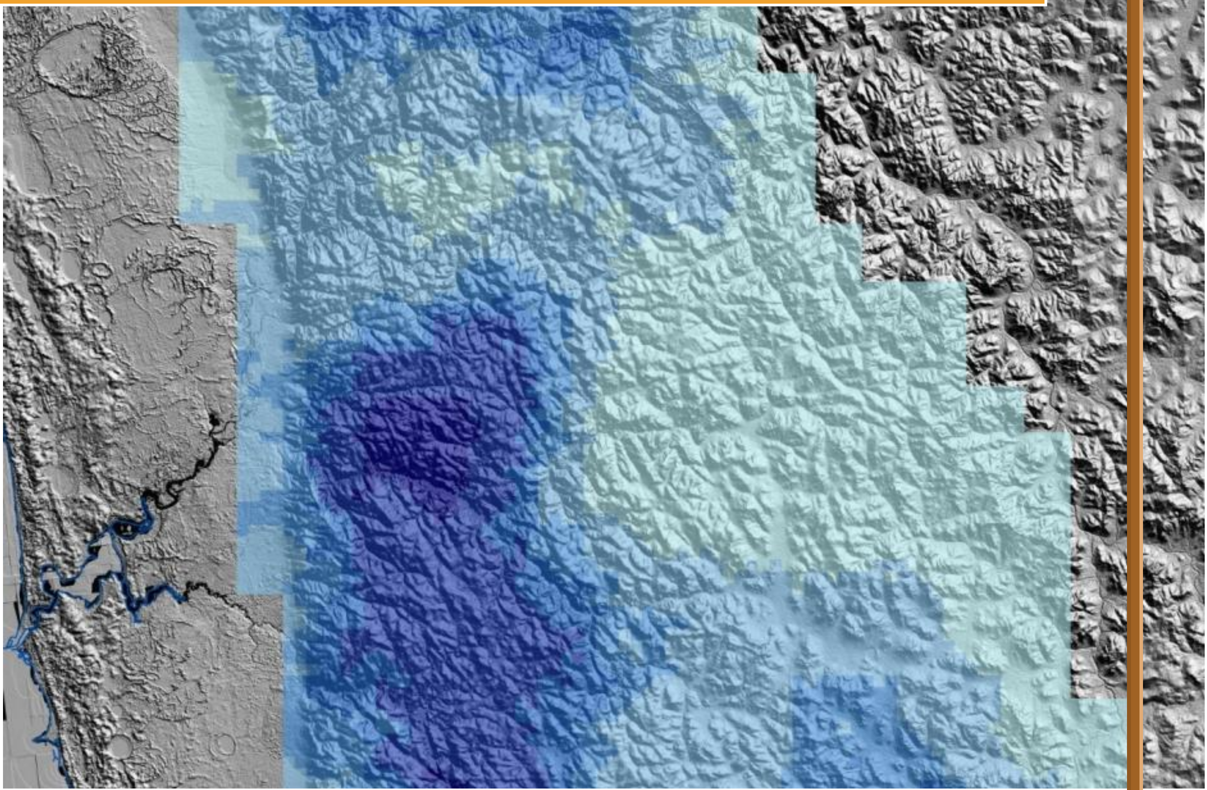
Department of Parks and Wildlife

South-west Forest Biodiversity Survey Gap Analysis



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CONTENTS

1 General introduction

Action 9.1 of the Forest Management Plan 2004-2013 states that the Department of Parks and Wildlife (DPAW) will undertake biological surveys of priority areas determined in consultation with the Conservation Commission (CCWA 2004). The biological surveys are used, where appropriate, to assist in evaluating the extent to which biodiversity is being conserved and the need for any review of the reserve system (CCWA 2004).

DPAW has established the FORESTCHECK program to inform forest managers about changes and trends in key elements of forest biodiversity associated with a variety of management activities (CALM Science Division 2001; DEC Science Division 2006). The program has been in operation since 2001, and to date, 48 monitoring grids have been established in four of the jarrah forest ecosystems mapped for the Western Australian Regional Forest Agreement (McCaw *et al.* 2011). FORESTCHECK monitoring also provides a sound basis for systematic biological survey of the forest (Abbott and Williams 2011).

DPAW is considering using the FORESTCHECK monitoring protocol to improve knowledge of biodiversity for parts of the forest that have not previously been well sampled. The purpose of this study is to identify geographic areas where survey information is lacking, species richness is high and the current extent and status of native vegetation provides the potential to improve the comprehensives, adequacy and representativeness of the conservation reserve system.

Spatial data will be reviewed, analysed and combined into a model with the aim of identifying geographical areas with relatively low survey effort; high species richness; high cover of native vegetation; and (for those areas that are DPAW managed) high levels of existing protection. In the final step, the influence of selected threats or impacts will be tested. Figure 1 shows a conceptual diagram for the methods used to address Action 9.1 of the Forest Management Plan 2004-2013 in this study.

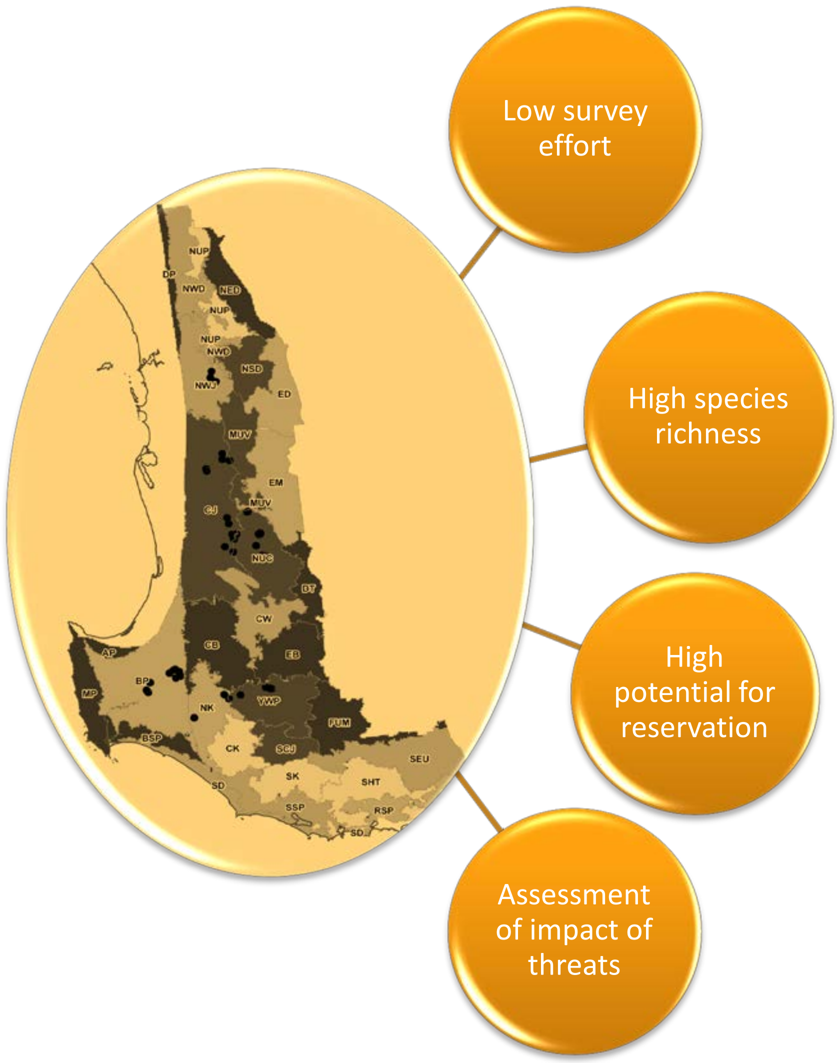


Figure 1 Conceptual diagram for the methods used in this study to address Action 9.1 of the Forest Management Plan 2004-2013 (CCWA 2004).

1.1 General methods

The Forest Management Plan 2004-2013 applies to all land categories vested in the Conservation Commission, and freehold land that contains native vegetation held in the name of the Executive Director of DPAW within the Swan, South West and Warren Regions, excluding marine waters (CCWA 2004). The focus of this study is an area that corresponds with the south-west forest region, as defined in the Western Australian Regional Forest Agreement (RFA 1999). This area is shown in Figure 2 and excludes the Swan Coastal Plain, which has been extensively modified by agriculture and urban development.

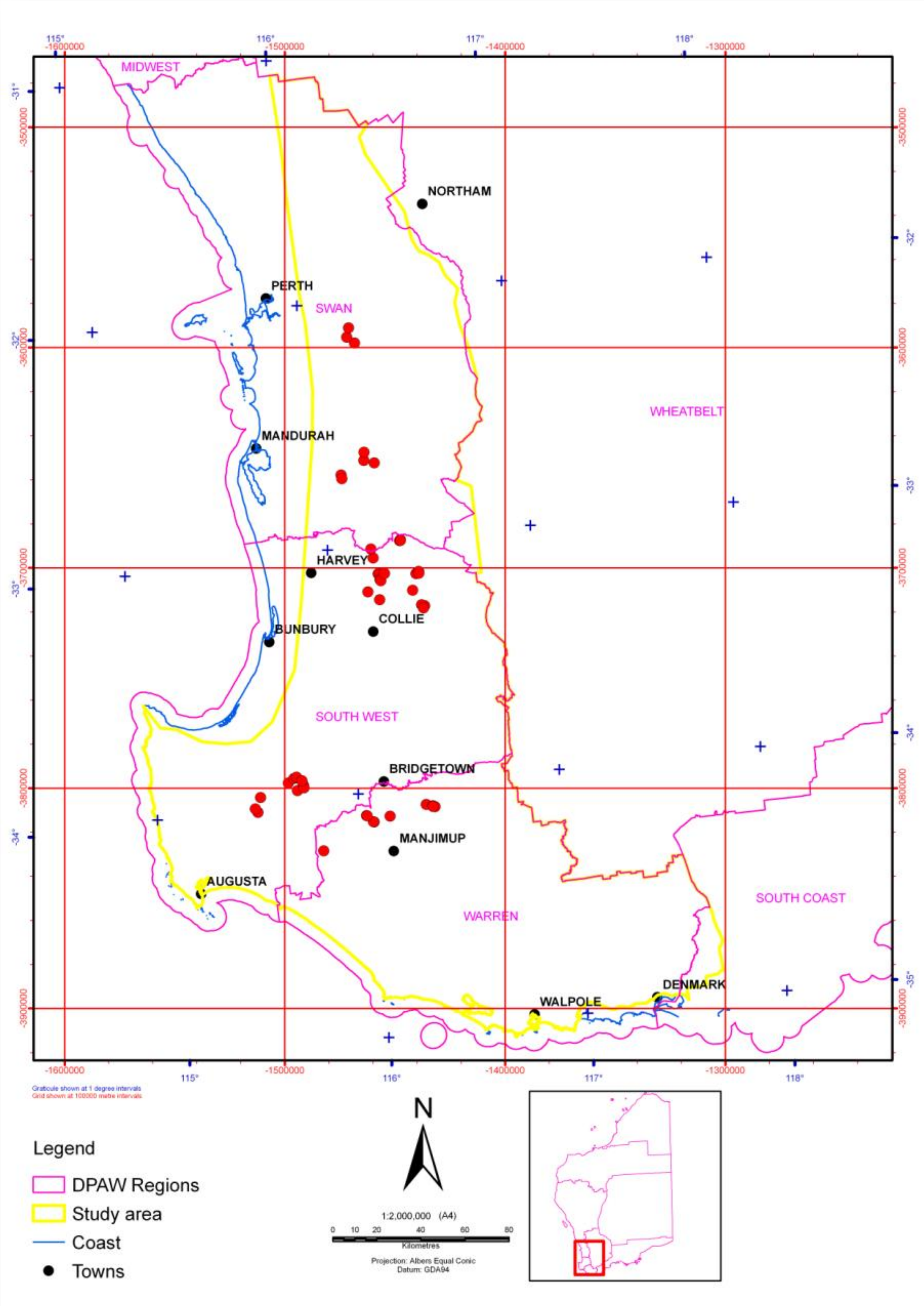


Figure 2 South-west Western Australia showing the study area in the context of DPAW administrative regions and existing FORESTCHECK monitoring grids in red.

1.2 Spatial analysis and modelling techniques

All spatial data were projected in Albers Equal Area Conical projection (Geocentric Datum of Australia 1994), because this projection minimises distortion for geographic areas between latitudes and is thus, ideal projection for area-weighted comparisons and modelling (Kennedy and Kopp 2000; Yildirim and Kaya 2008). The primary techniques used to represent and analyse spatial data in this study were grid based calculations, interpolation, extrapolation from grid data to land management units and multi-criteria analysis.

Grid calculations

Hawth's Analysis Tools (Beyer 2004) were used to generate a grid of 5km x 5km grid squares over the study area. This size of the grid squares was chosen to balance the need for adequate data resolution and sufficient computer processing speed. The data for each grid square was then divided by the area of land falling within the grid square, to calculate the magnitude of the data relative to the land area it contained. This is referred to as area-weighted data in the present study.

Interpolation

Interpolation is a process whereby the values for cells with missing data are predicted from the values in the surrounding cells (Childs 2004). This creates a fine-scale continuous surface that is more visually gradational than grids across landscapes. In this study, a point was generated for the geographic centre of each grid square and the value for that square was assigned to the point. ArcGIS 9.2 Spatial Analyst extension was then used to interpolate the data (ordinary kriging method, spherical semivariogram model, with a search radius of 12 points) across the study area, with an output cell size of 1 km^2. For a detailed explanation of interpolation techniques and algorithms, see de Smith *et al.* (2013).

Extrapolation of grid data to land management units

After calculating the area-weighted values for the grid squares, the GIS layer was converted from vector (polygon) to raster cell (or pixel) format. To translate the data from grid cells to land management units, the mean of the grid squares that fell within the land management unit was calculated and assigned to that land management unit (see example in Figure 3). This process was completed using the zonal statistics tool in the Spatial Analyst extension of ArcGIS 9.2.

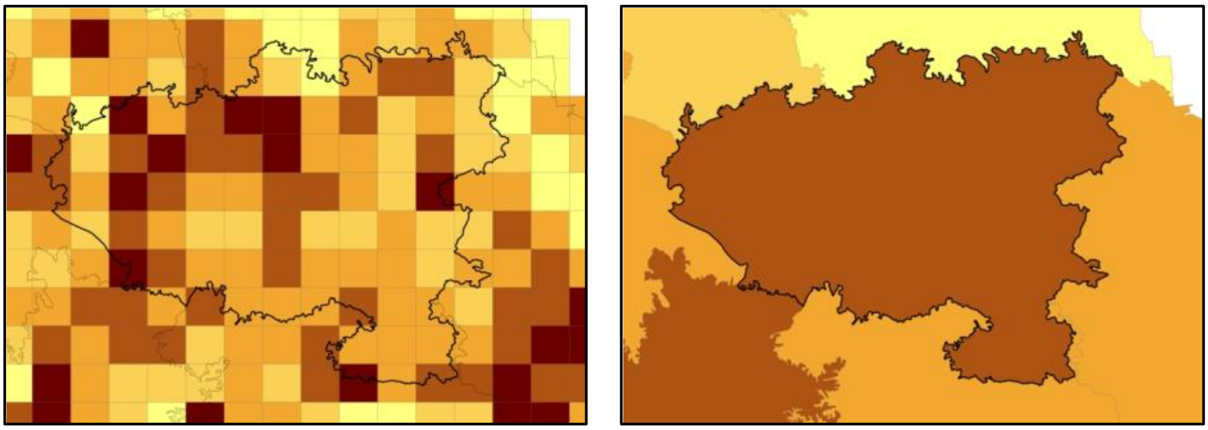


Figure 3 Example of grid data (left) extrapolated as the mean of the values for the overlaying land management unit (right). For clarity, only the graduated colours, and not their corresponding values, are shown.

The land management units used in this study were Landscape Conservation Units (LCUs), which were defined for the south-west forest by Mattiske and Havel (2002), to reflect recurrent patterns of landform and broad vegetation with similar underlying geology, landform, soil and climate and at a scale appropriate to management planning and operational practice. The codes for the Landscape Conservation Units are listed in Table 1 and shown in Figure 4. For full details of the classifications and characteristics of the LCUs, refer to Mattiske and Havel (2002).

Table 1 Codes for Landscape Conservation Units.

Landscape Conservation Unit	Code
Abba Plain	AP
Blackwood Plateau	BP
Blackwood Scott Plain	BSP
Central Blackwood	CB
Central Jarrah	CJ
Central Karri	CK
Collie Wilga	CW
Dandaragan Plateau	DP
Darkin Towering	DT
Eastern Blackwood	EB
Eastern Dissection	ED
Eastern Murray	EM
Frankland Unicup Muir Complex	FUM
Margaret Plateau	MP
Monadnocks Uplands and Valleys	MUV
North Eastern Dissection	NED
North Western Dissection	NWD
North Western Jarrah	NWJ
Northern Karri	NK
Northern Sandy Depression	NSD
Northern Upper Collie	NUC

Landscape Conservation Unit	Code
Northern Upper Plateau	NUP
Redmond Siltstone Plain	RSP
South Eastern Upland	SEU
Southern Dunes	SD
Southern Hilly Terrain	SHT
Southern Karri	SK
Southern Swampy Plain	SSP
Strachan Cattaminup Jigsaw	SCJ
Yornup Wilgarup Perup	YWP

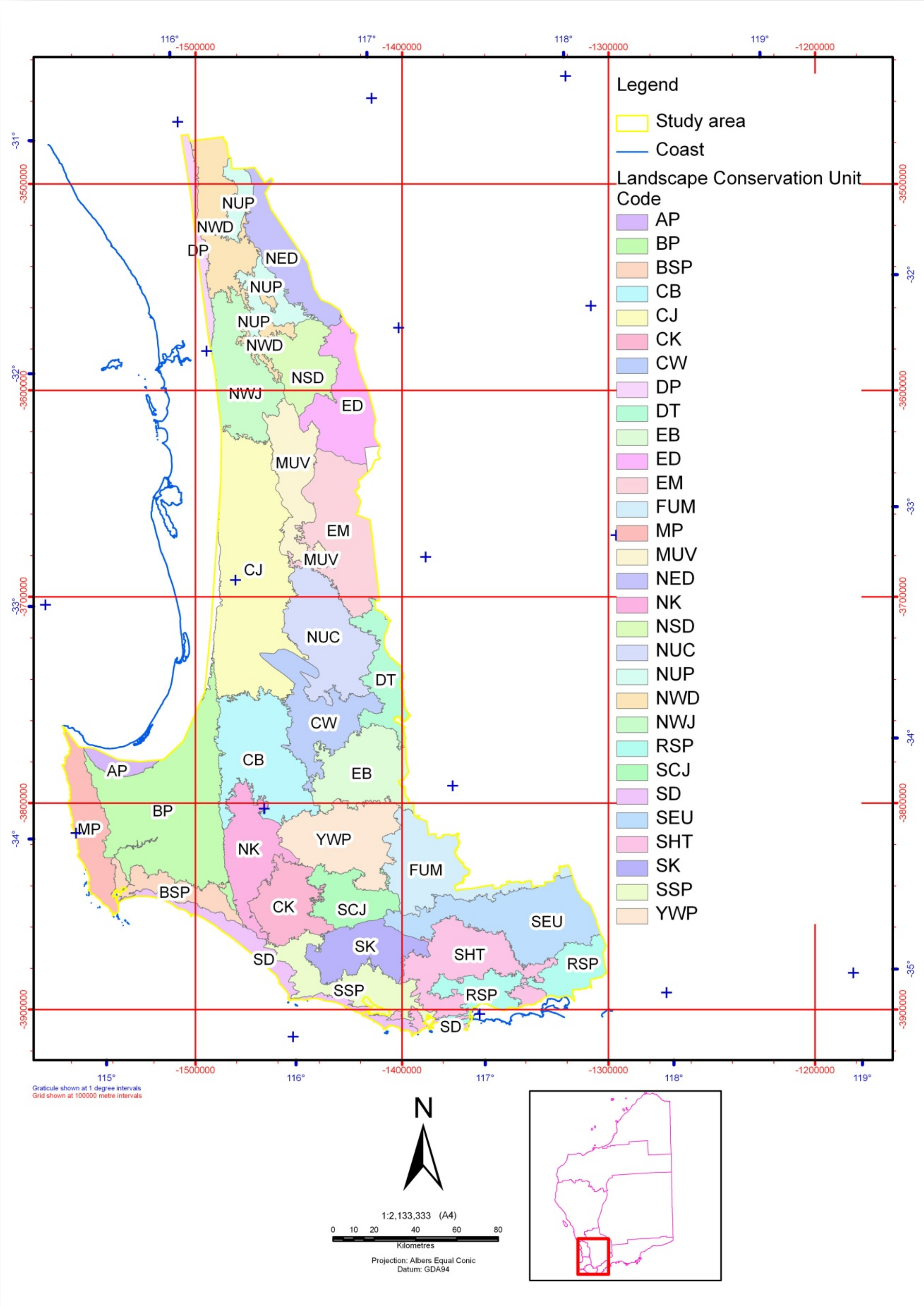


Figure 4 Landscape Conservation Units, developed by Mattiske and Havel (2002) and used for multi-criteria analysis in this study.

Multi criteria analysis

Multi-criteria analysis is a spatial modelling technique whereby layers of information are overlaid and calculations are used to classify grid cells or land management units according to set criteria. There are many approaches to multi-criteria modelling (Chakhar and Mousseau 2008; Drobne and Lisec 2009; Malczewski *et al.* 2010) and it is a technique commonly applied to assist in conservation and forestry management decision making (Mendoza and Martins 2006; Diaz-Balteiro and Romero 2008). The basis for combining multiple data layers in this study is described below.

Spatial layers can only be combined into a multi-criteria model if they are in an equitable spatial and data format. Thus, each layer must have the same datum, projection, grid squares or land units and the data they contain must be categorised into similar classes. A simplified example of this process is shown in Figure 5, where two layers, one with decimal data (between 0 and 0.5) and one with whole numbers (between 0 and 50) are re-scaled into equitable classes from 1 to 5. The layers can then be overlaid and arithmetic calculations can be used to rank the extent to which grid squares or land management units meet the criteria set for the model. Re-scaling of the data changes the format from numeric / continuous to numeric / categorical format and for this reason, the numeric values are no longer meaningful. This is why the resulting spatial datasets do not have numerical values but are ranked e.g. from 1 to 5, low (light) to high (dark).

This study used Multi-criteria Analysis Shell (MCAS-S) spatial decision support software (BRS 2011), which automates the process of matrix overlay calculation and multi-criteria modelling (Lesslie *et al.* 2008). It also has an advantage over standard GIS software, because all the layers in the model can be displayed concurrently and any changes made to the model are immediately updated and 'live' displayed (Lesslie *et al.* 2008).

