - 10
6 - 8
4 - 6
2 - 4
0 - 2
Planning units
Conserved
Earmarked
Available
Excluded
E


CLUZ3: Primary Production 2080
Best Selected (Target 2)
Selected
Selection Frequency (Target 2)
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16 - 18
14 - 16
12 - 14
10 - 12
8 - 10
6 - 8
4 - 6
2 - 4
0 - 2
Planning units
Conserved
Earmarked
Available
Excluded
F

4 CONCLUSIONS

Namibia has a well developed PAS covering nearly 45% of the country that achieves conservation targets for 93% of biodiversity features assessed in this study. This PAS is well placed to be able to adapt to the challenges of climate change.

Based on the two climate change biodiversity response model datasets used in this study the responses of biodiversity to climate change will not be uniform across the country and will include:

- National total primary production will decrease by 4.5% and 4.4% for the PAS.
- Changes in primary production will not be equal across the country with primary production increasing in the central interior and north-western sub-regions (Savanna) of the country by as much as 30% and decreasing in southern areas (Succulent and Nama Karoo) by as much as 40%.
- At least 7% of plant species modelled are estimated to shift their distribution range out of Namibia entirely with 52% of species showing range contractions and 41% showing range expansions.
- Changes in species composition are variable with the north and central areas expecting the greatest decrease in total relative species diversity and greatest degree of species change, and the Namib and southern areas expecting the greatest increase in relative species diversity with least degree of species change.

Given the spatial variability in responses adapting the PAS to these anticipated changes in biodiversity patterns and process will require a variety of strategies. Adaptation strategies could include:

- Building a PAS that is fully representative of current biodiversity patterns and processes (i.e. meets current targets).
    - The south of the country has been neglected by the PAS with areas of the eastern Orange River Valley, Nama Karoo and southern Kalahari requiring attention.
    - Focus on including climate change refugia into the PAS such as mountainous areas that contain habitats (elevation, south-facing slopes and kloofs) that can buffer species locally against macro-scale changes in climate.
    - Use information on the current distribution of biodiversity as well as modelled information on the future distribution of biodiversity to guide PAS expansion.
- Focus on maintaining biodiversity processes such as:
    - Facilitate species movement through building a landscape-levelbiodiversity corridor network that will allow biodiversity to respond to changing climates.Three large-scale corridors are suggested for Namibia – two already exist to a greater degree (the north-south Namib/Escarpment and east-west Kaokoveld-Caprivi corridors) and one (west-east southern Namib-Kalahari corridor) still needs to be created.
    - Promote persistent populations by consolidating areas within the existing PAS by removing fencing to create larger contiguous management areas that that meet viable animal population size requirements and facilitate species movement in response to seasonal variation.
    - Cooperate with neighbouring states when planning and implementing landscape-scale corridors to align conservation management efforts across political boundaries. Biodiversity does not recognise political boundaries.

Using reserve design software to explore PAS development scenarios aimed at creating a representative PAS that meets current targets as well as targets for the future distribution of biodiversity whilst maintaining the primary productivity of the PAS suggest that between a 20-45% increase in the size of the current PAS will be required to achieve this goal. The wide range in percentage increase is a result of difference target sets being used and different levels of PAS adjacency or continuity being applied. Given that one of the most important

recommendations for PAS CC adaptation is the creation or maintenance of landscape corridors, and that the Namibian PAS is relatively fragmented a PAS expansion figure towards the upper end of our predictions may actually be more realistic. It is important to note that our concept of PAS here includes all protected categories so we are not recommending that all this expansion should be the work of the state alone but that the private and communal sectors have an important contribution to make.

Multiple target sets (current biodiversity representivity, future biodiversity representivity and primary production) can be achieved simultaneously therefore it is important to include a wide variety of biodiversity features/targets when planning future PAS expansion. These scenarios do not take into account connectivity within the existing PAS. It is likely that without adding new areas to the PAS significant improvements in the landscape ecological functioning of the PAS could be achieved simply by improving management within the PAS.