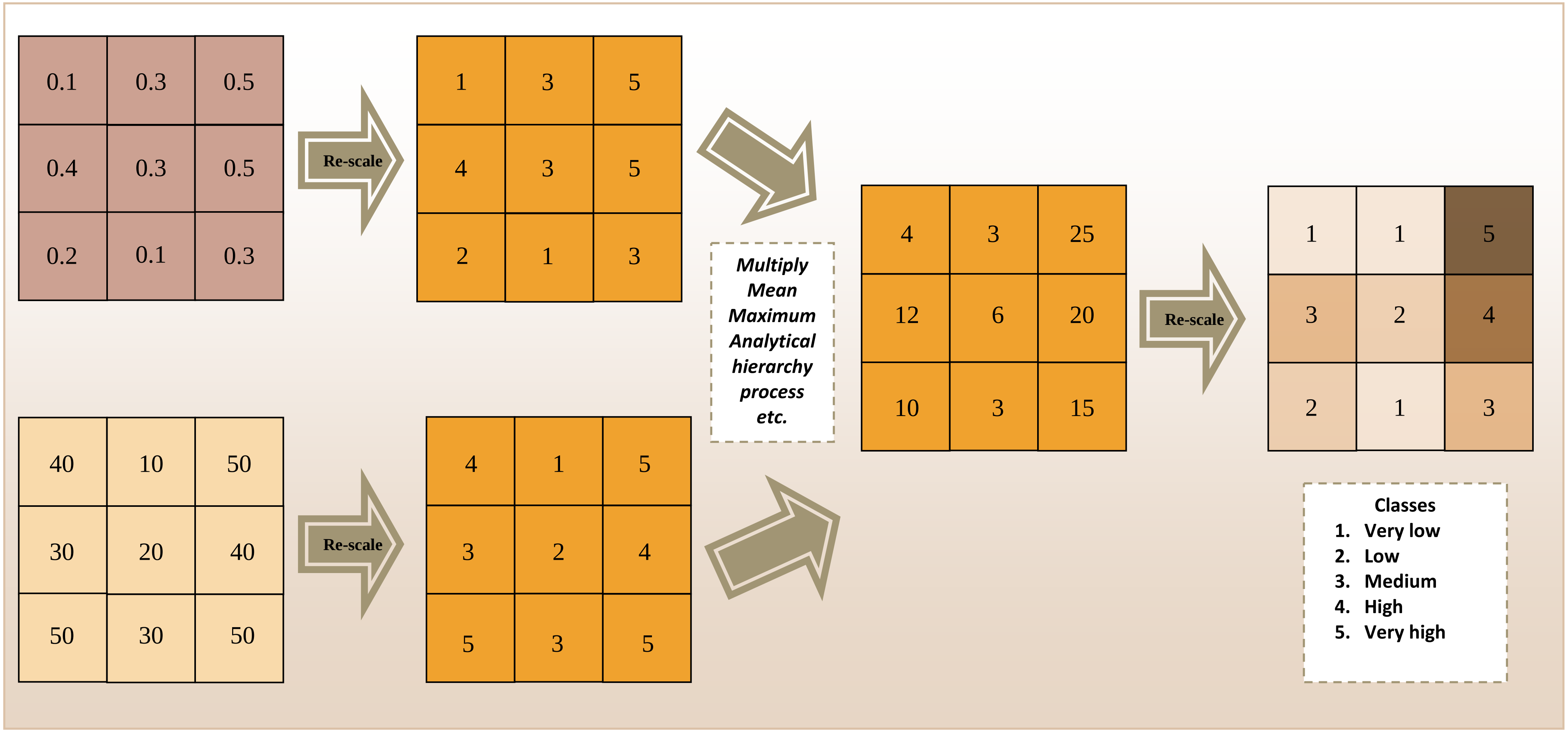


Figure 5 Simplified schematic diagram of the matrix overlay calculation process used to combine data layers with different formats into a multi-criteria model.

2 Biodiversity surveys

2.1 Introduction

A biodiversity survey gap analysis was undertaken to identify parts of the south-west forest that have not previously been well sampled. The review was not exhaustive, but included as many projects as possible that could be collected and processed over a period of two years. Information on biodiversity survey projects was documented in a relational database and spatial datasets for the projects were collated into a geo-database. Data were then combined into a composite model to identify poorly surveyed Landscape Conservation Units. A gap analysis for geophysical parameters was also conducted, to identify predictors for low survey effort.

2.2 Methods

Information on biodiversity survey projects was collected from a range of sources, including the DPAW Science Division library, journals and the internet. Projects were defined as quantitative, on-site documentation of biodiversity at a defined geographic location. Manipulative experiments, reviews, monitoring of land rehabilitation, summaries (e.g. 'desktop' surveys) and collated species lists were not considered biodiversity surveys for the purposes of this study. The original project reports were obtained for each project to minimise the chances of repeatedly documenting projects subsequently included in reviews, conference proceedings and book chapters.

The projects documented in this study included baseline surveys, ongoing biodiversity monitoring, environmental impact assessments for proposed and expanding developments, natural resource condition monitoring, comparative studies, research projects and monitoring of the effects of environmental change on biodiversity. Projects had been conducted by state and local government departments, non-government organisations (natural resource management groups), community groups, universities, environmental consultants and individuals.

Each project was assigned an individual number and details of the project were entered into a relational database, including: year(s) in which the projects were conducted; type of project (survey, monitoring or research); purpose(s); target geographical locations; original datum used to document spatial data; references; methods used to document spatial data; project leader; technical expert, organisation and (where possible) current contact details.

Spatial information was obtained from the project leader, maps or written descriptions in the documentation. If these data were not available electronically, the information was determined using GIS, by overlaying a geographical data layer (e.g. land tenure), or using drawing tools and converting the graphics to GIS shape files.

Spatial information included points for co-ordinates of individual sampling or trap points, points for general locations, lines for transects and polygons for survey areas. The most detailed information available was obtained for each project, but if these were not documented, the general location or spatial area targeted was used. The spatial data were stored in a geo-database (Datum GDA 94, zone 50) linked to the project database and these data were used to calculate the number of units and locations for each project and the total length for lines and total hectares surveyed for each project. Summary statistics on biodiversity survey projects were prepared using queries in the relational database.

Spatial data-sets were recorded once for each project and not for each day or time those locations were surveyed, for two reasons. First, the documentation rarely contained sufficient detail to determine precise sampling effort (e.g. number of trap nights) and second, the aim was to ‘characterise’ the projects and their associated spatial data in a quantitative fashion to represent relative survey effort. For ongoing monitoring projects, each season or year of sampling was documented as a separate project, because each period of sampling would represent a separate opportunity to document biodiversity.

The study area was divided into 1,874 5km x 5km grid squares and Hawth’s Analysis Tools (Beyer 2004) were used to calculate the total number of units and locations and total kilometres of line surveyed in each grid square. A spatial union was used in ArcGIS 9.2 to calculate the total area surveyed per grid square. These data were then area-weighted to calculate units, locations, kilometres of line and area surveyed per 25 km^2 of land for each grid square to account for variation in the area of land falling within each grid square. The resulting grids were combined composite model into a using MCAS-S (BRS 2011) and data for units, locations, lines and areas were equally weighted. Relative survey effort was mapped by grid squares, interpolation and Landscape Conservation Units.

Categorical response models were used to determine which elements of forest ecosystem, seasonal rainfall, soil, geology, fire frequency and vegetation complex were predictors of low numbers of survey units (grid points, sampling points, observation points, and trap points) and, thus, were indicative of low survey effort. The project units were displayed as a layer in ArcGIS 9.2 along with layers for the geophysical datasets. Spatial joins were then used in to classify the sampling units by the spatial datasets shown in Table 6. Categorical response models were then used to identify predictors of low survey effort using JMP® 9 software (SAS Institute Inc.).

2.3 Results

A total of 395 projects were reviewed in the survey gap analysis and they had been conducted between 1932 and 2010 (Figure 6). The trend line in Figure 6 shows that the number of projects in operation each year increased significantly over time. The number of projects shown in operation during the latter years (i.e. 2008 to 2010) is likely to be lower than the actual number in operation, because publication of results often takes several years, and the documents for projects in these years were less likely to be available than for other years at the time of this study.

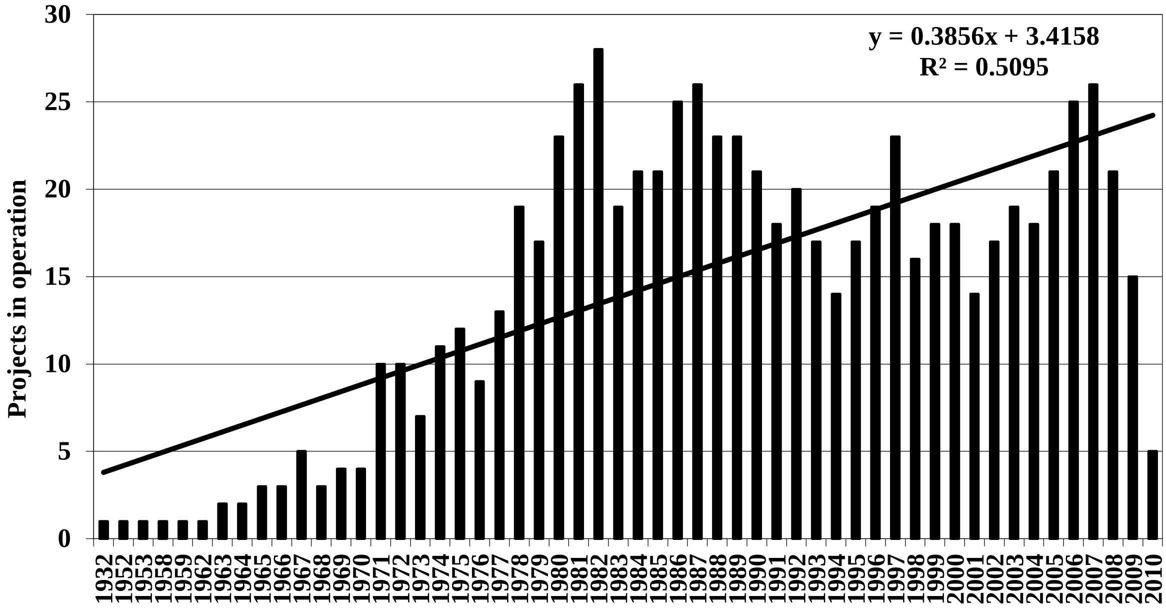


Figure 6 Number of projects in operation each year (*n* = 757) with linear trend line. Note that projects could be conducted over more than one year and this is why the cumulative number of projects in operation per year exceeds the total number of projects documented.

The primary subjects investigated were fauna (*n* = 157), vegetation and flora (*n* = 108), biodiversity (*n* = 93), conservation significant fauna (*n* = 21), cryptogams (*n* = 10) and conservation significant flora (*n* = 6). Projects fell into one of three categories: research (*n* = 28), monitoring (*n* = 149) and, most commonly, surveys (*n* = 218). The most commonly targeted taxa and topics were vegetation community, flora, vegetation condition and birds (Table 2).

Table 2 Taxa / topics targeted for biodiversity projects.

Taxa / topic	Number of projects
Vegetation community	175
Flora	138
Vegetation condition	89
Birds	83
Introduced flora	72
Freshwater invertebrates	54
Habitat characterisation	43
Conservation significant fauna	42
Freshwater fish	42
Conservation significant flora	41
Fauna	38
Vegetation cover	38
Vertebrates	36
Terrestrial invertebrates	35
Introduced fauna	30
Mammals	28
Cryptogams	19
Freshwater crayfish	17
Kangaroos	8
Frogs	4
Resource condition	3
Arboreal invertebrates	2
Commercial flora	2
Freshwater mussels	2
Freshwater turtles	2
Water rats	2
Benthic plants / algae	1
Spiders	1

The most common purposes identified for the projects were: survey biodiversity; compare biodiversity between habitats; assess conservation value; and study effects of water regime (Table 3).

Table 3 Purposes for biodiversity projects.

Purpose	Number
Survey biodiversity	115
Compare biodiversity between habitats	62
Assess conservation value	57
Study effects of water regime	33
Monitor population	32
Assess ecological water requirements	31
Study biology and ecology	23
Monitor outcomes of translocations	21
Monitor conservation value of roadside vegetation	19
Monitor effectiveness of forest management plan	17
Monitor birds in reserves and remnants	16
Assess impact of sand mining	15
Monitor effects of fire	14
Compare fire regimes	13
Assess impact of bauxite / alumina mining	12
Monitor effects of water flow regulation	12

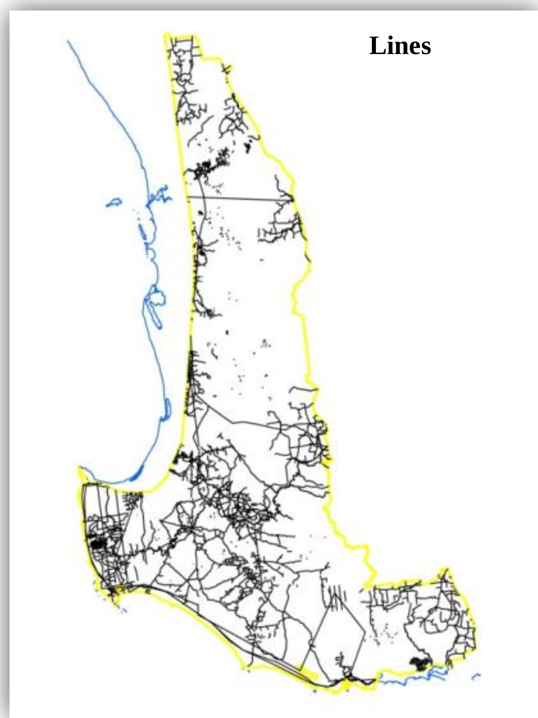
Purpose	Number
Study biology and ecology of single species	11
Monitor ecosystem health	10
Assess impact of heavy minerals mining	9
Monitor take for commercial harvest	9
Study effects of forestry	9
Assess threatening processes	8
Compare silvicultural treatments	8
Monitor impact of salinity	8
Assess impact of salinity	7
Study ecology of communities	7
Assess change in vegetation cover	6
Take from wild for laboratory research	6
Assess impact of reservoir	5
Assess impact of agricultural development	4
Assess impact of gold mining	4
Monitor effects of changes in groundwater	4
Assess impact of groundwater extraction	3
Assess impact of introduced species	3
Assess impact of urban development	3
Monitor effects of woodland management	3
Plan management of land use	3
Assess impact of dam construction	2
Assess impact of dieback (*Phytophthora cinnamomi*)	2
Assess impact of hard rock quarry	2
Assess impact of industrial development	2
Assess impact of peat mining	2
Assess impact of road construction	2
Assess impact of urea plant	2
Assess impact of weir	2
Assess land capability	2
Monitor effects of spring management	2
Assess endemism	1
Assess impact of biomass power plant	1
Assess impact of clay mining	1
Assess impact of clearing and sedimentation	1
Assess impact of fishing	1
Assess impact of irrigation slot boards	1
Assess impact of leaf skeletonizer *U. lugens*	1
Assess impact of seismic lines	1
Assess impact of water supply development	1
Assess impact wind farm	1
Monitor effects of cats	1
Monitor effects of revegetation	1
Study use of fishway	1

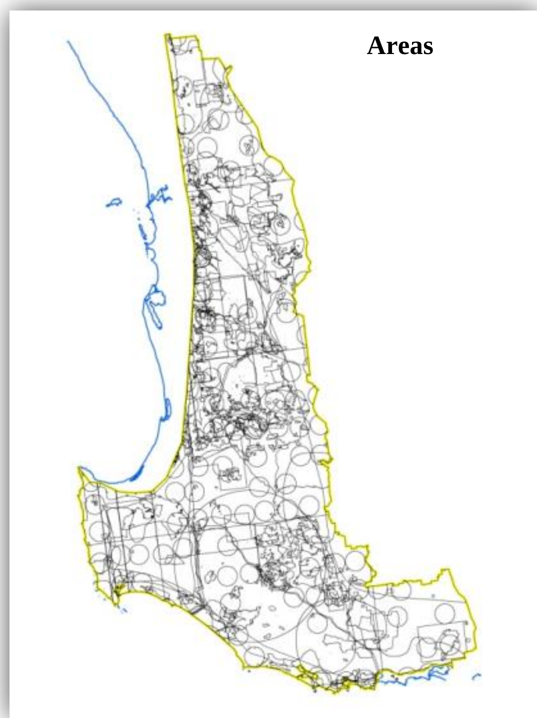
The spatial data collated for the projects included transects, roadsides, areas, quadrats, trap points, sampling (collection) points, observation points and general locations (Table 4). The means per project for the spatial data are shown in Table 4.

Table 4 Summary of spatial data for biodiversity projects (*n* = number of projects with the data type, s.e. = standard error).

Spatial data	Type	Mean per project	s.e.	*n*	Min.	Max.
Lines	Air transect	4.20	0.47	10	1	5
	Foot transect	37.97	10.80	61	1	469
	Roadside	60.79	13.20	19	2	180
	Transect	29.63	9.27	8	1	69
	Vehicle transect	1.00	0.00	3	1	1
Total line length (km)	Air transect	329.68	95.67	10	60.86	1,156.71
	Foot transect	33.05	13.82	61	0.13	780.51
	Roadside	299.75	63.25	19	0.17	1,073.05
	Transect	25.01	13.18	8	0.43	114.96
	Vehicle transect	11.78	3.43	3	6.39	18.14
Areas	Polygon	6.60	1.19	190	1	158
	Hectares	265,363	62,570	190	0.89	4,256,440
Units	Grid point	64.78	25.46	23	1	540
	Observation point	79.66	10.09	58	1	348
	Quadrat	45.93	9.29	42	1	335
	Sampling point	866.52	162.11	82	1	4419
	Trap point	64.78	25.46	23	1	540
Locations	Point	9.59	1.18	63	1	36

The lines, areas, units and locations surveyed in the biodiversity projects are shown in Figure 7, the relative magnitude of survey effort for the four data types is shown in Figure 8 and the composite model is shown in Figure 9. Relative survey effort for the study area is shown by grid squares in Figure 10 and interpolation in Figure 11.





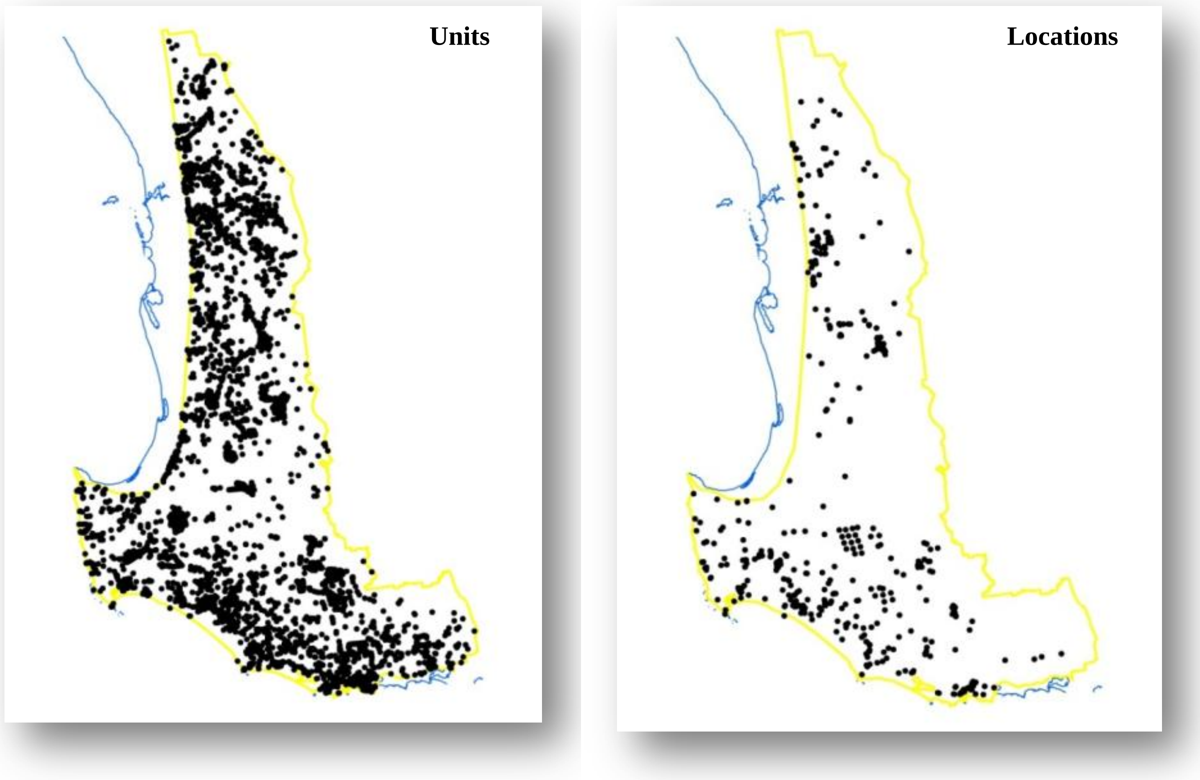
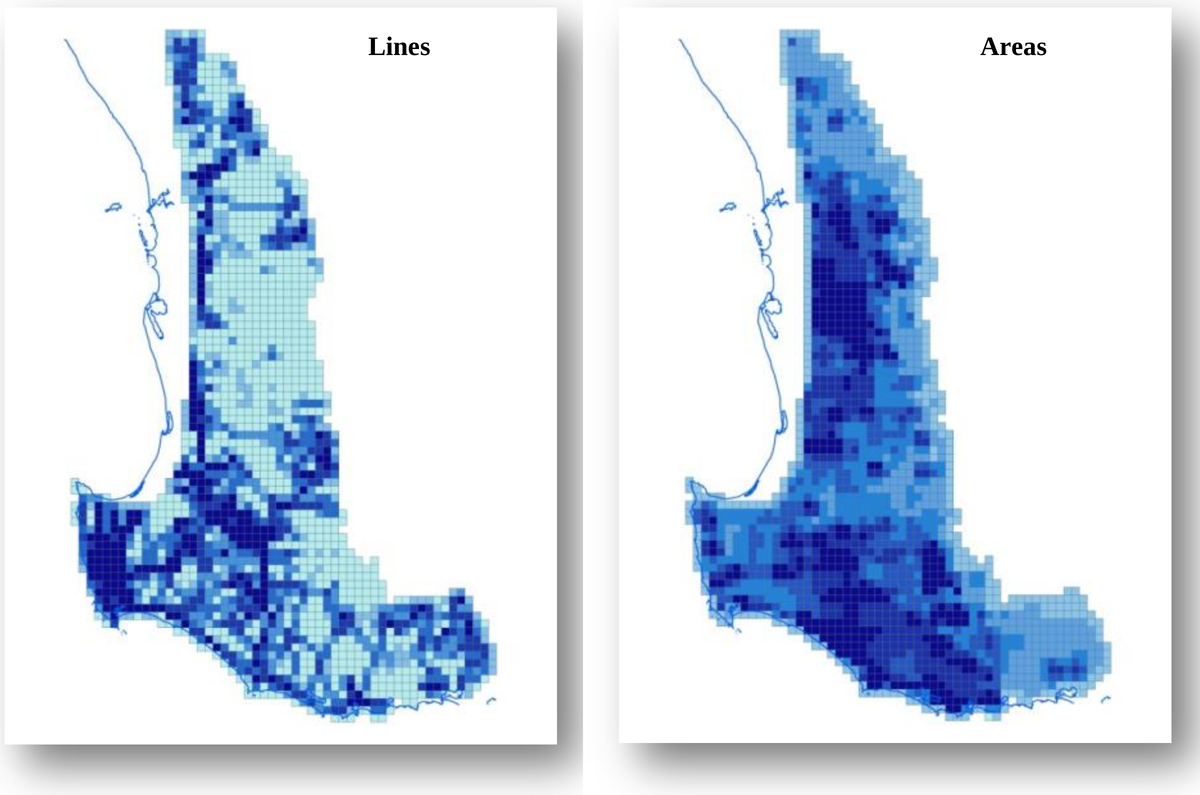


Figure 7 Spatial data collated for surveys conducted in the study area. Yellow shows study area and blue shows coast.



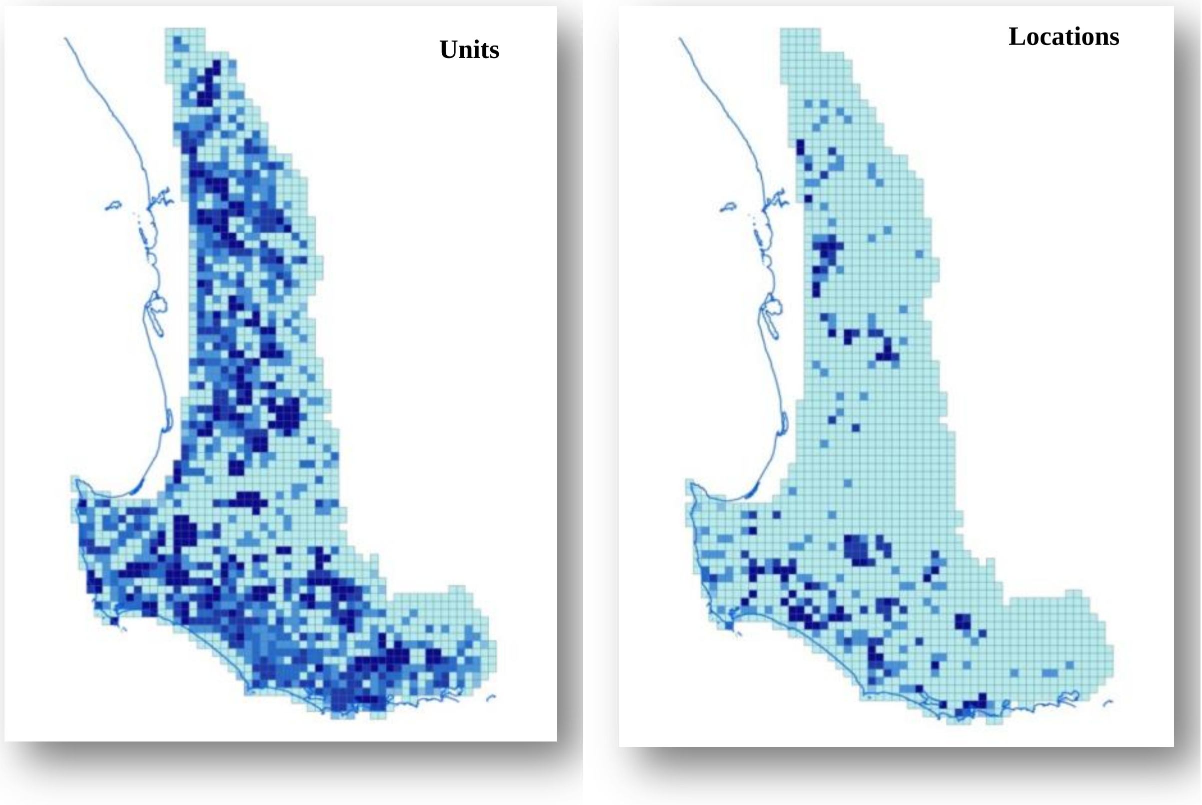


Figure 8 Relative survey effort for the four data types from light (low) to dark (high) by grid squares. Note that the lightest blue shows grid squares with no observations.

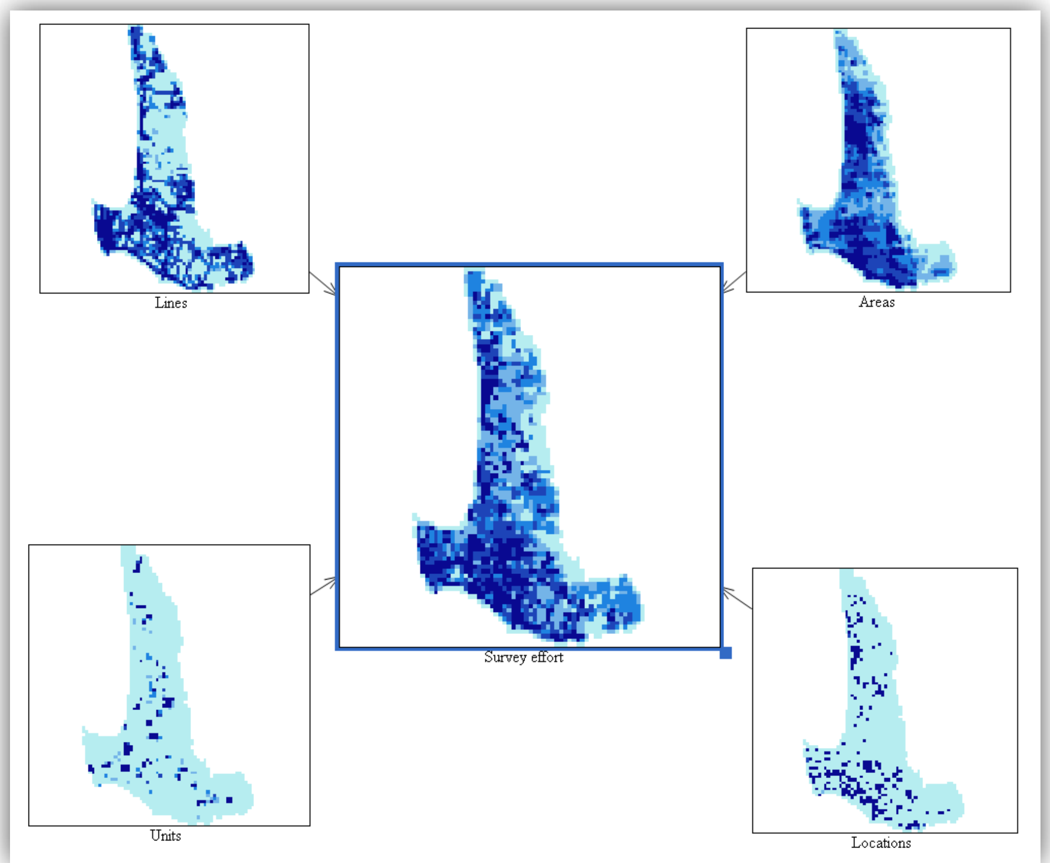


Figure 9 Composite model for relative survey effort from light (low) to dark (high) by grid squares.

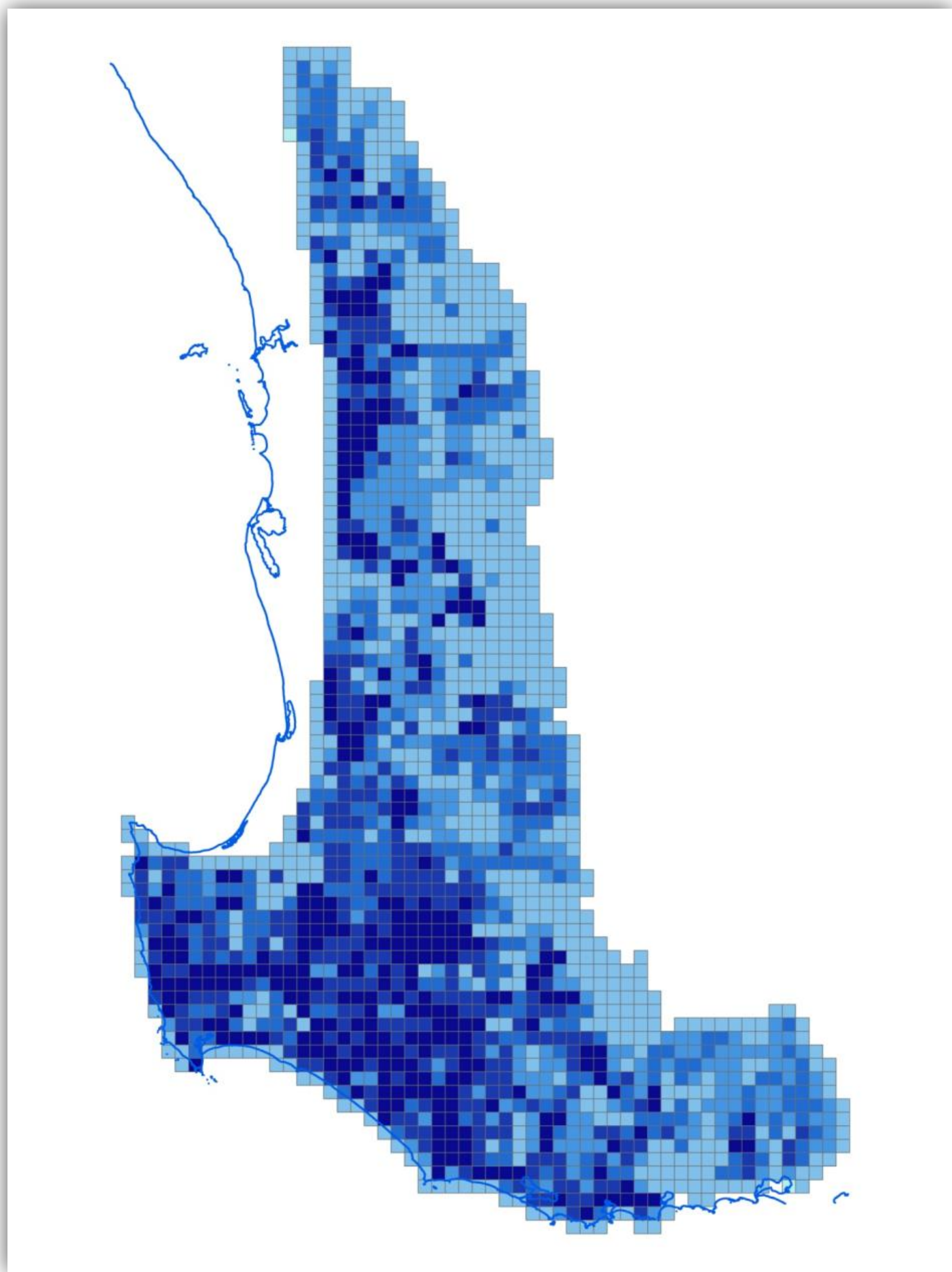


Figure 10 Relative survey effort from light (low) to dark (high), by grid squares.

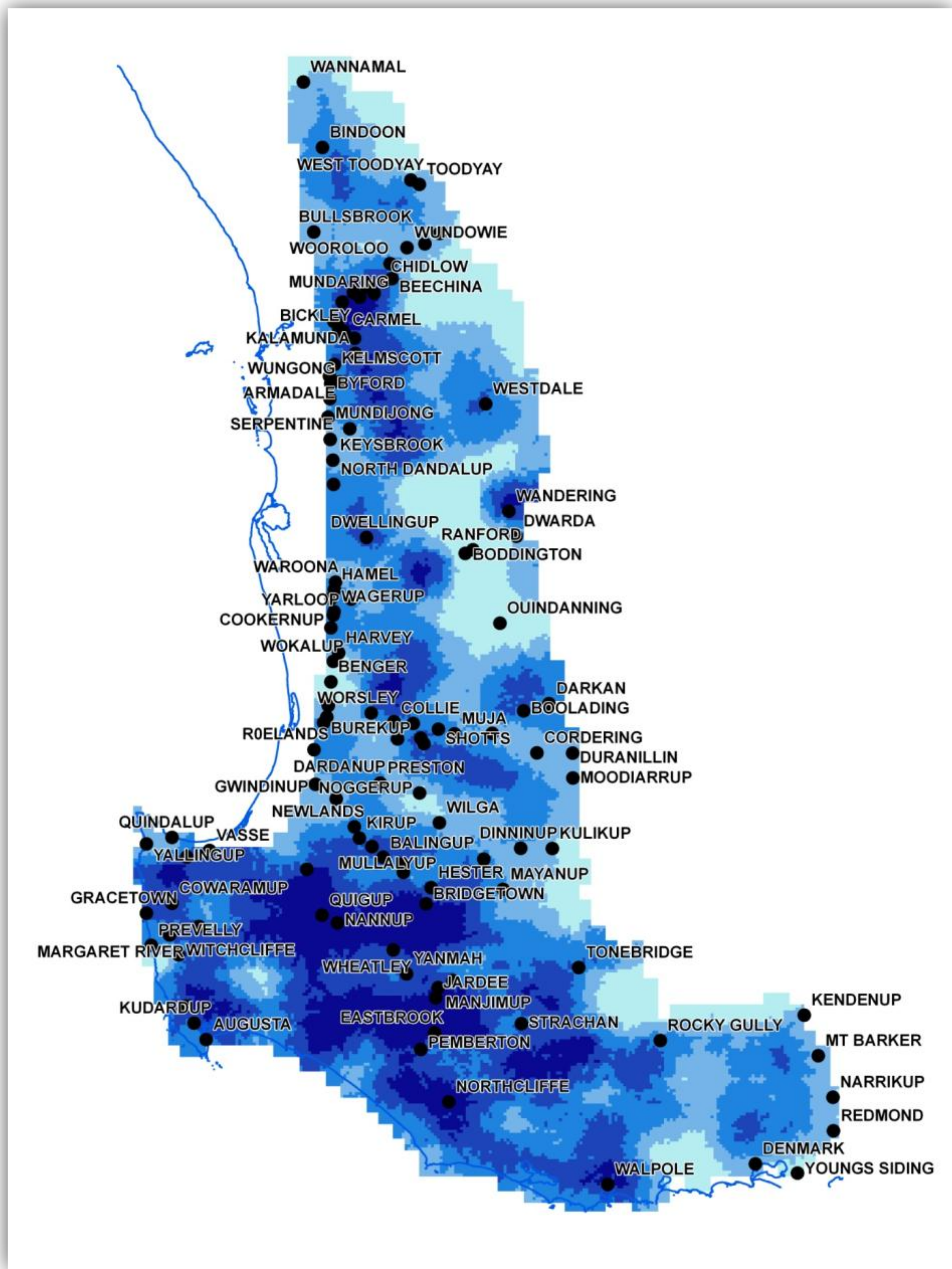
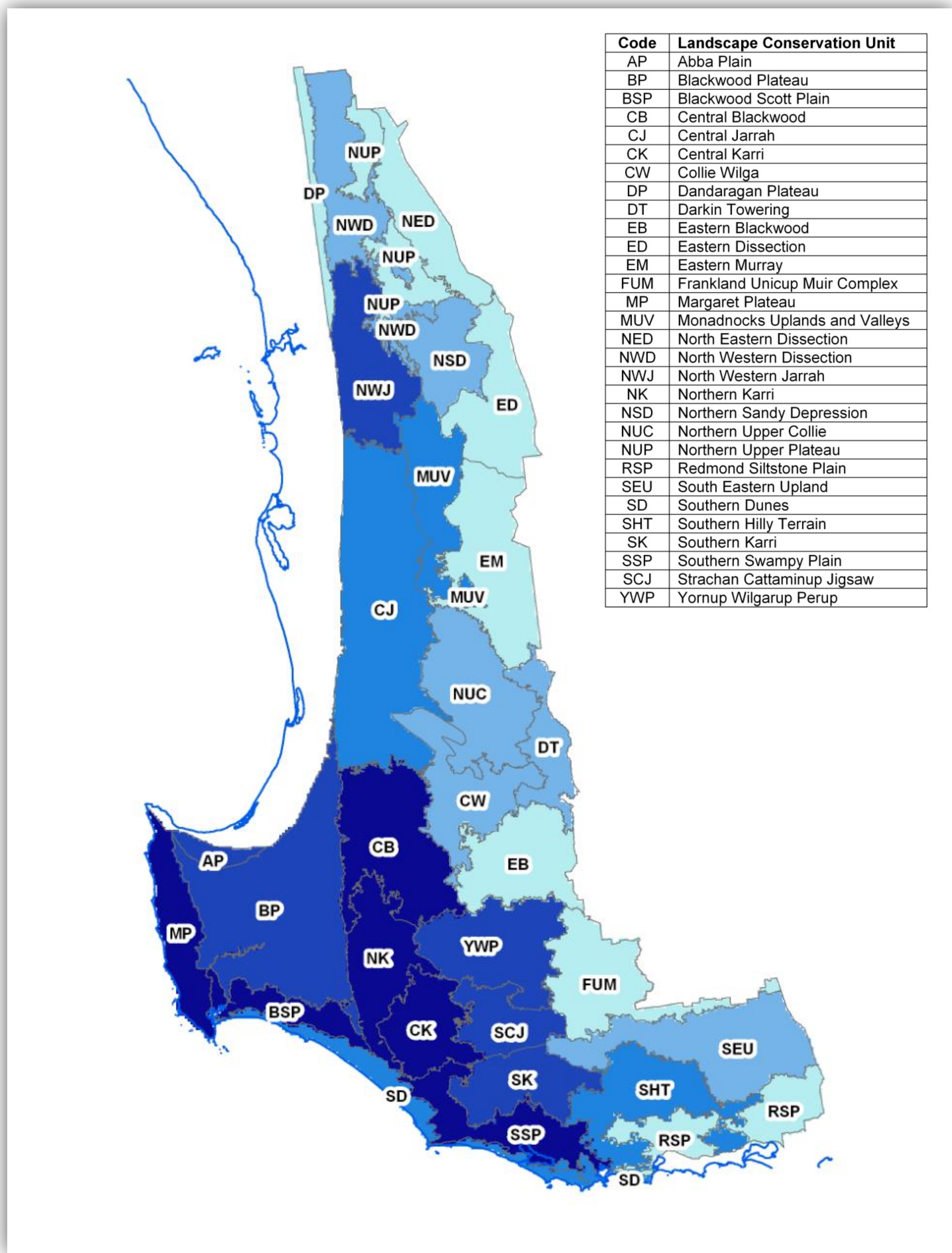


Figure 11 Relative survey effort shown with towns from light (low) to dark (high) by interpolation.

Table 5 shows the area-weighted statistics for the survey data for Landscape Conservation Units and the composite model for survey effort is shown for LCUs in Figure 12. With the exception of Dandaragan Plateau, LCUs with the lowest survey effort were primarily on the eastern margins of the study area, including Northern Upper Plateau, North Eastern Dissection, Eastern Murray, Eastern Blackwood, Frankland Unicup Muir Complex, and Redmond Siltstone Plain (Figure 12).

Table 5 Area-weighted survey data for Landscape Conservation Units.

Land Conservation Unit		per 10,000 hectares or 100 km^2			
Name	Size (Ha)	Area (Ha)	Line length (km)	Locations	Units
Abba Plain	23,033	105,937	86,023	1.74	24.75
Blackwood Plateau	367,646	118,932	44,516	2.58	754.23
Blackwood Scott Plain	63,149	126,611	72,086	13.62	72.84
Central Blackwood	208,244	117,427	57,707	1.30	316.94
Central Jarrah	394,140	134,500	19,306	1.32	129.04
Central Karri	101,315	142,147	34,571	2.07	78.57
Collie Wilga	134,104	108,898	10,754	0.15	330.12
Dandaragan Plateau	37,747	109,633	21,026	3.71	28.08
Darkin Towering	79,182	98,897	42,208	0	1.77
Eastern Blackwood	142,691	106,235	24,724	0	1.54
Eastern Dissection	136,358	98,895	18,784	0.07	8.95
Eastern Murray	191,021	105,745	0	0.47	13.98
Frankland Unicup Muir Complex	151,097	107,816	11,023	0.73	100.40
Margaret Plateau	101,650	124,152	108,257	1.77	171.77
Monadnocks Uplands and Valleys	122,010	135,803	1,623	2.21	107.29
North Eastern Dissection	110,538	95,944	20,197	0.18	10.58
North Western Dissection	161,000	106,789	21,300	0.31	76.77
North Western Jarrah	155,197	125,852	27,438	3.09	105.16
Northern Karri	126,172	140,070	21,055	2.46	147.97
Northern Sandy Depression	100,364	118,329	5,245	0.20	50.81
Northern Upper Collie	179,306	115,727	7,833	0.11	590.16
Northern Upper Plateau	88,714	100,168	11,801	0.56	316.52
Redmond Siltstone Plain	120,100	109,791	16,025	0.58	12.16
South Eastern Upland	212,358	95,796	26,187	0.05	102.42
Southern Dunes	80,077	146,824	32,173	0.50	43.58
Southern Hilly Terrain	172,601	120,106	19,898	1.39	227.69
Southern Karri	109,299	130,739	11,948	1.28	15.65
Southern Swampy Plain	117,861	137,144	26,136	4.33	19.26
Strachan Cattaminup Jigsaw	82,277	129,115	18,342	1.46	30.63
Yornup Wilgarup Perup	166,047	127,677	24,737	1.69	169.11



Code	Landscape Conservation Unit
AP	Abba Plain
BP	Blackwood Plateau
BSP	Blackwood Scott Plain
CB	Central Blackwood
CJ	Central Jarrah
CK	Central Karri
CW	Collie Wilga
DP	Dandaragan Plateau
DT	Darkin Towering
EB	Eastern Blackwood
ED	Eastern Dissection
EM	Eastern Murray
FUM	Frankland Unicup Muir Complex
MP	Margaret Plateau
MUV	Monadnocks Uplands and Valleys
NED	North Eastern Dissection
NWD	North Western Dissection
NWJ	North Western Jarrah
NK	Northern Karri
NSD	Northern Sandy Depression
NUC	Northern Upper Collie
NUP	Northern Upper Plateau
RSP	Redmond Siltstone Plain
SEU	South Eastern Upland
SD	Southern Dunes
SHT	Southern Hilly Terrain
SK	Southern Karri
SSP	Southern Swampy Plain
SCJ	Strachan Cattaminup Jigsaw
YWP	Yornup Wilgarup Perup

Figure 12 Relative survey effort from light (low) to dark (high) by Landscape Conservation Units.

The relative contribution of geophysical parameters to survey effort for units (n = 79,094), including frequency and probability values, are shown in Appendix 1; poorly surveyed parameters were those with a probability value of < 0.05 and are shown in bold. A summary of habitat parameters with relatively low survey effort is shown in Table 6, except for vegetation complexes, which are too numerous to list here, but are shown in Appendix 1. For more information on the sources of, and descriptions for, the parameters, refer to the metadata on the associated spatial datasets shown in Table 6.

Table 6 Summary of habitat parameters with relatively low survey effort for units (for definition of units, refer to Table 4).

Parameter (meta data for spatial datasets)	Relatively low survey effort
Forest Ecosystem (Department of Parks and Wildlife, Forest Ecosystems, 31 Dec 2011, 1:50,000)	Wandoo, Darling Scarp, Whicher Scarp, rocky outcrops, sand dunes and coastal habitats, karri, tingle and some jarrah habitats, peppermint and coastal heathland.
Seasonal rainfall (Bureau of Meteorology, Seasonal Rainfall for Australia, 09 Aug 2005)	Drier areas with winter dominant rainfall 500-800mm.
Soil (Department of Agriculture and Food WA, 01 Nov 2009, Atlas of Australian soils 1967, 1:2,000,000)	Soils associated with rivers, swamps, valleys and dunes.
Geology (Geological Survey of Western Australia, 30 Jun 2003, Regolith Map (500 meter grid) of Western Australia, 1:500,000)	Aeolian sandplain, (alluvium in drainage channels, floodplains, and deltas; Lacustrine deposits, including lakes, playas, and fringing dunes); water; coastal deposits, including beaches and coastal dunes.
Fire frequency (Department of Parks and Wildlife, Number of times burnt between 1937 and 2012)	Very long and very short values.
Vegetation complex (Department of Conservation and Land Management, 01 Sep 1996, 1: 50,000)	Refer to Appendix 1.