In the short term Namibia's PAS expansion strategy should focus on:

1. Creating new protected areas in the Nama Karoo and Orange River Valley to improve the representation of these ecosystems within the PAS.
2. Focus on improving connectivity within and between existing components of the PAS.

The change assessment of primary production within the PAS presented here is fairly simplistic. It is assumed here that there is a direct relationship between PP and animal biomass. This is correct, however, the manner in which PP is proportioned between plant functional types (grass vs. shrub vs. tree) has important implications for the types of animals that are able to utilise this biomass. Changes in dominant plant functional types or vegetation structure would result in changes in animal communities so whilst animal biomass may remain constant or increase in response to increase in total primary production the types of animals able to occupy the veld would change significantly. The data available to this project would allow for more detailed analysis on PAS carrying capacity and animal community changes in response to climate change.

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6 APPENDIX 1: INPUT DATA

Dataset Name	Description	Source
Biodiversity Distribution (Current)		
Vegetation Types	Namibian vegetation types (polygon shp file)	Atlas of Namibia
Agricultural Land-Types	Agricultural land-types based on broad soil and rainfall groups (polygon shp file)	Atlas of Namibia
Species Distribution	Current modelled distribution of species at quarter degree square based on PRECIS herbarium records (approximately 18km raster grid).	Broennimann *et al.* (2006) & Midgley *el al.* (2005) via Guy Midgley at SANBI
Climate change refugia (south-facing slopes)	Steep, south-facing mountain slopes that act as local-scale climate change refugia for species. Calculated from the SRTM digital elevation model	SRTM DEM v3 (http://www2.jpl.nasa.gov/srtm/cbanddataproducts.html)
Biodiversity Distribution (Future)		
Species Distribution	Predicted (2080) modelledspecies distribution based on PRECIS quarter degree square herbarium recordsand the HadCM3 General Circulation Model B2 IPCC SRES climate change projections(approximately 18km raster grid).	Broennimann *et al.* (2006) & Midgley *el al.* (2005) via Guy Midgley at SANBI
Net Primary Production	Predicted (2080) Average Annual Plant Production interpolated from modelled biomass production using the ECHAM5 IPCC (2007) SRES A1B climate change projections (1km raster grid). See Appendix 2	• Modelled biomass from Scheiter and Higgins (2009) • Observed Average Annual Plant Production (average 1993-2000) from the Atlas of Namibia • Average Plant Production interpolation by this project. Data available from Philip Desmet (factoryrider@absamail.co.za)
Protected Areas	An up-to-date map of the extent of all categories of existing and establishing protected areas in Namibia.	Atlas of Namibia and updated by this project. Available from Katharina Dierkes (maproom@iway.na)]
Context Information		
Land Cover	Approximate current extent of transformed areas (urban areas and crop-lands) (1km raster grid).	Urban areas – Earth@Nite dataset (http://www.ngdc.noaa.gov/dmsp/) Crop lands – Global Land Cover data from the Atlas of

		Namibia
Cost	A relative index of degree of difficulty of including a PU into the PAS. Based on (1) weighted distance to settlements and (2) extent of transformed areas (urban and crop-lands), and summed per planning unit (1km raster grid)	Generated by this project from the land-cover datasets
Planning Units	The unit to which all input biodiversity, land-cover and cost information was summarized and assessed. Layer comprises a continuous coverage of approximately 9x9km polygons covering the entire extent of Namibia (total of 10477 planning units). PU's exactly ¼ size of species model pixel size (polygon shp file).	Generated by this project

7 APPENDIX 2: DOWN-SCALING OF ADGVM MODEL OUTPUTS

The ADGVM vegetation model data were "downscaled" from a 20km to 1km grid level by relating the model outputs (total biomass [present]) to observed average annual (scaled) NDVI (1993-2000) (Average annual plant production from the Namibian Atlas).

Process Steps:

1. Demonstrate relationship between observed total annual plant production (1km) and modelled total biomass (20km).
2. Convert current and future total biomass to annual plant production using regression equation at 20km grid level.
3. Calculate delta or %change in total biomass at 20km grid level.
4. Interpolate delta from 20km to 1km grid level using latitude, longitude and elevation as co-variables.
5. Multiply current plant production (1km) by delta (1km) to produce 2080 predicted plant production.