2.4 Discussion

The primary purpose of this survey gap analysis was to identify poorly surveyed geographic areas in the south-west forest by reviewing historical survey information. Assuming the sample of projects in this study is representative, there was a significant increase in the number of biological surveys being conducted in the study area over time. This suggests that the need to, or requirement for, gathering knowledge about biodiversity in the forest has grown steadily during that period. The reasons for this are likely to include the growing human population requiring more land and resources and thus, the associated need for impact assessments, biodiversity surveys and monitoring of resource condition for conservation management and planning. Alternatively, it may be that more information about biological surveys has been documented and made publically available over time.

The primary project type was fairly evenly spread between fauna, biodiversity and flora, but within these, the most common taxa / topics targeted were vegetation community, flora, vegetation condition and birds. This suggested that the projects primarily targeted taxa and topics that were readily documented and processed and thus, time and cost effective to study. Freshwater taxa were, by contrast, relatively poorly surveyed, probably because they are labour intensive and time consuming to study and samples require significant post-processing and specialised expertise for identification (particularly macro-invertebrates). Freshwater taxa, therefore, might be considered a priority for additional survey.

The categorical response model for geophysical landscape characteristics identified a number of fine scale parameters that were poorly surveyed in the study area. These were primarily drier areas with mean annual rainfall 500-800 mm, short and long intervals since last fire, riparian, rocky, wetland and coastal habitats and forest ecosystems including tingle, bullich, yate, sand dunes, wandoo, Darling Scarp, swamps, peppermint and coastal heath. There are limitations to modelling the geophysical characteristics of survey units, such as the accuracy and quality of data used in the analyses. Nevertheless, the model presented here should provide some general guidelines for selecting landscape characteristics that have, to date, been poorly surveyed.

This survey gap analysis demonstrated that the western parts of the study area were relatively well surveyed and the eastern parts of the study area were relatively poorly surveyed. There may be a number of reasons for this, including lower vegetation cover, lower biodiversity and fewer developments in the east and thus, less need for biological survey and impact assessment. These factors will be assessed in the following part of the report and the outcomes of the analyses will be combined with survey effort in the final composite model.

3 Species richness

3.1 Introduction

Indices of species richness were used to estimate biodiversity for a range of taxonomic groups in the study area. These were combined into a composite model to give equal weight to each group and to examine variation in combined species richness across the study area. Species accumulation curves and related indices were used to assess the adequacy of survey for each taxonomic group.

Data from the Western Australian biodiversity 'atlas', Naturemap, were used to map species richness across the study area. Naturemap is the largest biological database in Western Australia and the benefits of using it for analyses of richness are that the data are quality controlled and synonyms for taxa are centrally managed using a unique identification number for each recognised taxa.

Collated databases like Naturemap provide a practical means of assessing biodiversity for large geographic areas, but they are characterised by spatially biased and incomplete patterns of observation (Soberón and Peterson 2004; Robertson *et al.* 2010). A number of non-parametric richness species estimates have been developed to overcome these limitations (Colwell and Coddington 1994). These use frequency counts and data on rare and infrequent species, to estimate the number of undetected species (Chao 2005; Chao *et al.* 2009). Species richness estimates are therefore, an effective means for representing regional diversity (Magurran 2004) and there are a range of diversity indices that all yield similar results (Colwell and Coddington 1994).

Species accumulation curves represent sample-based rarefaction (Mao *et al.* 2005) or expected species richness (Ugland *et al.* 2003). These can be used to assess adequacy of survey or completeness of species detection (Colwell *et al.* 2004), since the curve approaches asymptote when a high proportion of species present have been detected (Colwell and Coddington 1994). The ratio of observed to expected taxa has also been used as a measure of completeness of survey (García Márquez *et al.* 2012) and both methods were used in this study to assess adequacy of survey for taxa in the study area.

3.2 Methods

The Naturemap database was launched in 2007 and records are imported on an ongoing basis, as time and resources permit. Co-ordinates for observations of biodiversity (taxa) were obtained on 16 March 2012 and data from 1980 to 2010 (inclusive) were used for the analyses to represent 'current' species richness. The data were from a range of sources, including: Birds Australia Atlases; BugBase (south-west forest insect reference collection); dieback surveys; fauna survey returns (licenses to take fauna); FORESTCHECK; Salinity Action Plan; Swan Coastal Plain survey; WA Seabirds; Mammals on WA Islands; Orchid Atlas of WA; Threatened Fauna Database; Declared Endangered Flora Database; WA Herbarium Specimen Database; and the WA Museum Specimen Database (Naturemap Data Directory, accessed 16 March 2012).

The study area was divided into 5km x 5km grid cells and each grid cell was assigned an individual number. The observational data were clipped to the study area with a 10km buffer to ensure that each grid square represented an equal area surveyed (i.e. 25 km^2), because some of the grid squares extended beyond the edge of the study area. Observational data points were then assigned a grid cell number using a spatial join in ArcGIS 9.2. Grid referenced data were then exported to Microsoft Excel and pivot tables were used to count the number of taxa observed for each grid square for each taxonomic group.

The software package EstimateS (Colwell 2009) was used to calculate the species richness estimations. Bootsrap and jackknife estimators were selected for use in this study, because they are effective for estimating richness and rarity across landscapes (Colwell and Coddington 1994). The second-order jackknife estimator (Burnham and Overton 1978, 1979) is more accurate for taxa with a relatively small number of quadrats sampled and the bootstrap estimator is more accurate for taxa with a relatively large number of quadrats sampled (Smith and van Belle 1984). Thus, in this study, second-order jackknife (Jackknife 2) was used where half or fewer of the grid squares contained observations and Bootsrap was used where more than half the grid squares contained observations (Table 7). See Colwell (2004) and Colwell (2009) Appendix A for the species richness index equations used.

Species richness for each grid square was mapped for aquatic species (fish and freshwater invertebrates), birds, cryptogams, dicotyledons, mammals, monocotyledons, reptiles and amphibians and terrestrial invertebrates. Only those species with 'current' names recognised on the Western Australian Museum and Herbarium species lists (current synonyms) were included in the analysis for birds, dicotyledons, fish, mammals, monocotyledons and reptiles and amphibians. However, recognised but as yet un-named species were included for invertebrates and cryptogams due to the large number of observations for which the taxonomy had yet to be resolved.

The resulting species richness layers were combined in a matrix overlay model in MCAS-S (BRS 2011) to calculate combined richness across the study area. Each group of species was given equal weight in the model. Estimated species richness was mapped by grid squares, interpolation and Landscape Conservation Units.

EstimateS software (Colwell 2009) was used to compute the expected species accumulation curves (Mau Tau), with 95% confidence intervals for each taxonomic group. See Colwell (2004) and Colwell (2009) Appendix A for the Mau Tau equations used in the calculations. The accumulation curves, and the ratio of observed to estimated taxa (after García Márquez *et al.* 2012), were used to assess completeness of survey for each group of taxa in the study area.

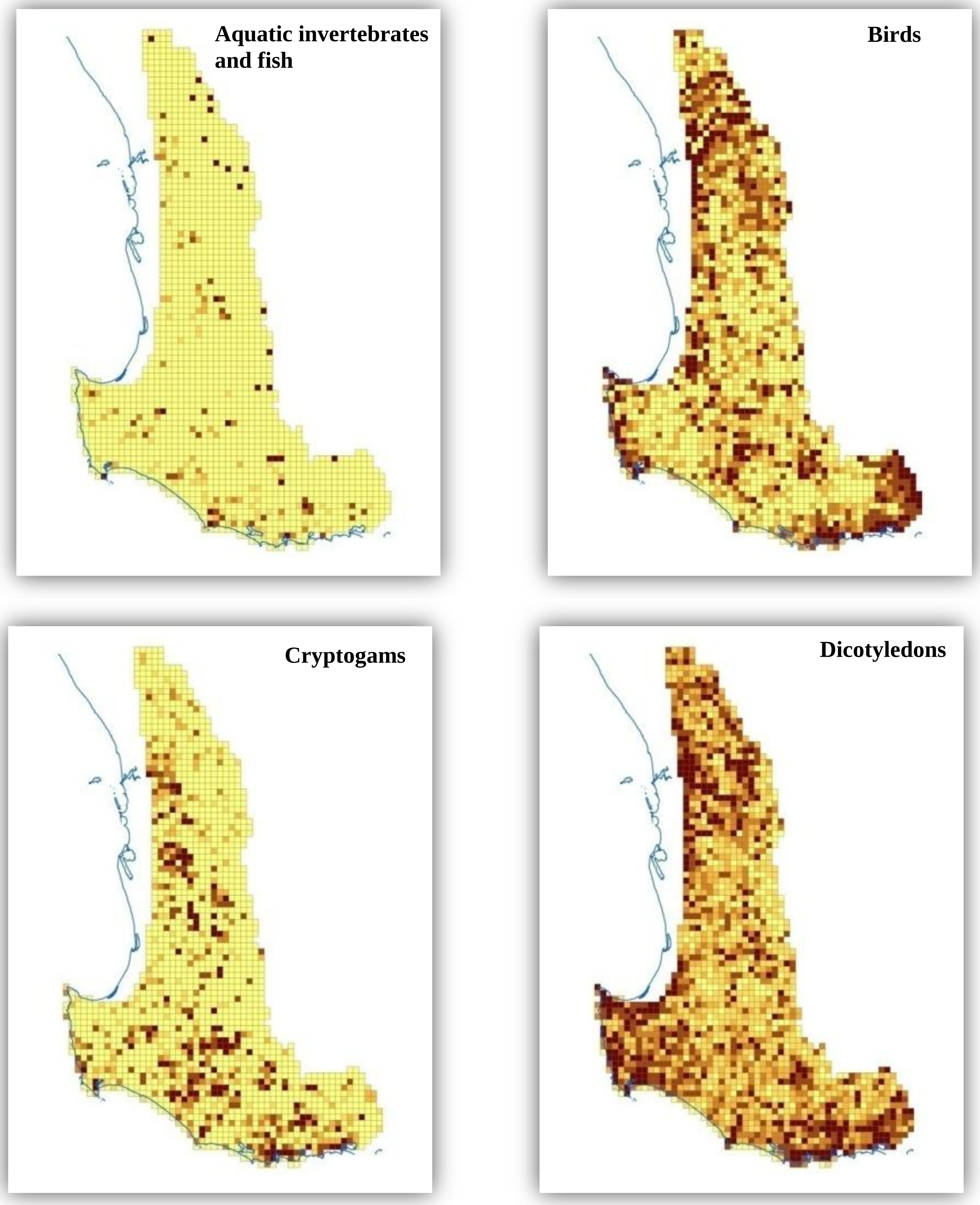
3.3 Results

The total number of taxa in the Naturemap biodiversity dataset for this study was 11,643 (Table 7). Geographic coverage for the observations was relatively low for aquatic invertebrates and fish, cryptogams, mammals and terrestrial invertebrates and relatively high for birds, dicotyledons, monocotyledons and reptiles and amphibians (Table 7). Completeness of survey was relatively low for aquatic invertebrates and fish, cryptogams, mammals and terrestrial invertebrates and relatively high for birds, dicotyledons, monocotyledons and reptiles and amphibians (Table 7).

Table 7 Index used to calculate species richness for each group of taxa, grid squares (*n* = 1,874) with observations and index of survey completeness (observed / expected taxa).

Group	Species richness index	Grid squares with observations		Taxa		Completeness of survey
		n	%	Observed	Estimated	
Aquatic invertebrates and fish	Jackknife 2	274	14.6	429	798	0.54
Birds	Bootstrap	1,220	65.1	328	363	0.90
Cryptogams	Jackknife 2	746	39.8	2,115	3,818	0.55
Dicotyledons	Bootstrap	1,698	90.6	2,695	3,423	0.79
Mammals	Jackknife 2	783	41.8	80	147	0.54
Monocotyledons	Bootstrap	1,423	75.9	1,025	1,093	0.94
Reptiles and amphibians	Jackknife 2	592	31.6	138	193	0.72
Terrestrial invertebrates	Jackknife 2	280	14.9	4,833	9,729	0.50

Figure 13 shows species richness for each group of taxa and Figure 14 shows the composite model of species richness for all groups. The resulting species richness model for the study area is shown by grid squares in Figure 15, interpolation in Figure 16 and Landscape Conservation Units in Figure 17. Landscape Conservation Units with the highest combined species richness were North Western Jarrah, Margaret Plateau, Abba Plain, Yornup Wilgarup Perup, Southern Hilly Terrain and Redmond Siltstone Plain (Figure 17).



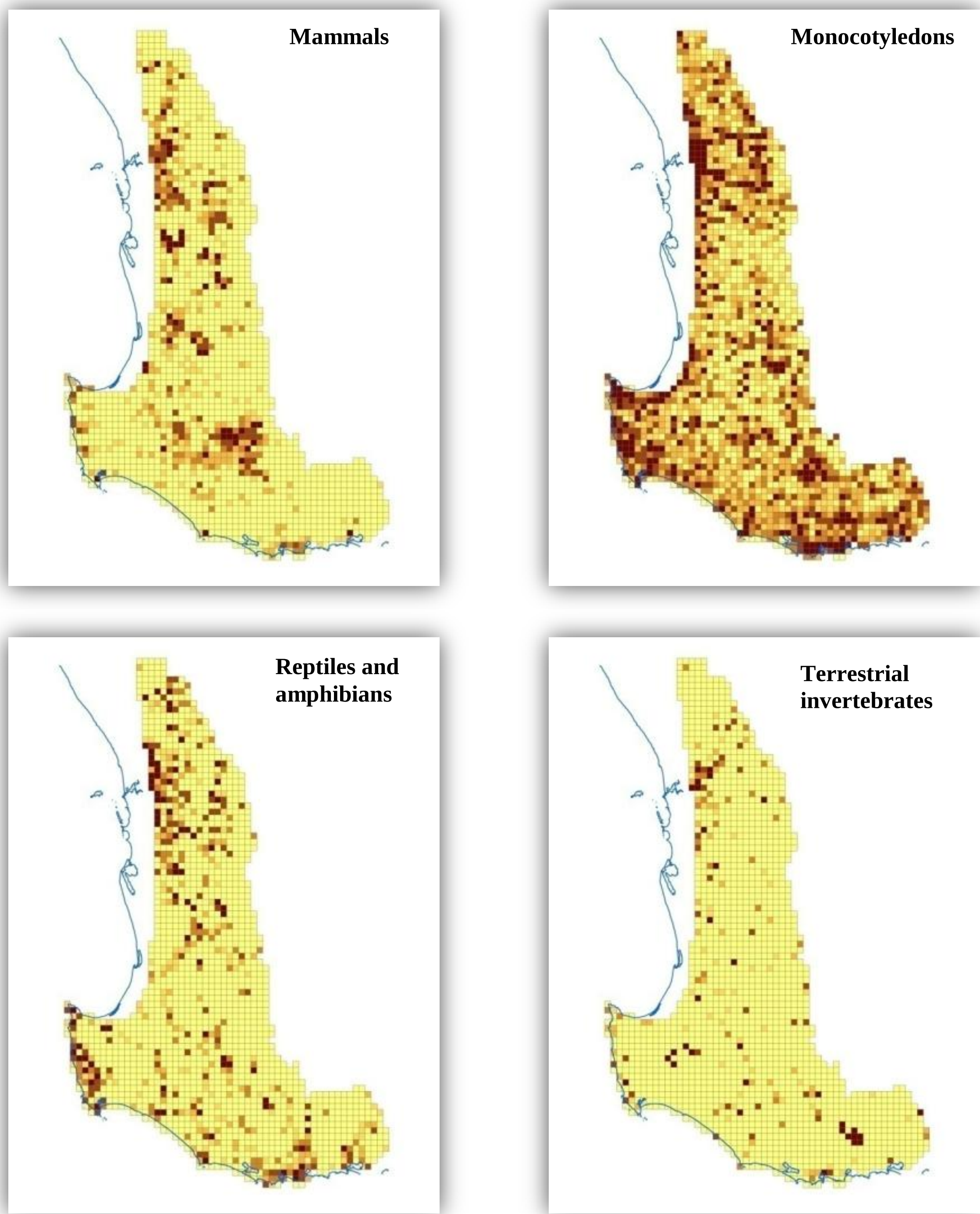


Figure 13 Species richness for eight groups of taxa, from light (low) to dark (high) by grid squares. Note that the lightest yellow shows grid squares with no observations.

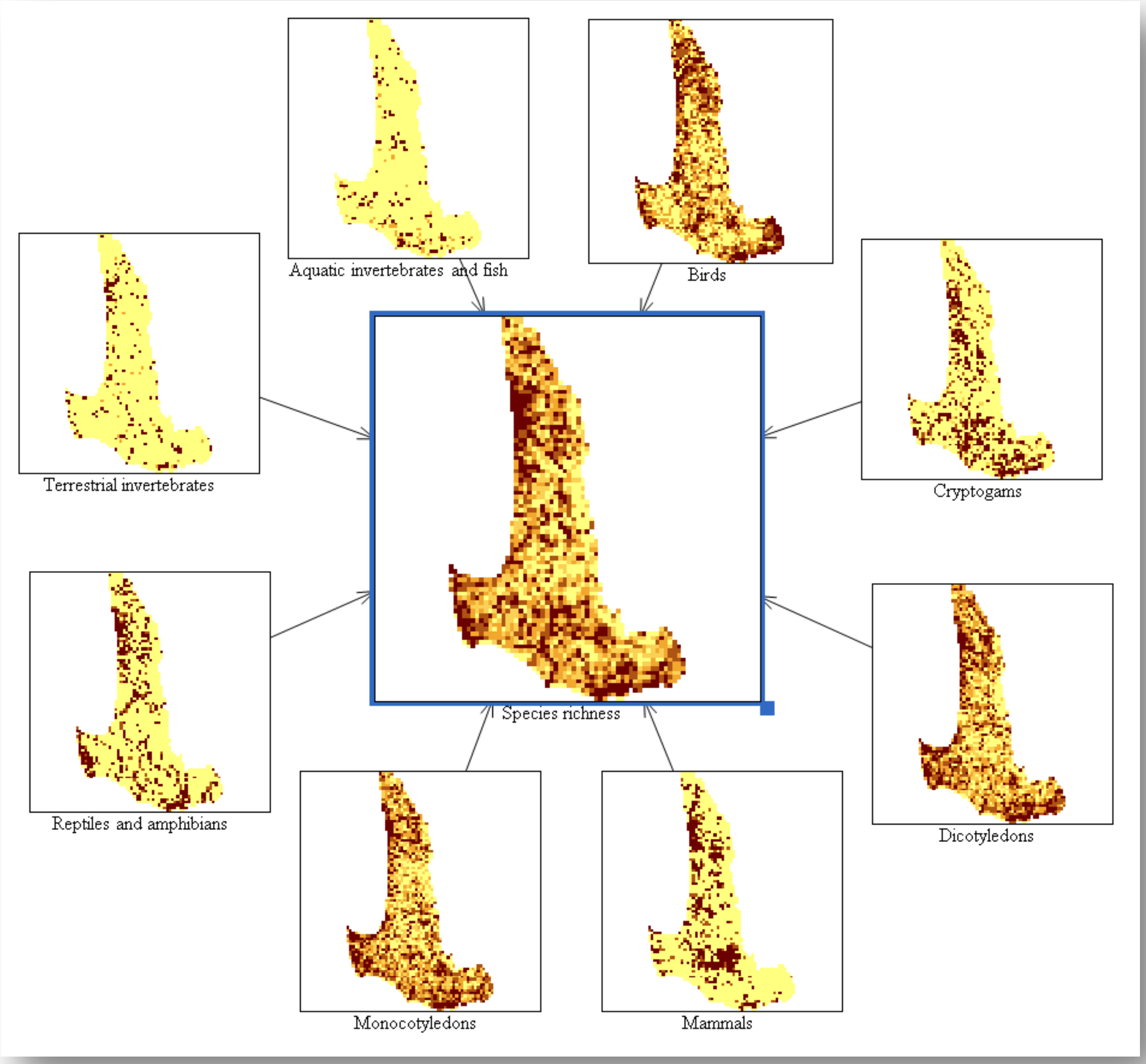


Figure 14 Composite model for species richness from light (low) to dark (high) by grid squares.

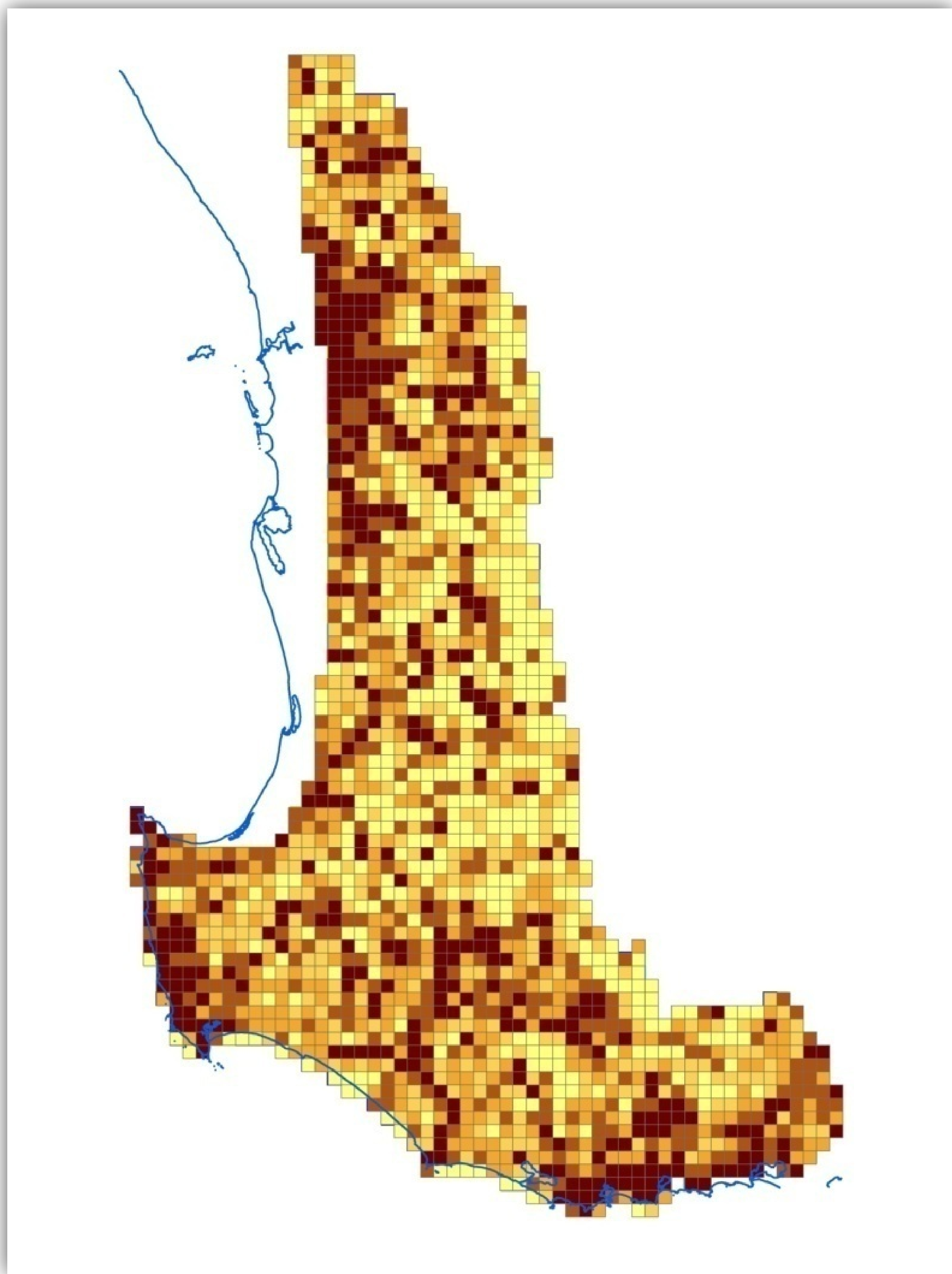


Figure 15 Relative species richness from light (low) to dark (high) by grid squares.