Data were interpolated with ANUSPLINinterpolation software (Hutchinson, 2001) and using the Integrated Toolset ANUSPLIN interface extension for ArcView 3 (http://www.daff.gov.au/brs/climate-impact/toolset).
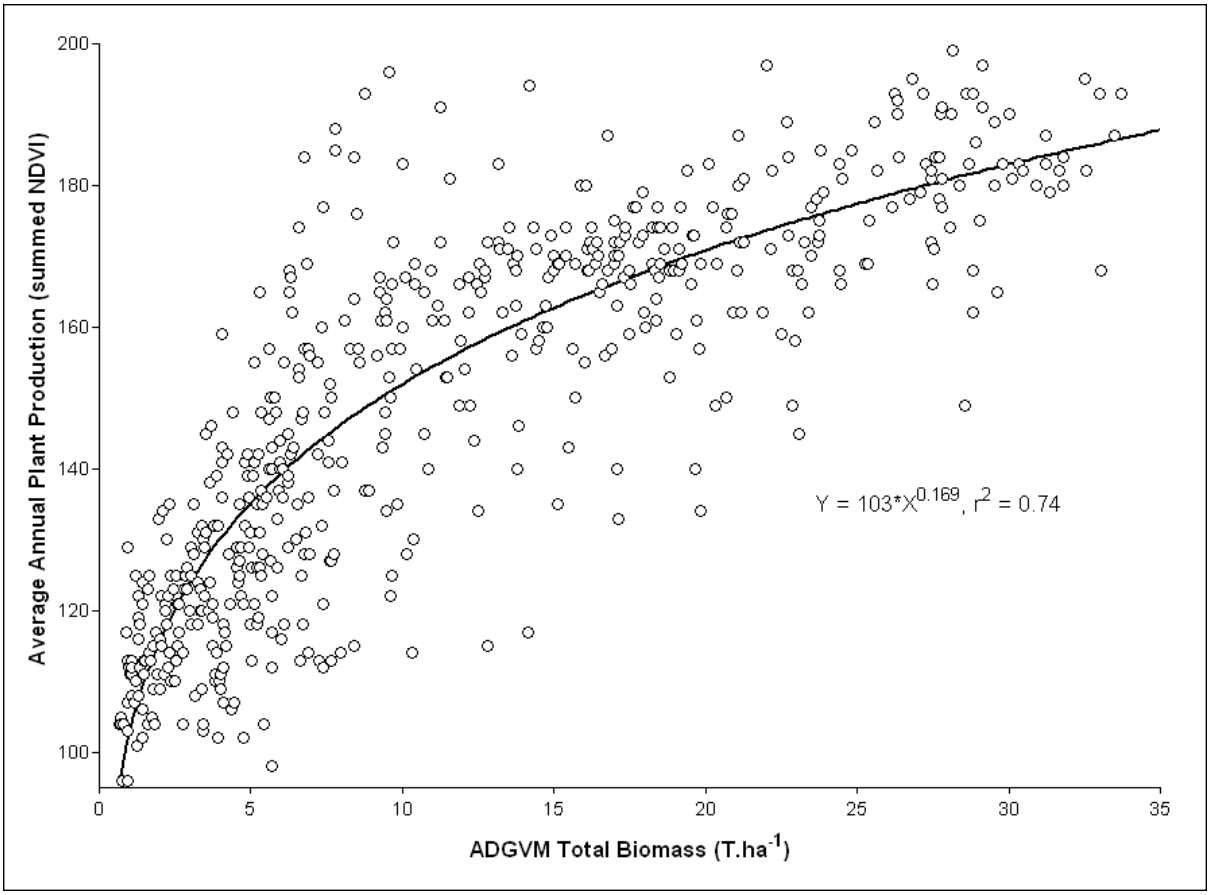
FIGURE 13 THE OBSERVED RELATIONSHIP BETWEEN MODELLED CURRENT TOTAL BIOMASS AND OBSERVED CURRENT PLANT PRODUCTION (RELATIVE UNIT).