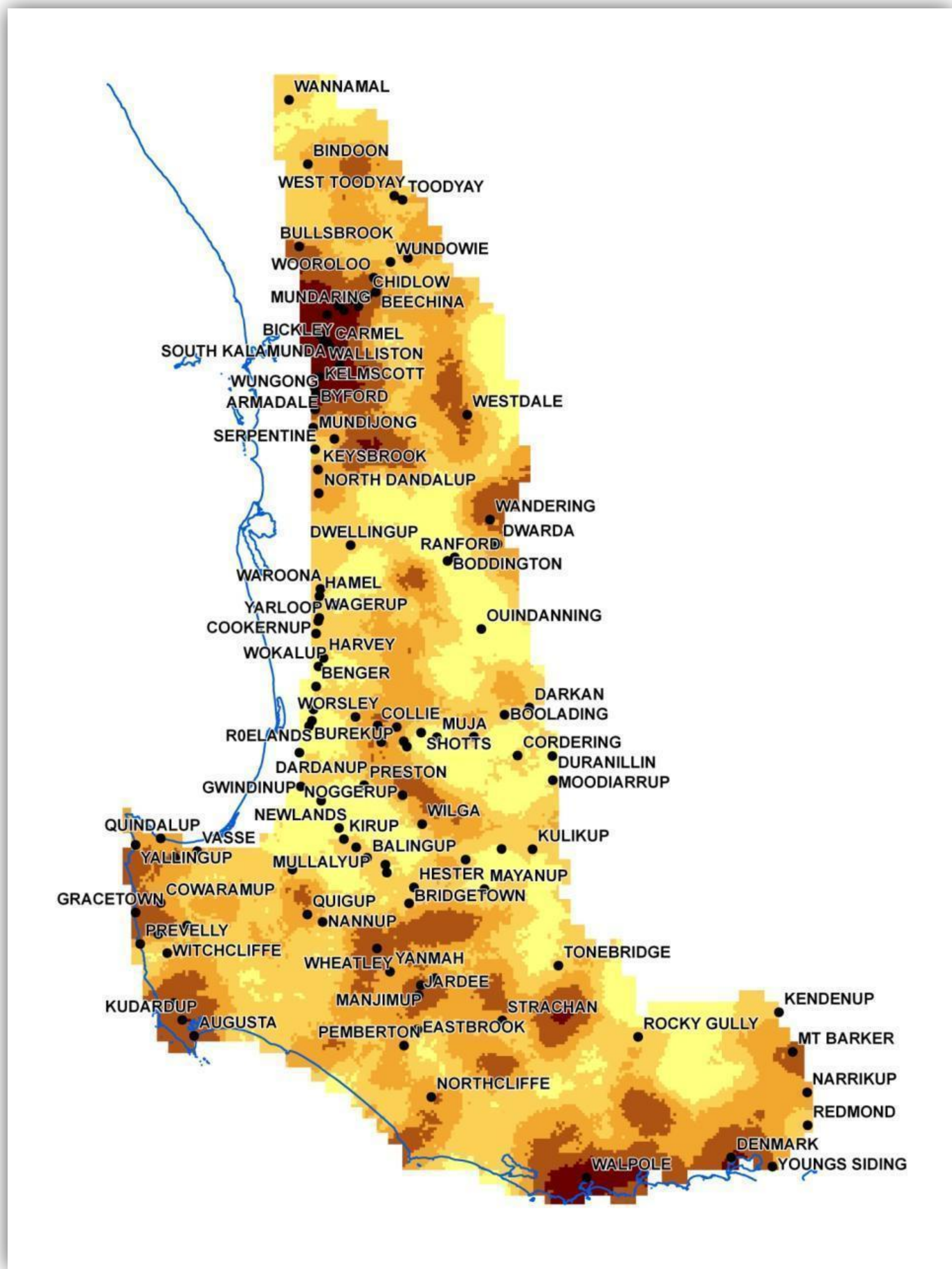
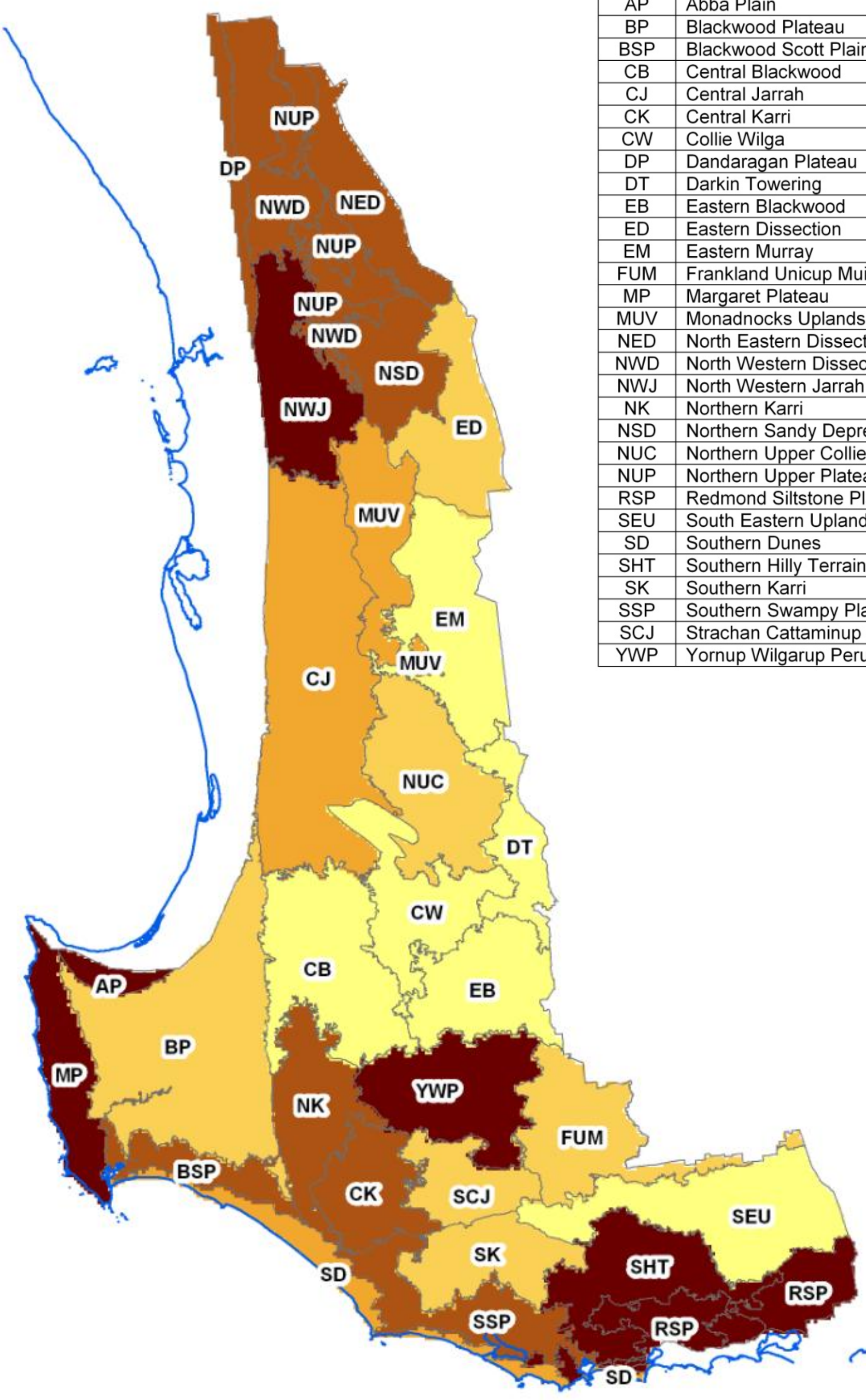


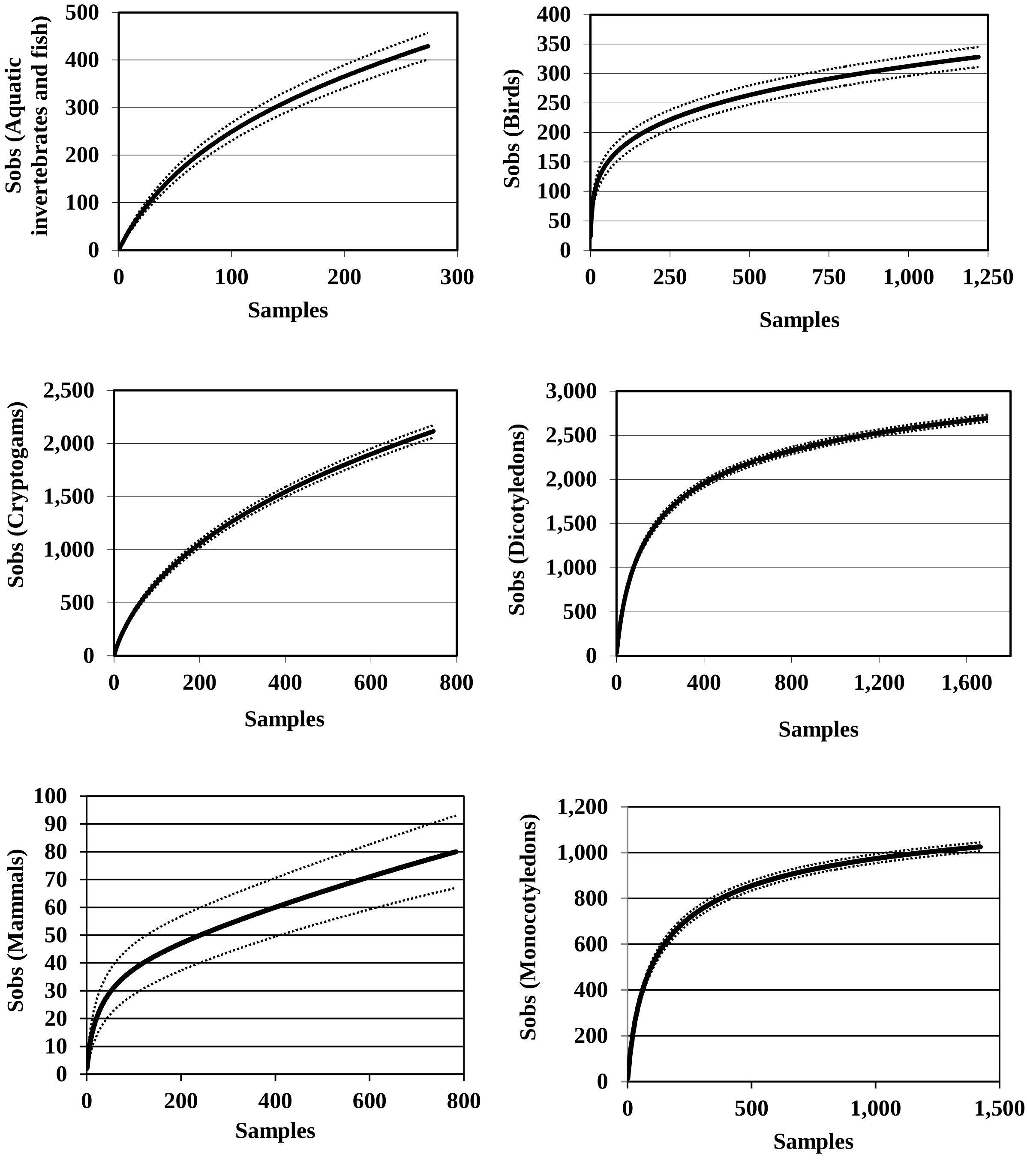
Figure 16 Relative species richness shown with towns from light (low) to dark (high) by interpolation.



Code	Landscape Conservation Unit
AP	Abba Plain
BP	Blackwood Plateau
BSP	Blackwood Scott Plain
CB	Central Blackwood
CJ	Central Jarrah
CK	Central Karri
CW	Collie Wilga
DP	Dandaragan Plateau
DT	Darkin Towering
EB	Eastern Blackwood
ED	Eastern Dissection
EM	Eastern Murray
FUM	Frankland Unicup Muir Complex
MP	Margaret Plateau
MUV	Monadnocks Uplands and Valleys
NED	North Eastern Dissection
NWD	North Western Dissection
NWJ	North Western Jarrah
NK	Northern Karri
NSD	Northern Sandy Depression
NUC	Northern Upper Collie
NUP	Northern Upper Plateau
RSP	Redmond Siltstone Plain
SEU	South Eastern Upland
SD	Southern Dunes
SHT	Southern Hilly Terrain
SK	Southern Karri
SSP	Southern Swampy Plain
SCJ	Strachan Cattaminup Jigsaw
YWP	Yornup Wilgarup Perup

Figure 17 Relative species richness from light (low) to dark (high) by Landscape Conservation Units.

The sample based species accumulation curves for birds, dicotyledons, monocotyledons and reptiles and amphibians reached relatively stable values of taxa detection, suggesting that a high proportion of species were included in the dataset (Figure 18). However, the curves for aquatic invertebrates and fish, cryptogams, mammals and terrestrial invertebrates did not stabilise entirely (Figure 18), suggesting these groups of taxa could be considered to be less adequately represented in the Naturemap dataset.



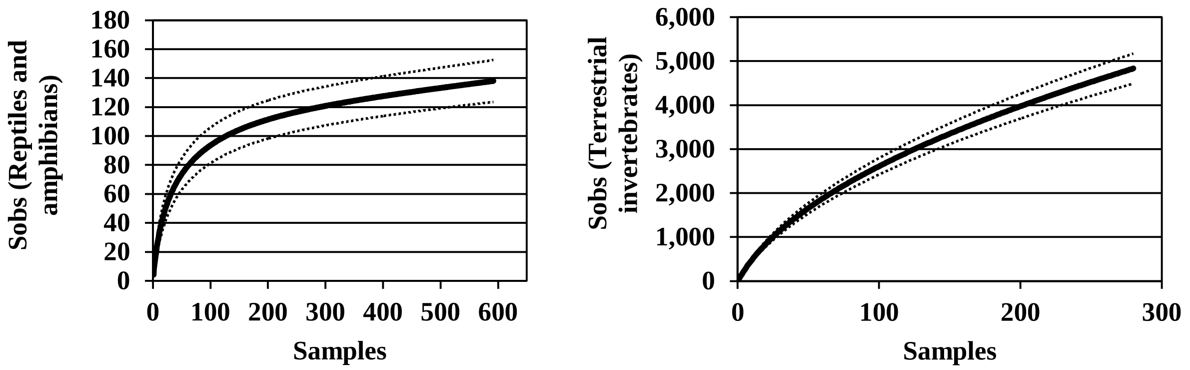


Figure 18 Sample based species accumulation curves for eight groups in the study area (Sobs = estimated observations; Mau Tau formula (Colwell *et al.* 2004)). Dashed lines show 95% confidence interval.

3.4 Discussion

The shape of sample-based species accumulation curves can vary with factors such as categories of taxa used in the estimates, taxa abundance and density (Chao *et al.* 2009), the modelling technique employed (Dengler 2008; Dengler 2009; Dengler and Oldeland 2010) and patterns of observation (Thompson and Withers 2003; Dengler and Oldeland 2010). They are, therefore, indicative of the completeness of species detection (Colwell *et al.* 2004).

The species accumulation curves and completeness of survey indices in this study suggested that, at the time the data were downloaded, the survey data were incomplete for aquatic invertebrates and fish, cryptogams, mammals and terrestrial invertebrates. There may be a number of reasons for this, including the number of studies targeting different groups of taxa, priorities for data migration into the Naturbase dataset and the purposes for conducting the surveys. For instance, the biodiversity data used in this analysis were collected between 1980 and 2010 (inclusive) to represent ‘current’ species richness. It may be that during that time, priorities have shifted from recording biodiversity across large spatial areas to impact assessments and resource condition monitoring. As a result the coverage of geographical areas and taxa targeted is likely to have become biased toward locations where human impacts are concentrated, threatened taxa and taxa that are most valued by the broader community.

These issues are common to all collated databases or ‘atlases’ (Soberón and Peterson 2004; Robertson *et al.* 2010) and the purpose of the jackknife and bootstrap and richness estimators used in this study is to overcome these kinds of limitations by estimating species richness for relatively poorly surveyed areas (Colwell and Coddington 1994; Chao *et al.* 2009). The resulting composite model of biodiversity for the study area identified a number of areas of high species richness including the northwest jarrah forest, Margaret Plateau, Abba Plain / Whicher Scarp, Warren Region and the south east of the study area. The patterns of species richness recorded in this study broadly concur with previous studies for mammals, reptiles and amphibians (How and Cowan 2006), plants (Gioia and Pigott 2000) and birds (Abbott 1999). All these studies were conducted at different scales and using different methods, however, which can influence the outcomes of the analyses (Hurlbert and Jetz 2007). The results of this species richness assessment will be added to the model in the final section of the report.

4 Risk

4.1 Introduction

A threat analysis was conducted to quantify the spatial influence of some of the factors that potentially threaten biodiversity in the study area. An environmental risk calculation tool (Schill and Raber 2008; Schill and Raber 2009) was used to model the combined impacts of populated areas, roads and mines.

4.2 Methods

The Nature Conservancy Protected Area Tools for ArcGIS 9.3 (Schill and Raber 2008) were used to produce an Environmental Risk Surface, which represents the cumulative impact of factors that can have a negative effect on biodiversity. Risk factors considered in this study included built-up areas, roads and active mines because these threats are likely to result in permanent removal of native vegetation, major disturbance of the soil profile, and significant change in the patterns of stream-flow and groundwater recharge.

Risk factors were added to ArcGis 9.2 as a layer and clipped with a 30 km buffer to the study area. Elements of these parameters were assigned intensities, influence distances and weights, after McPherson *et al.* (2008) and Schill and Raber (2008), based on the relationship between the threat and the ecosystem response to that threat (Table 8). Built-up areas (cities and towns) were assigned a convex decay pattern, because their influence is likely to gradually decline with distance and then decline sharply when the maximum distance of influence is reached. Roads were given a concave decay pattern, because the impact of roads is likely to decrease rapidly with distance from the road. Mines were given a linear decay pattern, because the influence would be likely to decline constantly over the distance of influence. Mines were weighted to have twice the impact of the other factors (Table 8), since in general, little or no habitat is retained, whereas built-up areas and roads can still retain habitat.

Table 8 Parameters used to create the Environmental Risk Surface for the study area.

Element (metadata)	Class	Decay	Intensity (%)	Influence distance (metres)	Weight
Built-up Areas (GeoScience Australia, Sep 2004, 1:250,000)	Towns and cities	Convex	95	500	1
Roads (GeoScience Australia Sep 2004, 1:250,000)	Principal Road (Sealed)	Concave	30	60	1
	Secondary Road (Sealed)		15	60	1
	Minor Road (Sealed Unsealed)		10	30	1

Element (metadata)	Class	Decay	Intensity (%)	Influence distance (metres)	Weight
	Track (Unsealed)		5	30	1
Mines (Minedex, Department of Mines and Petroleum, 4 Nov-2011)	Alumina, base metal, construction material, energy, industrial mineral, iron, precious metal, specialty metal, steel alloy metal, other (non-minerals)	Linear	50	1,000	2

The Environmental Risk Surface tool was used to calculate an index of intensity for each element in the model to calculate aggregate risk across the study area (Schill and Raber 2008). After the risk surface had been calculated, the zonal statistics tool of the spatial analyst extension for ArcGIS 9.2 was used to calculate the area-weighted mean risk (or impact) value for grid squares. The results were mapped by grid squares, interpolation and Landscape Conservation Units.

4.3 Results

Spatial data for the built-up areas, mines and roads included in the calculation of the Environmental Risk Surface are shown in Figure 19 and the composite risk surface is shown in Figure 20. Mean risk for the study area is shown by grid squares in Figure 22, interpolation in Figure 23 and Landscape Conservation Units in Figure 24. LCUs with the greatest risk were Dandaragan Plateau, North Eastern Dissection, North Western Jarrah, Eastern Dissection, Eastern Murray and Margaret Plateau (Figure 24).

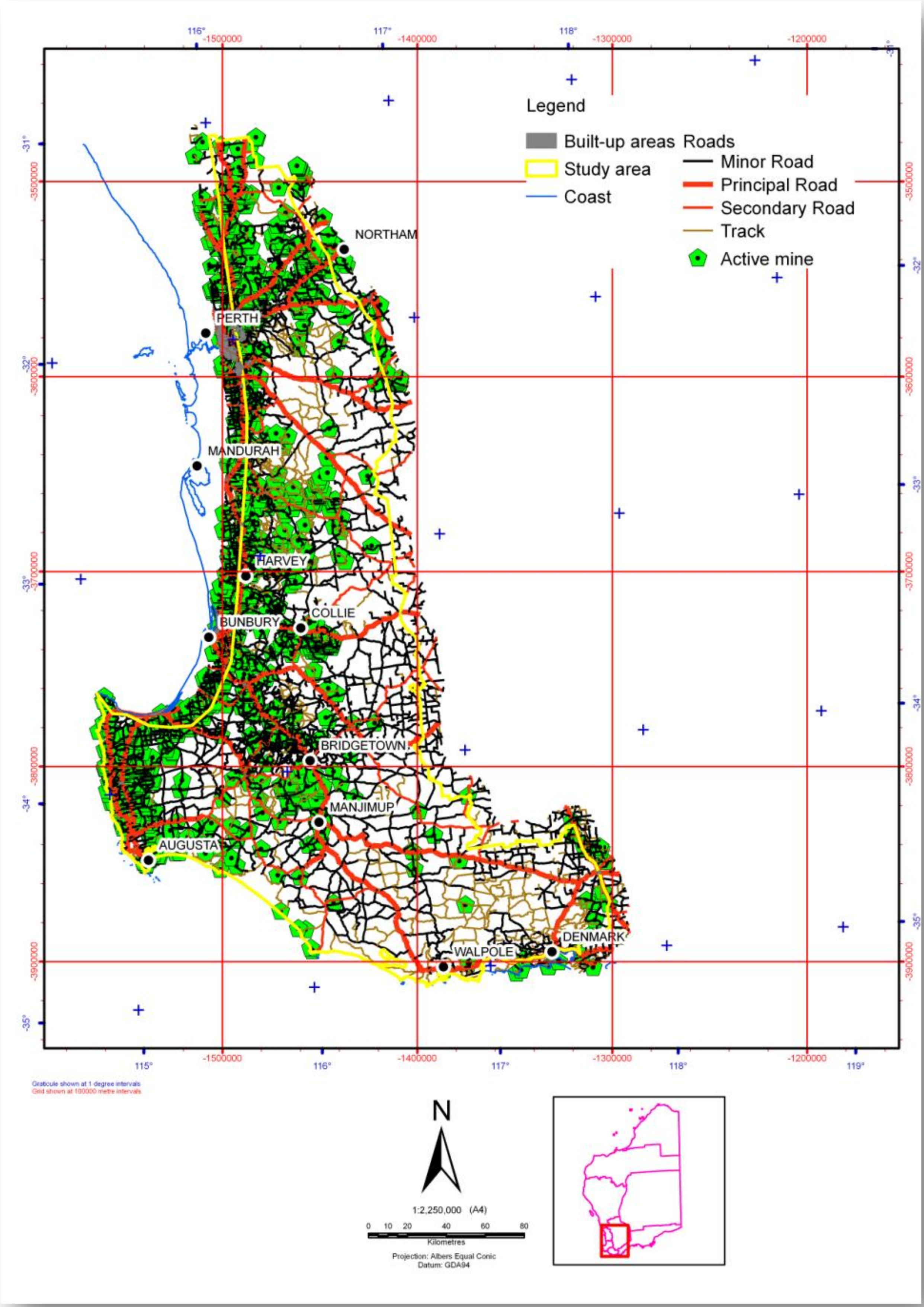


Figure 19 Spatial data used to create the Environmental Risk Surface shown with major towns.

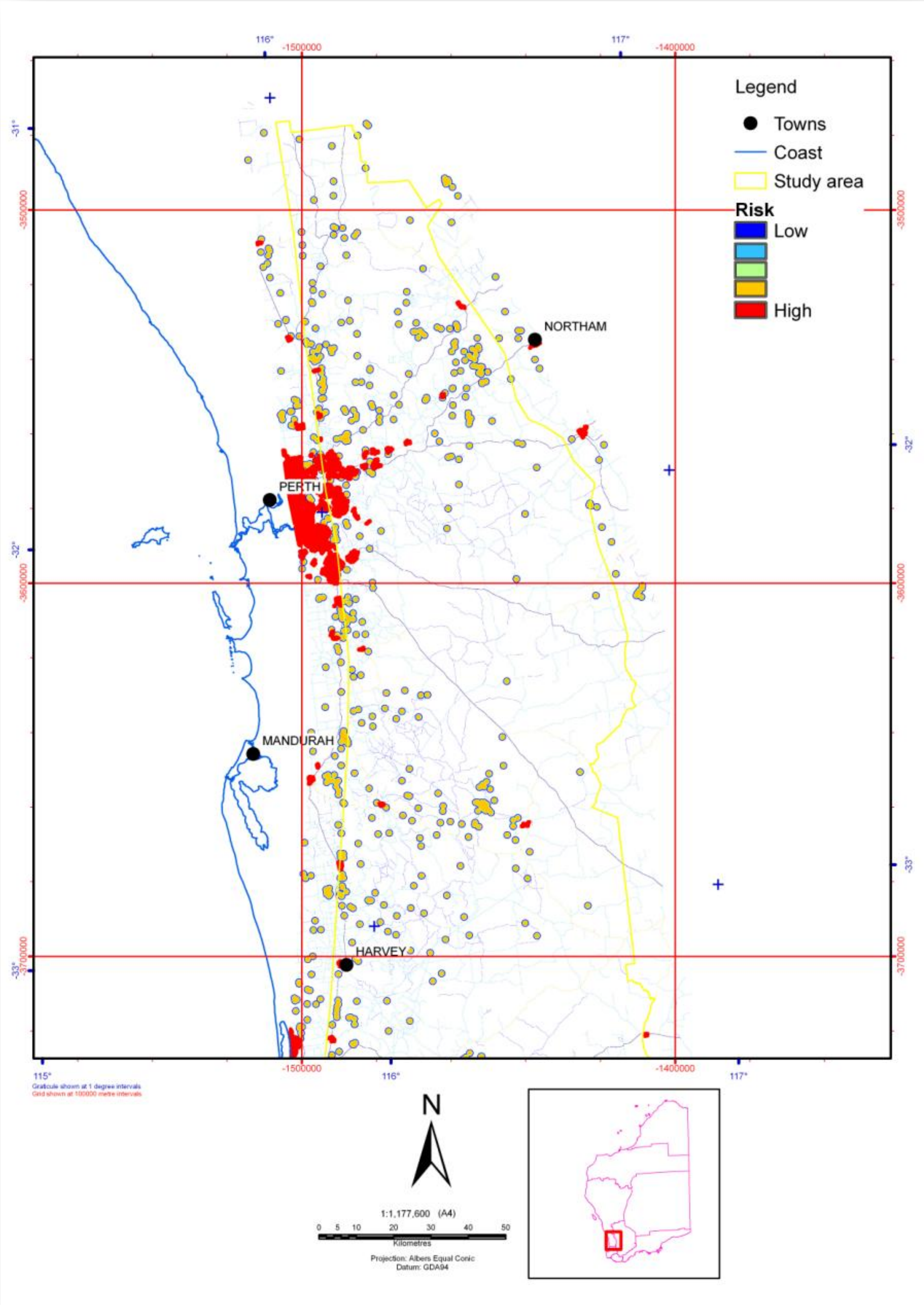


Figure 20 Environmental Risk Surface showing mean risk with major towns for the northern part of the study area.

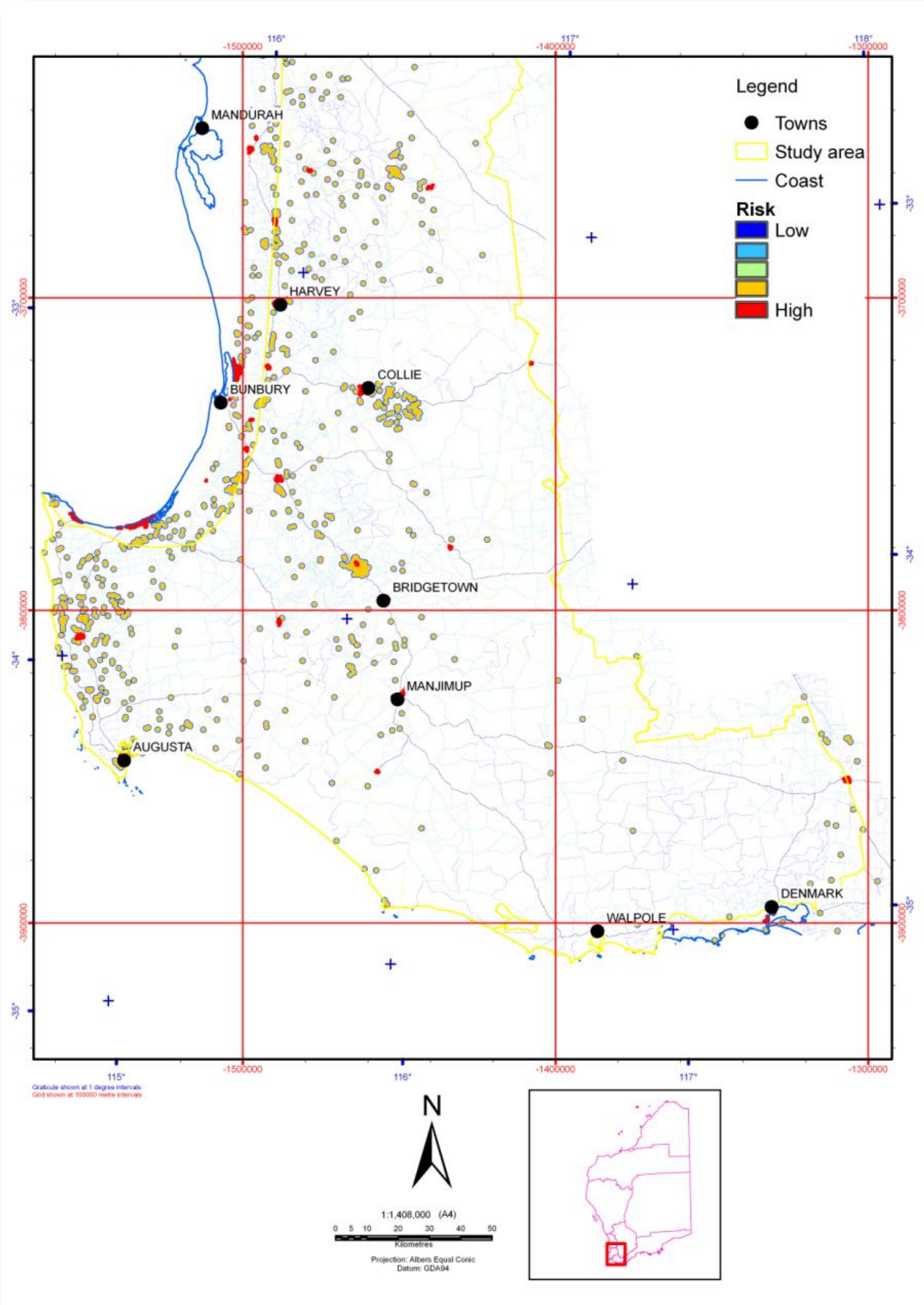


Figure 21 Environmental Risk Surface showing mean risk with major towns for the southern part of the study area.

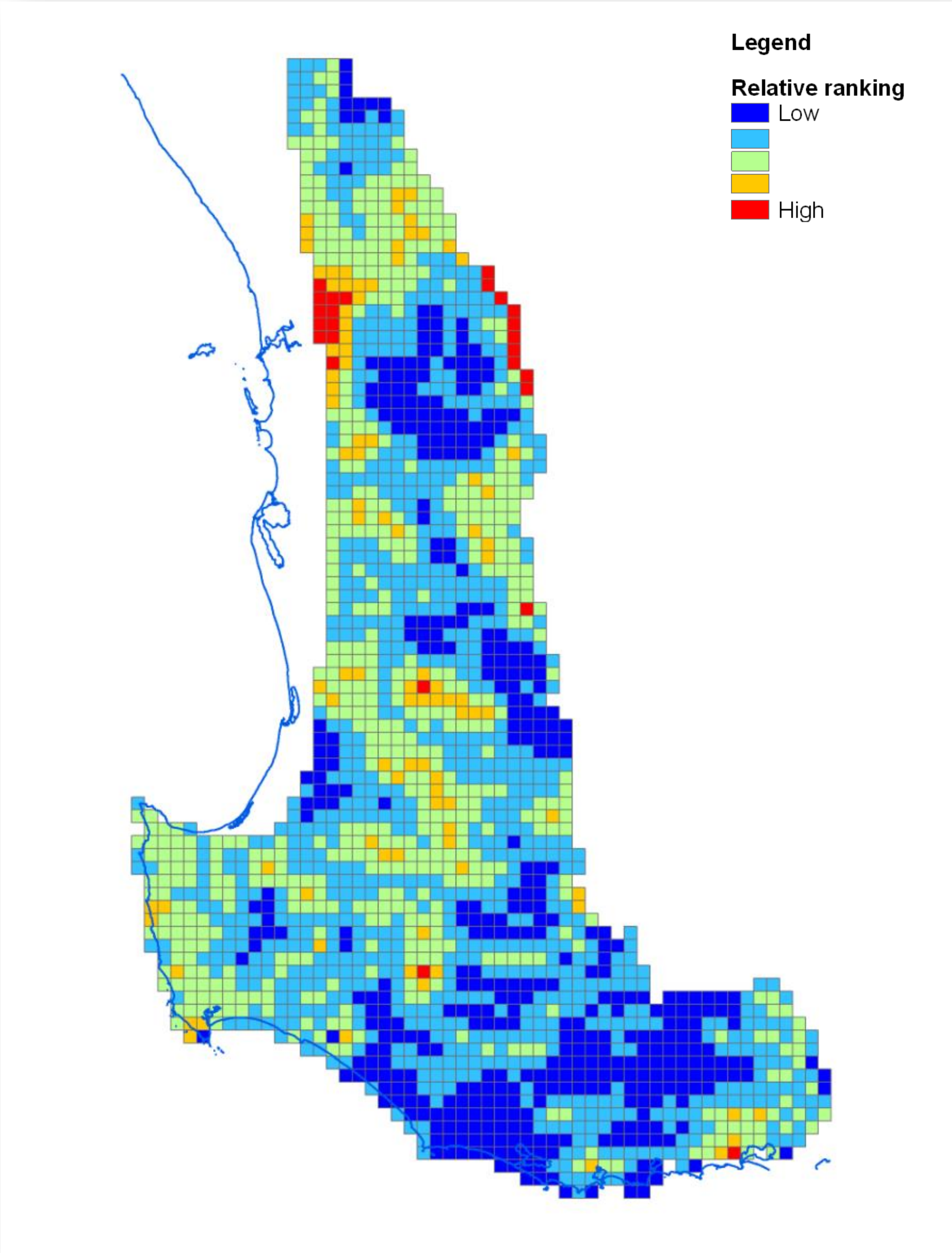


Figure 22 Mean risk by grid squares.

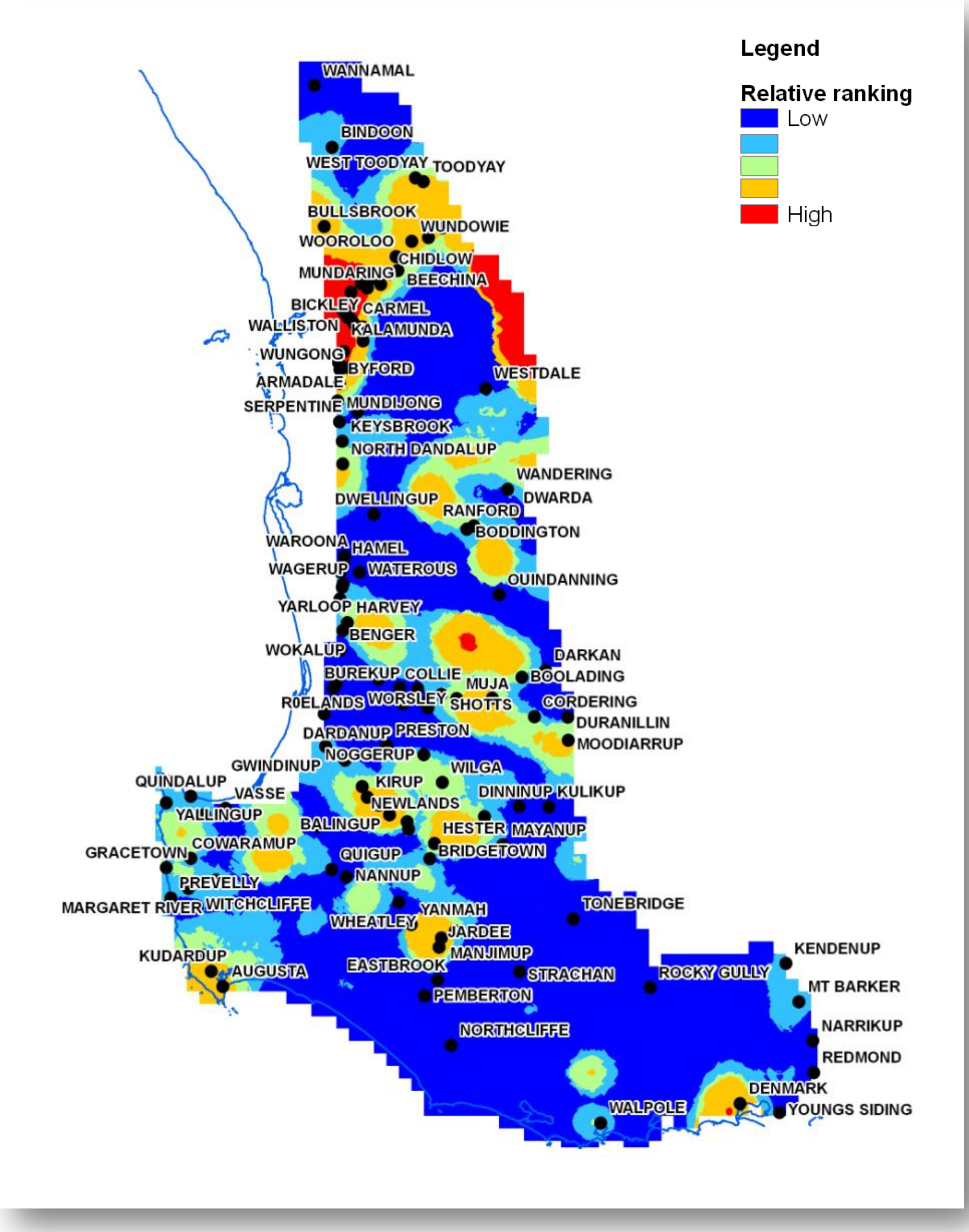
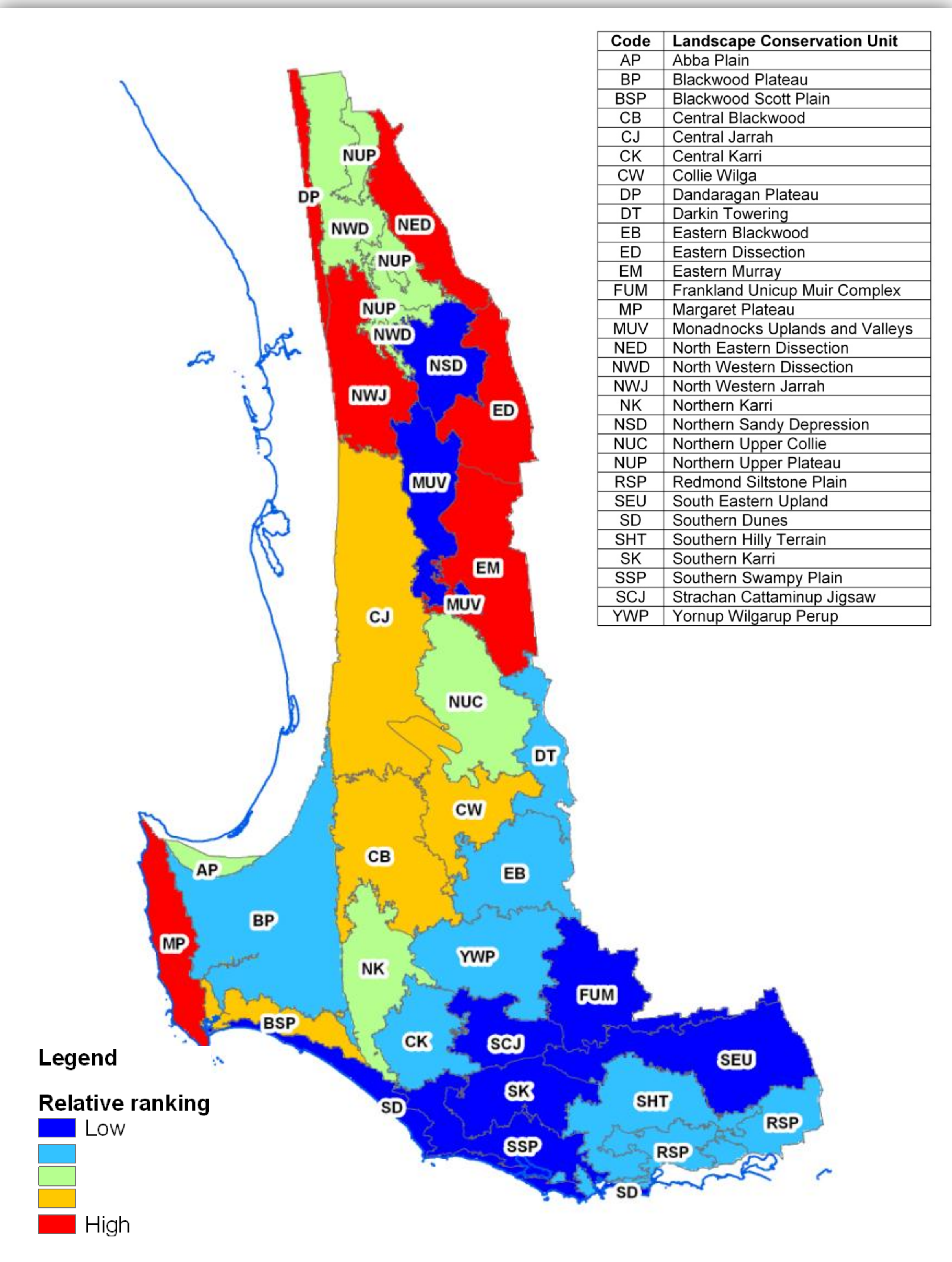


Figure 23 Mean risk shown with towns by interpolation.



Code	Landscape Conservation Unit
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Figure 24 Mean risk by Landscape Conservation Units.

4.4 Discussion

The risk surface produced for the study area showed that potential threats were concentrated in areas of human habitation and mining operations. Spatial modelling of threats is a new and developing science and, as such, there are a number of limitations associated with the technique. Some studies have quantified the spatial elements of impacts, such as distance of influence, weighting and patterns of decay of the intensity of impact over distance e.g. for roads by Trombulak and Frissell (2000) and McPherson *et al.* (2008). However, more data area needed for a greater range of threats to accurately quantify patterns of impact on biodiversity and environmental condition.

There are likely to be more threats to biodiversity in the study area than have been represented in this study, particularly in relation to freshwater ecosystems. The Environmental Risk Surface tool does have provision for including threats to freshwater ecosystems, but more data on the issues specific to the study area would be needed to accurately represent these potential threats. In this study, the three greatest terrestrial risks have been included, but the model could be further developed to include a broader range of threats, including dieback disease. The influence of the risk surface resulting from the present analysis on the model will be assessed in the final section of this report.

5 Extent and status of native vegetation

5.1 Introduction

Native vegetation in the study area and was analysed to assess its relative cover remaining and its conservation status. Vegetation statistics were analysed to determine the extent of pre-European native vegetation remaining and, for the vegetation managed by DPAW, the protection status. The data were combined into a multi-criteria analytical hierarchy model to identify areas that, if added to the reserve system, would contribute most to the enhancement of the Comprehensive, Adequate and Representative (CAR) Reserve System under the set criteria (JANIS 1997).

5.2 Methods

The extent and status of vegetation in each LCU was calculated from statistics prepared by DPAW's GIS Branch, using the corporate data layers shown in Table 9. For each LCU, the proportion of pre-European native vegetation remaining was calculated. For native vegetation that is managed by DPAW, the proportion in the first tier and second tier of protection was calculated according to the criteria shown in Table 10.

Table 9 Layers used in the analysis of the extent and status of native vegetation in the study area.

Layer (meta data)
Pre-European Vegetation (Department of Agriculture and Food / Department of Parks and Wildlife, May 2011, 1:250,000)
Remnant Vegetation (Department of Agriculture and Food / Department of Parks and Wildlife, May 2011, 1:20,000 – 1:100,000)
DPAW Estate (Department of Parks and Wildlife, 30 Jun 2011)

Table 10 Criteria used to classify native vegetation managed by DPAW by level of protection, based on CAR (JANIS 1997).

Criteria	Description
First tier - IUCN Category 1-4	1. Strict Nature Reserve / Wilderness Area: protected areas managed mainly for science or wilderness protection 2. National Park: protected area managed mainly for ecosystem protection and recreation 3. Natural Monument: protected area managed mainly for conservation of specific natural features 4. Habitat / Species Management Area: protected area managed mainly for conservation through management intervention
Second tier - IUCN Category 5-6 and no IUCN	5. State forest and other DPAW managed lands (vesting purpose not conservation) 6. Proposed for vesting as a conservation reserve (currently state forest)

A multi-criteria analytical hierarchy model, incorporating the extent and status of native vegetation in the study area was constructed using MCAS-S (BRS 2011). The analytical hierarchy process (AHP) employs a linear additive model via pair-wise comparisons between criteria and options. There are many variations and options that can be employed via AHP and more information on the process can be found in Saaty (2003). The AHP applied in the present model is shown in Table 11. Extent of native vegetation and IUCN 1-4 were of equal importance, current extent of native vegetation was strongly more important than IUCN 5-6 and no IUCN and IUCN 1-4 was very strongly more important than IUCN 5-6 and no IUCN. The resulting algorithm was X = 0.5189456 * (IUCN 1-4) + 0.354201 * (IUCN 5-6 and no IUCN) + 0.1268534 * (Proportion of native vegetation remaining).

Table 11 Analytical hierarchy process used in the composite model of the extent and status of native vegetation in the study area.

	Analytical hierarchy process multipliers		
Criteria	Current extent of native vegetation	IUCN 1-4	IUCN 5-6 and no IUCN
Current extent of native vegetation	1	1	5
IUCN 1-4 (Tier one)	1	1	7
IUCN 5-6 and no IUCN (Tier two)	1/5	1/7	1

5.3 Results

Land Conservation Units with the greatest proportion of pre-European native vegetation remaining northern central and southern parts of the forest (Figure 25), including Northern Sandy Depression, Monadnocks Uplands and Valleys, Strachan Cattaminup Jigsaw, Southern Dunes, Southern Hilly Terrain, Southern Karri and Southern Swampy Plain (Table 12). LCUs with the highest proportion of DPAW managed native vegetation in criteria with ICUN 1-4 were South Eastern Upland, Southern Dunes, Southern Hilly Terrain, Southern Karri, Redmond Siltstone Plain and Southern Swampy Plain (Table 12 and Figure 26). LCUs with the highest proportion of DPAW managed native vegetation with ICUN 5-6 and no IUCN were Monadnocks Uplands and Valleys, Central Jarrah, Northern Karri and Central Karri (Table 12 and Figure 27). The proportion of native vegetation that is DPAW Managed is shown for each LCU in Table 12, but this parameter was not included in the model because it is represented by the sum of the two IUCN criteria and thus was already a part of the model.

Table 12 Extent of pre-European and current native vegetation and protection status for Landscape Conservation Units.

Land Conservation Unit	Pre-European Extent (ha)	Current Extent (Ha)	Current Extent (%)	IUCN 1-4 (ha)	IUCN 1-4 (%)	IUNC 5-6 and no IUCN (ha)	IUNC 5-6 and no IUCN (%)	Total DPAW managed (ha)	Total DPAW managed (%)
Abba Plain	23,030	2,243	9.7	22	1.0	0	0	22	1.0
Blackwood Plateau	367,525	298,662	81.3	79,604	26.7	197,647	66.2	277,251	92.8
Blackwood Scott Plain	62,489	32,700	51.8	16,593	50.7	4,841	14.8	21,434	65.5
Central Blackwood	208,121	96,929	46.6	9,562	9.9	62,928	64.9	72,490	74.8
Central Jarrah	393,896	324,988	82.5	46,886	14.4	247,935	76.3	294,821	90.7
Central Karri	101,253	71,855	71.0	12,558	17.5	49,559	69.0	62,117	86.4
Collie Wilga	134,009	71,950	53.7	10,402	14.5	34,153	47.5	44,555	61.9
Dandaragan Plateau	37,724	11,690	31.0	896	7.7	7	0.06	903	7.7
Darkin Towering	79,120	19,361	24.5	454	2.3	2,015	10.4	2,469	12.8
Eastern Blackwood	142,584	39,651	27.8	4,798	12.1	18	0.04	4,816	12.1
Eastern Dissection	136,253	54,906	40.3	16,279	29.6	17,774	32.4	34,053	62.0
Eastern Murray	190,876	73,262	38.4	1,562	2.1	24,755	33.8	26,316	35.9
Frankland Unicup Muir	150,977	71,076	47.1	29,671	41.7	1,071	1.5	30,742	43.3
Margaret Plateau	100,885	52,727	51.9	25,691	48.7	1,234	2.3	26,925	51.1
Monadnocks Uplands Valleys	121,923	107,235	88.0	9,395	8.8	77,227	72.0	86,621	80.8
North Eastern Dissection	110,457	46,873	42.4	4,561	9.7	9,982	21.3	14,543	31.0
North Western Dissection	160,895	88,185	54.8	17,200	19.5	22,423	25.4	39,623	44.9
North Western Jarrah	155,097	126,882	81.8	27,237	21.5	72,077	56.8	99,315	78.3
Northern Karri	126,103	110,243	87.4	26,030	23.6	79,383	72.0	105,413	95.6
Northern Sandy Depression	100,290	93,337	93.1	40,662	43.6	44,774	48.0	85,436	91.5
Northern Upper Collie	179,175	140,039	78.2	30,403	21.7	82,313	58.8	112,716	80.5
Northern Upper Plateau	88,652	59,628	67.3	6,499	10.9	20,839	34.9	27,338	45.8
Redmond Siltstone Plain	120,008	82,479	68.7	45,849	55.6	11,378	13.8	57,226	69.4
South Eastern Upland	212,194	111,752	52.7	60,215	53.9	10,934	9.8	71,149	63.7
Southern Dunes	78,548	71,805	89.7	58,697	81.7	20	0.03	58,716	81.8
Southern Hilly Terrain	172,445	157,732	91.5	141,292	89.6	4,159	2.6	145,451	92.2
Southern Karri	109,220	102,087	93.5	70,683	69.2	26,864	26.3	97,547	95.6
Southern Swampy Plain	113,304	103,276	87.7	91,367	88.5	2,615	2.5	93,982	91.0
Strachan Cattaminup Jigsaw	82,217	72,739	88.5	21,665	29.8	46,696	64.2	68,361	94.0
Yornup Wilgarup Perup	165,928	127,266	76.7	55,157	43.3	61,981	48.7	117,138	92.0
Total	4,225,199	2,823,556	66.8	961,888	34.1	1,217,603	43.1	2,179,491	77.2

Code	Landscape Conservation Unit
AP	Abba Plain
BP	Blackwood Plateau
BSP	Blackwood Scott Plain
CB	Central Blackwood
CJ	Central Jarrah
CK	Central Karri
CW	Collie Wilga
DP	Dandaragan Plateau
DT	Darkin Towering
EB	Eastern Blackwood
ED	Eastern Dissection
EM	Eastern Murray
FUM	Frankland Unicup Muir Complex
MP	Margaret Plateau
MUV	Monadnocks Uplands and Valleys
NED	North Eastern Dissection
NWD	North Western Dissection
NWJ	North Western Jarrah
NK	Northern Karri
NSD	Northern Sandy Depression
NUC	Northern Upper Collie
NUP	Northern Upper Plateau
RSP	Redmond Siltstone Plain
SEU	South Eastern Upland
SD	Southern Dunes
SHT	Southern Hilly Terrain
SK	Southern Karri
SSP	Southern Swampy Plain
SCJ	Strachan Cattaminup Jigsaw
YWP	Yornup Wilgarup Perup

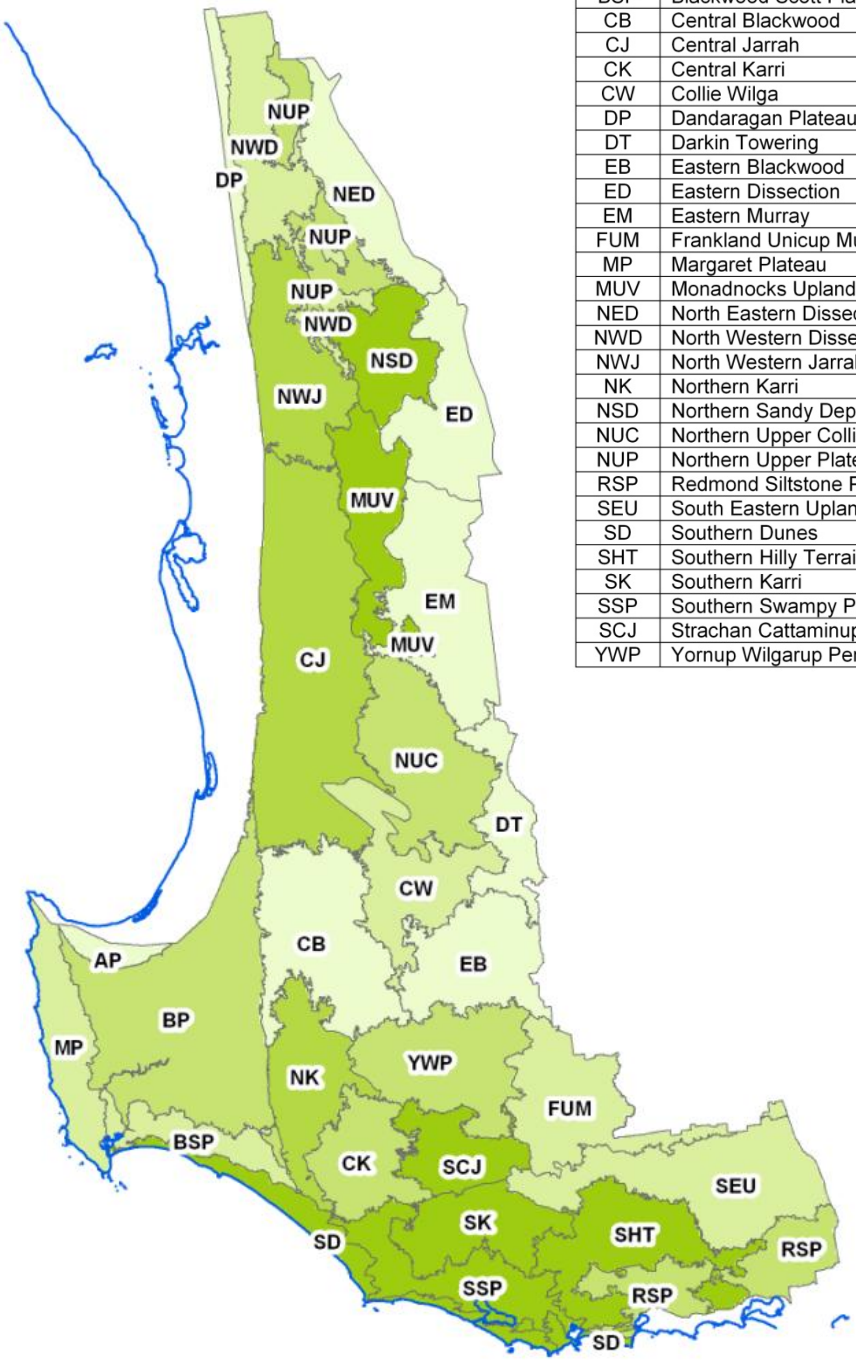


Figure 25 Proportion of native vegetation remaining from low (light) to high (dark) for Landscape Conservation Units.

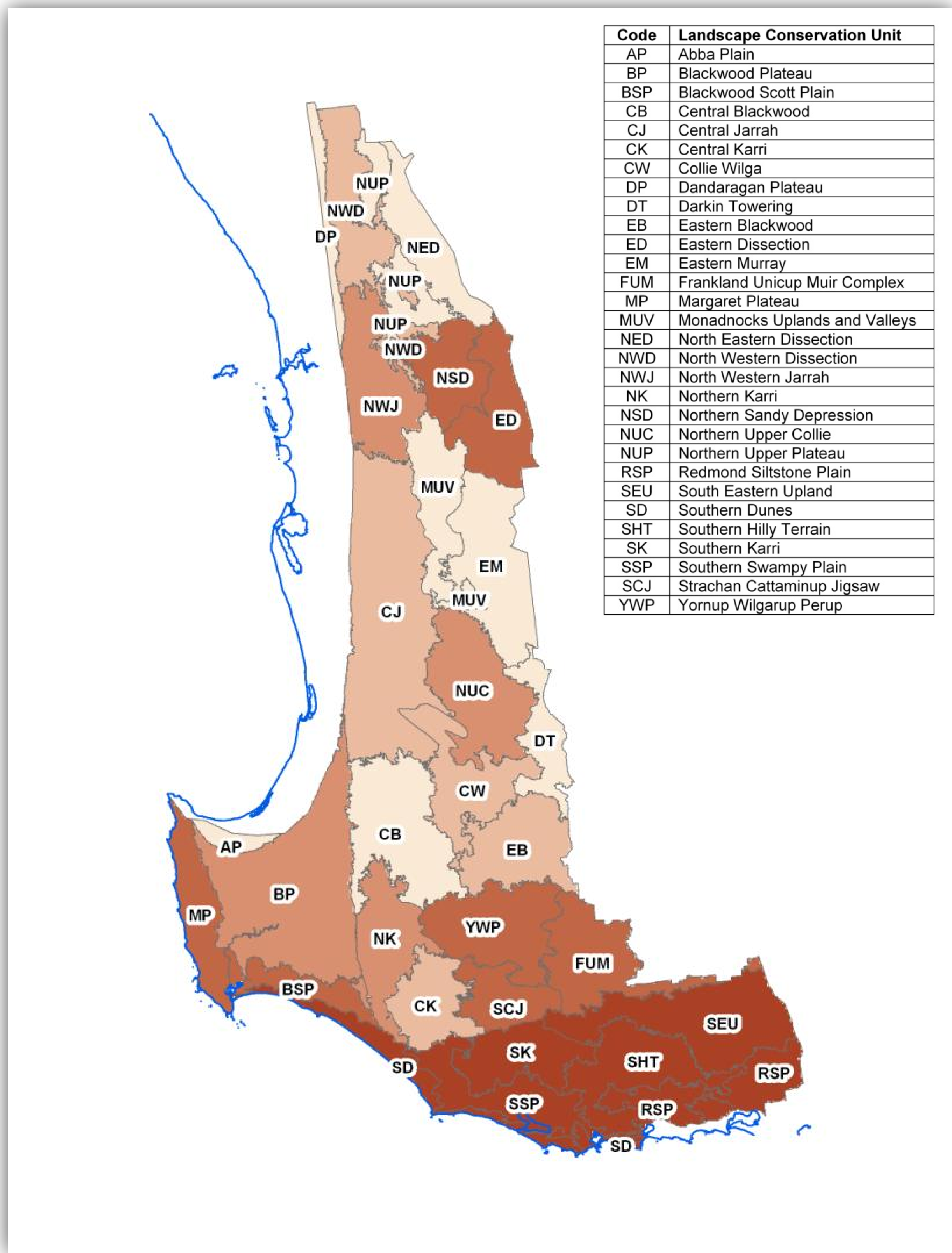
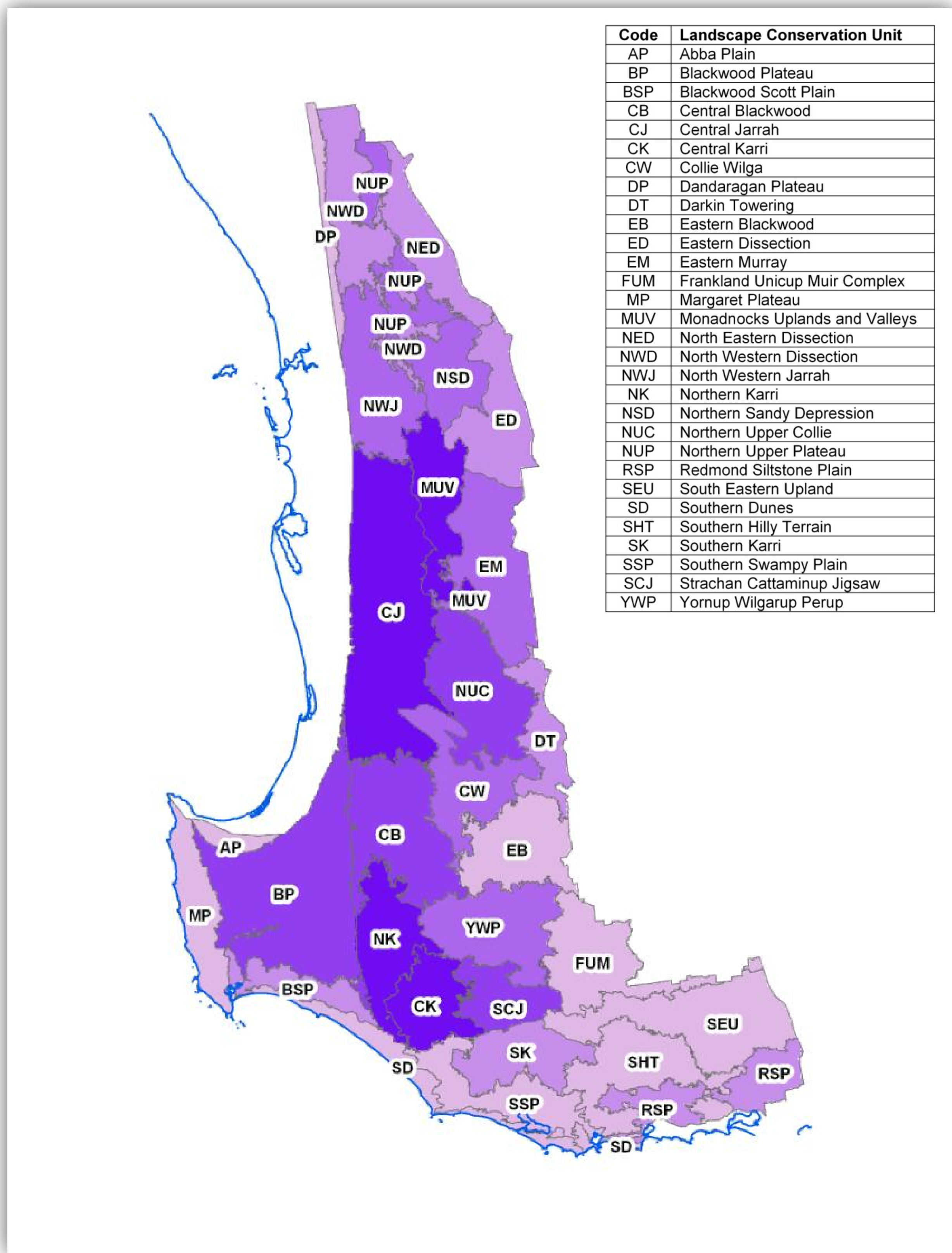


Figure 26 Proportion of DPAW managed native vegetation with criteria IUCN 1-4 from low (light) to high (dark) for Landscape Conservation Units.



Code	Landscape Conservation Unit
AP	Abba Plain
BP	Blackwood Plateau
BSP	Blackwood Scott Plain
CB	Central Blackwood
CJ	Central Jarrah
CK	Central Karri
CW	Collie Wilga
DP	Dandaragan Plateau
DT	Darkin Towering
EB	Eastern Blackwood
ED	Eastern Dissection
EM	Eastern Murray
FUM	Frankland Unicup Muir Complex
MP	Margaret Plateau
MUV	Monadnocks Uplands and Valleys
NED	North Eastern Dissection
NWD	North Western Dissection
NWJ	North Western Jarrah
NK	Northern Karri
NSD	Northern Sandy Depression
NUC	Northern Upper Collie
NUP	Northern Upper Plateau
RSP	Redmond Siltstone Plain
SEU	South Eastern Upland
SD	Southern Dunes
SHT	Southern Hilly Terrain
SK	Southern Karri
SSP	Southern Swampy Plain
SCJ	Strachan Cattaminup Jigsaw
YWP	Yornup Wilgarup Perup

Figure 27 Proportion of DPAW managed native vegetation with criteria IUCN 5-6 and no IUCN category from low (light) to high (dark) for Landscape Conservation Units.

Table 13 shows the rankings for the three criteria used in the model for the extent and conservation status of native vegetation for each of the LCUs (shown in Figure 25, Figure 26 and Figure 27).

Table 13 Rankings from 1 (high) to 5 (low) on the basis of current extent and level of protection for native vegetation for Landscape Conservation Units.

Land conservation unit	Proportion of native vegetation		
	Remaining	IUCN 1-4	IUCN 5-6 and no IUCN
Abba Plain	5	5	5
Blackwood Plateau	3	3	2
Blackwood Scott Plain	4	2	4
Central Blackwood	5	5	2
Central Jarrah	2	4	1
Central Karri	3	4	1
Collie Wilga	4	4	3
Dandaragan Plateau	5	5	5
Darkin Towering	5	5	4
Eastern Blackwood	5	4	5
Eastern Dissection	5	2	4
Eastern Murray	5	5	3
Frankland Unicup Muir Complex	4	2	5
Margaret Plateau	4	2	5
Monadnocks Uplands and Valleys	1	5	1
North Eastern Dissection	5	5	4
North Western Dissection	4	4	4
North Western Jarrah	2	3	3
Northern Karri	2	3	1
Northern Sandy Depression	1	2	3
Northern Upper Collie	3	3	2
Northern Upper Plateau	3	5	3
Redmond Siltstone Plain	3	1	4
South Eastern Upland	4	1	5
Southern Dunes	1	1	5
Southern Hilly Terrain	1	1	5
Southern Karri	1	1	4
Southern Swampy Plain	1	1	5
Strachan Cattaminup Jigsaw	1	2	2
Yornup Wilgarup Perup	3	2	3

The multi-criteria model in Figure 28 shows the degree to which the Landscape Conservation Units satisfied the criteria in the analytical hierarchy process (Table 11). LCUs that ranked highest in the model were Northern Sandy Depression, Blackwood Plateau, Northern Karri, Strachan Cattaminup Jigsaw and Southern Karri (Figure 29).

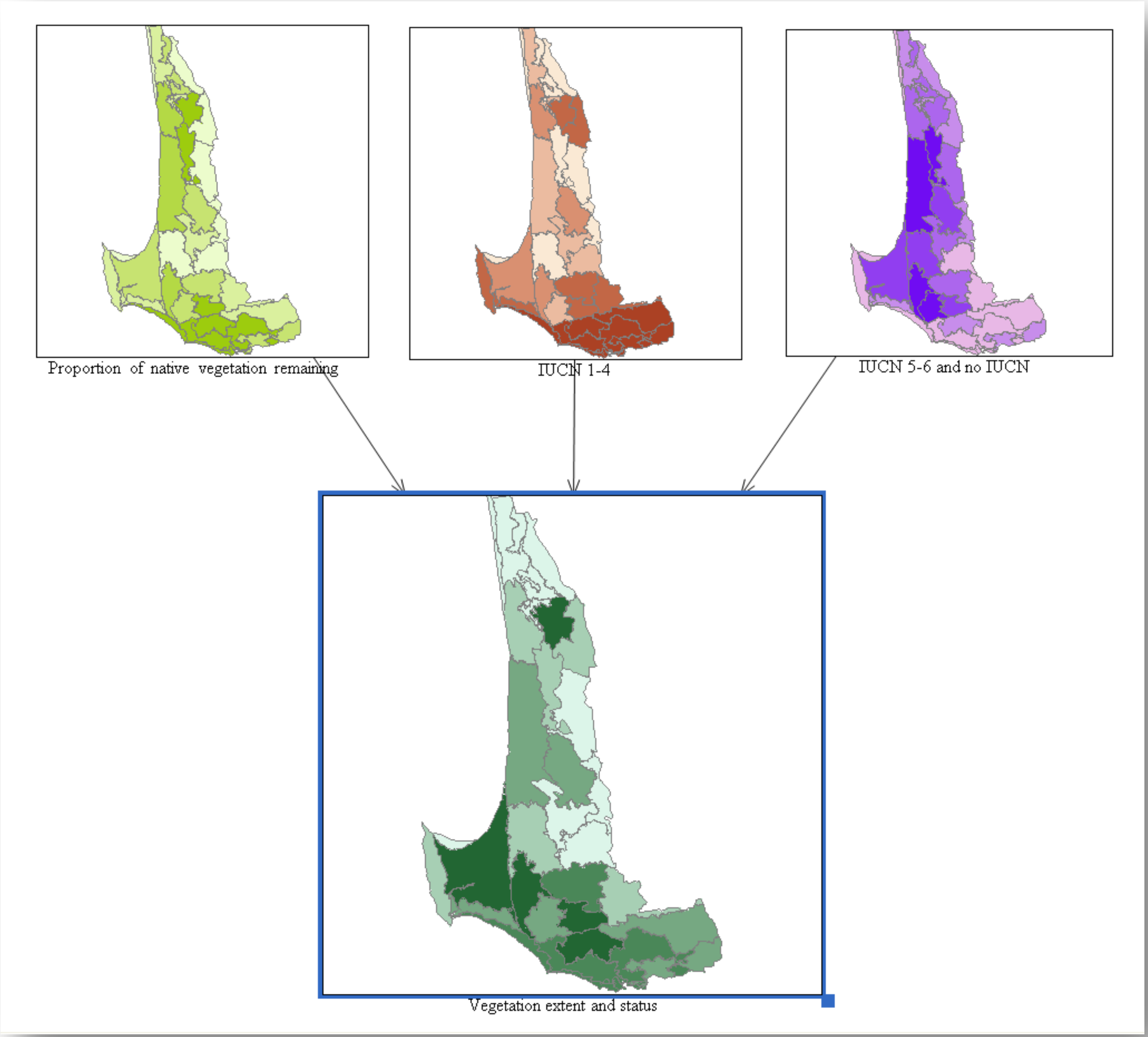


Figure 28 Multi-criteria analytical hierarchy model showing relative priority for further reservation or increasing protection from light (low) to high (dark) for Landscape Conservation Units.

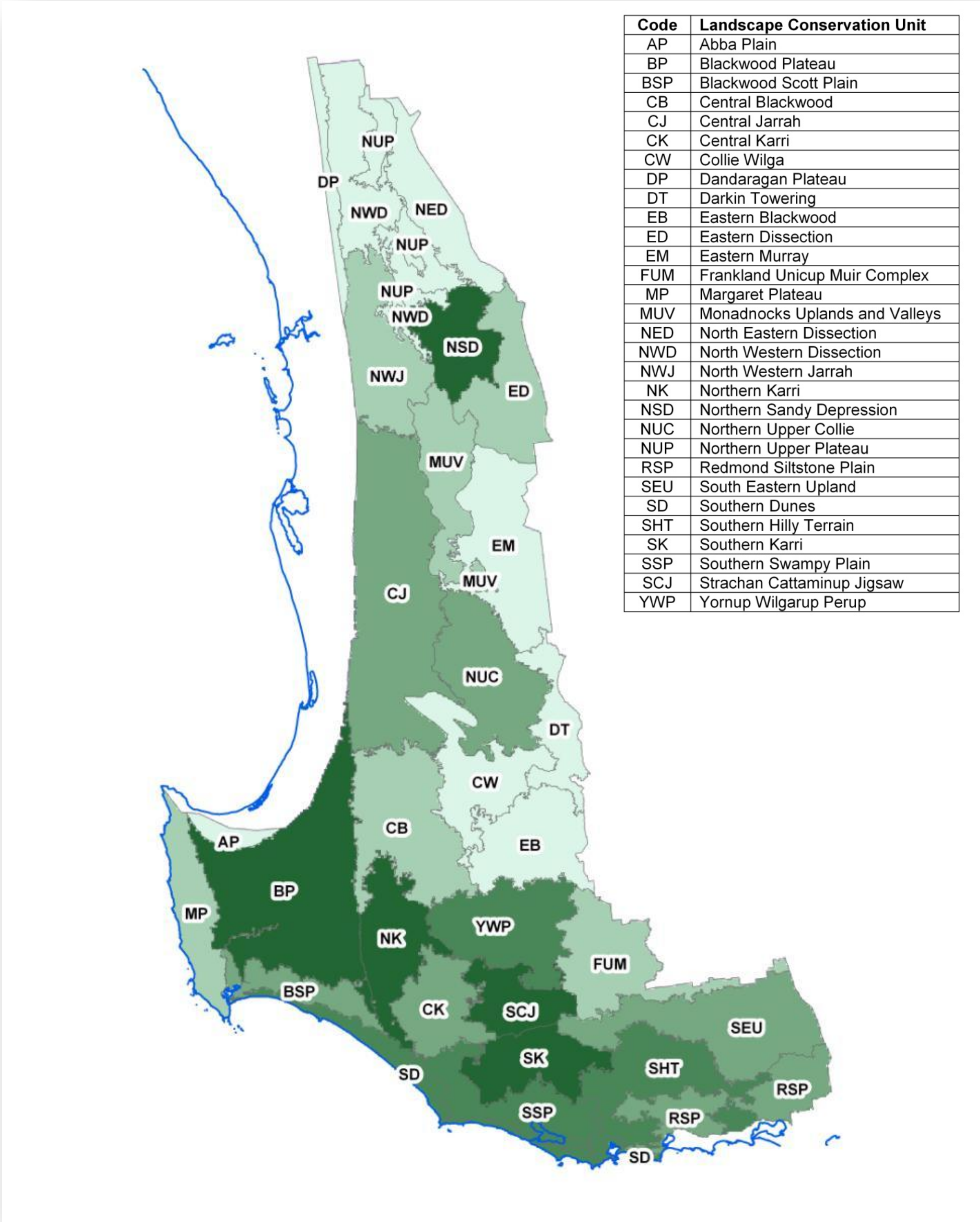


Figure 29 Priority for further reservation or increasing protection from light (low) to high (dark) for Landscape Conservation Units.

5.4 Discussion

The analysis of the extent and status of native vegetation in this study area showed that the proportion of pre-European native vegetation remaining was highest in northern central and southern parts of the study area. Relatively more native vegetation was protected under the first-tier protection (IUCN 1-4) in the south-east of the study area, while second-tier criteria protection (IUCN 5-6 and no IUCN category) predominated in the central parts of the forest. These complex patterns would be difficult to interpret qualitatively, but the multi criteria analytical hierarchy process applied in this analysis has made it possible to identify LCUs that were a priority for further reservation or increasing protection via quantitative algorithms. This process identified Northern Sandy Depression and Blackwood Plateau, Northern Karri, Strachan Cattaminup Jigsaw and Southern Karri as the highest priority LCUs for increasing protection or adding to the reserve system under the auspices of the Comprehensive, Adequate and Representative (CAR) Reserve System (JANIS 1997).

While this study analysed vegetation extent and status at the relatively broad scale of Landscape Conservation Units, other analyses have been conducted at different scales. For example, the Forest Management Plan 2004-2013 (CCWA 2004) examined reservation level at the scale of forest ecosystem and old-growth forest occurrence, defined for the Western Australian Regional Forest Agreement (RFA 1999), and in relation to vegetation associations mapped by Beard and Hopkins (Hopkins *et al.* 1996). Havel and Mattiske (2000) also assessed levels of extent and reservation for vegetation complexes in the forest management area. The information presented in this study could thus be combined with these finer scale analyses to further refine the model of priority for biodiversity survey sites.

6 Synthesis

6.1 Introduction

The premise of this study was to address Action 9.1 of the Forest Management Plan 2004-2013, which states that the Department of Parks and Wildlife (DPAW) will undertake biological surveys of priority areas determined in consultation with the Conservation Commission (CCWA 2004). When required, these biological surveys are used to assist in evaluating: the extent to which biodiversity is being conserved; and the need for any review of the reserve system (CCWA 2004).

The FORESTCHECK program is used by DPAW to inform forest managers about changes and trends in key elements of forest biodiversity associated with a variety of management activities (CALM Science Division 2001; DEC Science Division 2006). FORESTCHECK monitoring has also been demonstrated to be an effective means of systematically surveying biodiversity in the forest (Abbott and Williams 2011).

DPAW is considering using the FORESTCHECK monitoring protocol to survey parts of the forest that have not previously been well sampled. This study set out to develop a quantitative approach to prioritise parts of the south-west forest which are of a high priority for additional biodiversity surveys. In previous sections of this report, spatial modelling and analysis was used to identify Landscape Conservation Units that were poorly surveyed, but had relatively high species richness and relatively more remnant vegetation with relatively high levels of existing protection. In this section, the resulting data layers will be combined into a multi-criteria model to rank Landscape Conservation Units on the basis of priority for locating biodiversity survey sites. The model will be presented with and without the environmental risk layer produced in Section 4, to assess the influence of threatening factors on the model for survey site selection.

The final model will help scientists to place survey sites in poorly known locations and where there is an opportunity to add to a Comprehensive, Adequate and Representative (CAR) Reserve System under the set criteria (JANIS 1997).

6.2 Methods

A multi-criteria model was constructed in MCAS-S (BRS 2011) to prioritise LCUs on the basis for additional biodiversity survey. The model layers were survey effort (low to high), species richness (high to low), vegetation extent and status (high to low) and risk (low to high) and each layer was assigned equal weight.

6.3 Results

Table 14 shows the rankings, from 1 (high) to 5 (low) for each of the layers in the model, which are shown in Figure 30. The resulting priorities for additional survey, excluding and including risk, are shown in Table 14. Excluding risk, the highest priority LCUs were Northern Sandy Depression, Yornup Wilgarup Perup, Southern Hilly Terrain, Southern Swampy Plain and Redmond Siltstone Plain (Table 14 and Figure 31). Including risk, the highest priority LCUs were Northern Sandy Depression, Yornup Wilgarup Perup, Southern Hilly Terrain, Southern Swampy Plain and Redmond Siltstone Plain (Table 14 and Figure 32).

This analysis also identified five LCUs ranked as being second highest priority for additional survey: Monadnocks Uplands and Valleys, Northern Karri, Northern Upper Plateau, Strahan Cattaminup Jigsaw, Southern Karri and Southern Dunes. These LCUs remained second highest priority regardless of whether risk was included or not. The North Western Jarrah was also rated as second highest priority if risk was not considered.

Table 14 Rankings for each criteria used in the model and priority for additional survey from 1 (high) to 5 (low) for Landscape Conservation Units.

Land conservation unit	Layers in the model				Priority for survey	
	Survey Effort	Species richness	Vegetation extent and status	Risk	Excluding risk	Including risk
Abba Plain	2	1	5	3	5	4
Blackwood Plateau	2	4	1	4	4	3
Blackwood Scott Plain	1	2	3	2	5	5
Central Blackwood	1	5	4	2	5	5
Central Jarrah	3	3	3	2	3	4
Central Karri	1	2	3	4	4	4
Collie Wilga	4	5	5	2	5	5
Dandaragan Plateau	5	2	5	1	2	4
Darkin Towering	4	5	5	4	5	5
Eastern Blackwood	5	5	5	4	5	5
Eastern Dissection	5	4	4	1	3	4
Eastern Murray	5	5	5	1	5	5
Frankland Unicup Muir Complex	5	4	4	1	3	2
Margaret Plateau	1	1	4	1	4	5
Monadnocks Uplands and Valleys	3	3	4	5	2	2
North Eastern Dissection	5	2	5	1	2	3

Land conservation unit	Layers in the model				Priority for survey	
	Survey Effort	Species richness	Vegetation extent and status	Risk	Excluding risk	Including risk
North Western Dissection	4	2	5	3	3	3
North Western Jarrah	2	1	4	1	2	4
Northern Karri	1	2	1	3	2	2
Northern Sandy Depression	4	2	1	5	1	1
Northern Upper Collie	4	4	3	3	4	4
Northern Upper Plateau	5	2	5	3	2	2
Redmond Siltstone Plain	5	1	3	4	1	1
South Eastern Upland	4	5	3	5	4	2
Southern Dunes	3	3	2	5	2	2
Southern Hilly Terrain	3	1	2	4	1	1
Southern Karri	2	4	1	5	2	1
Southern Swampy Plain	1	2	2	5	1	1
Strachan Cattaminup Jigsaw	2	4	1	5	2	2
Yornup Wilgarup Perup	2	1	2	4	1	1

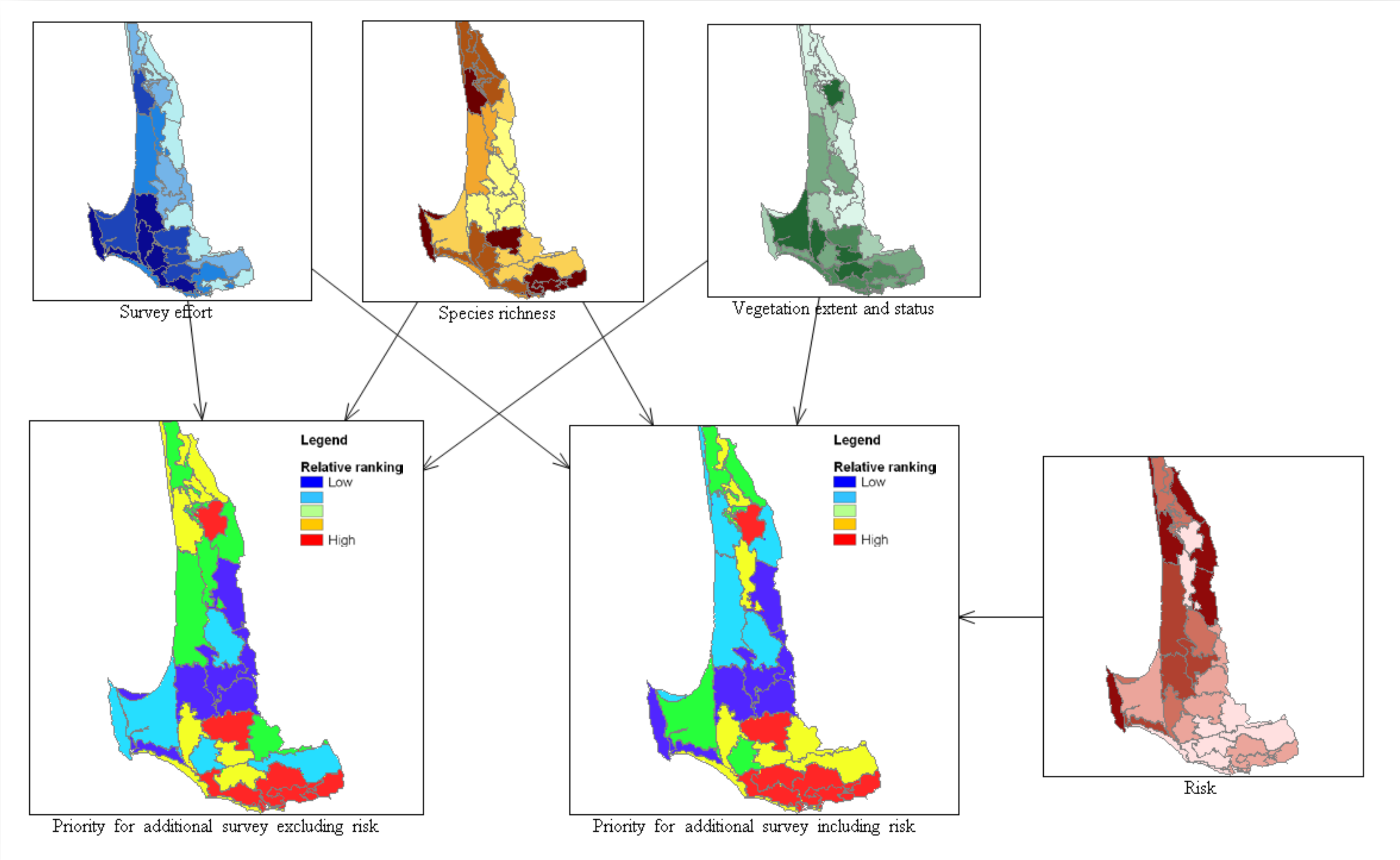


Figure 30 Multi-criteria model ranking Landscape Conservation Units by priority for additional survey.

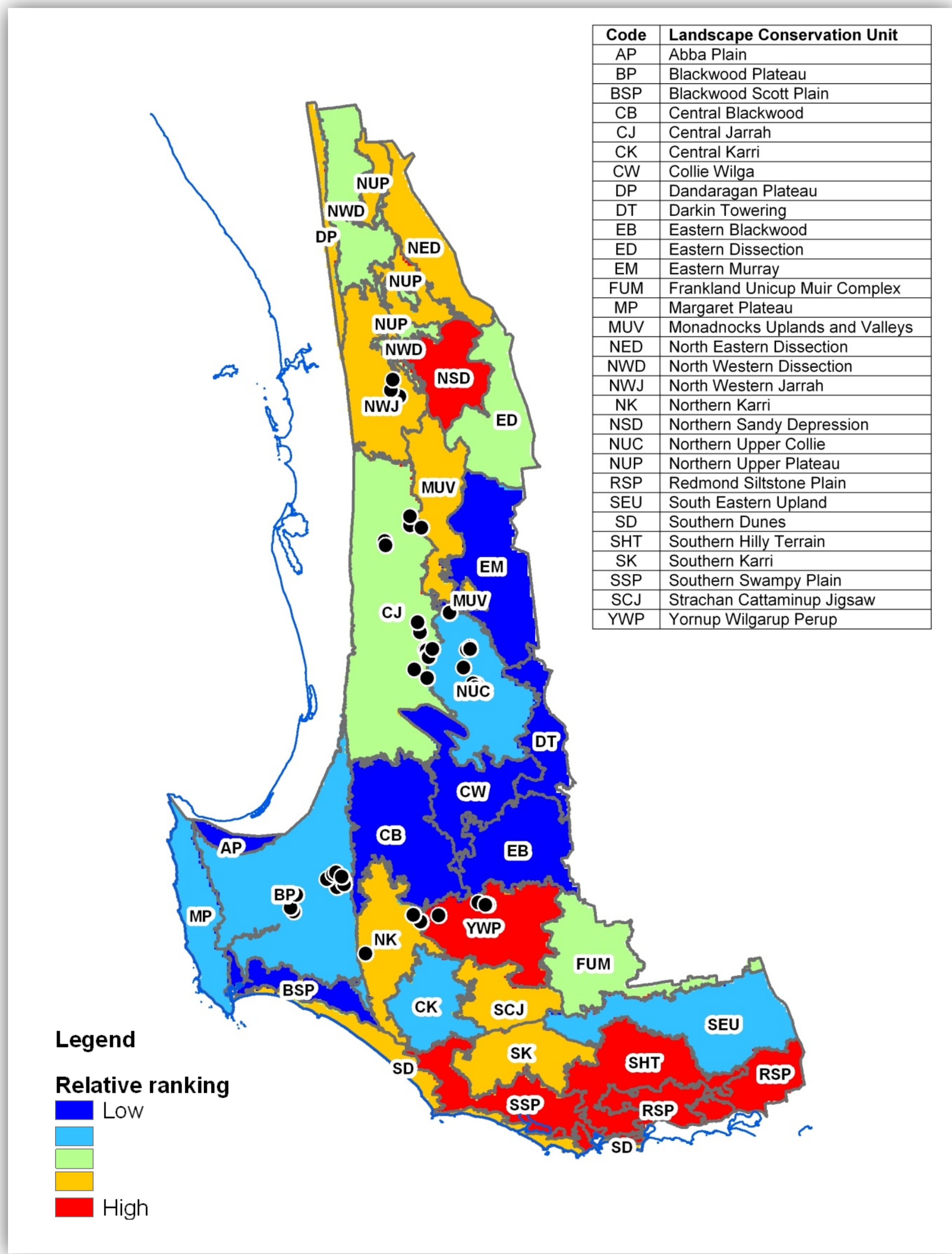


Figure 31 Priority for additional survey sites excluding risk for Landscape Conservation Units. Existing FORESTCHECK sites are shown with black circles.

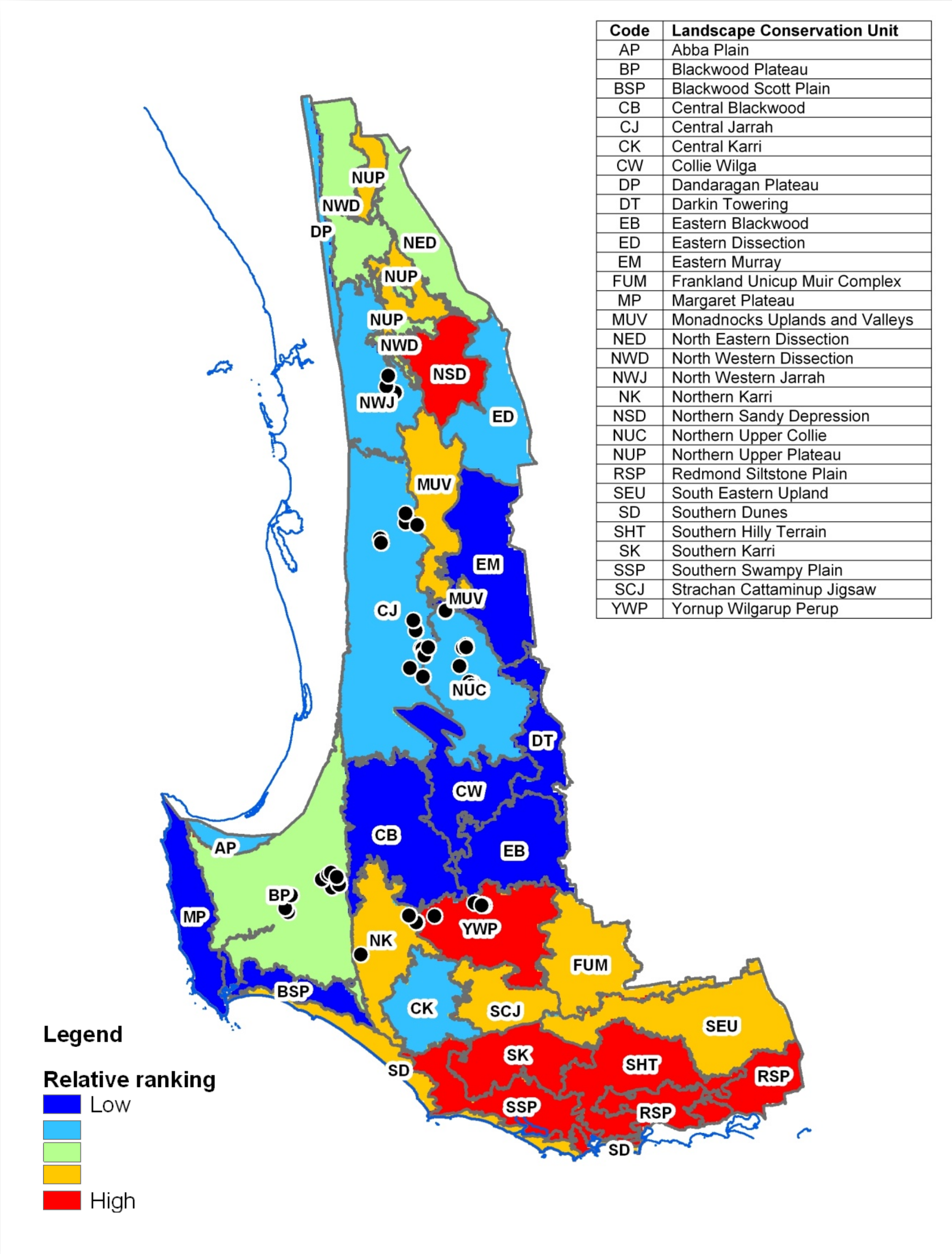


Figure 32 Priority for additional survey sites for Landscape Conservation Units. Existing FORESTCHECK sites are shown with black circles.

6.4 Discussion

Traditional biodiversity survey gap analyses use the number of 'collections' (or observations) as a surrogate for survey effort to identify priority areas for additional surveys (e.g. Funk *et al.* 2005). Observational datasets are used to model species distributions on the basis of environmental variables, then predict distributions where taxa are likely to occur, but have not previously been recorded (Ferrier 2002). The results can then be used to identify locations where additional records for individual taxa may be obtained (Ferrier *et al.* 2007), or to predict where additional surveys might glean the most new information on biodiversity (Funk *et al.* 2005). This technique is effective for survey gap analyses for single species or small groups of closely related taxa e.g. Ferrier (2002).

However, using observations as surrogates for survey effort in survey gap analyses has a number of disadvantages relating to; standardisation of sampling methods; scale and resolution; quantification of sampling effort; and variation in data accuracy and quality (Soberón and Peterson 2004; Robertson et al. 2010). In addition, data where surveys have been conducted, but no species were observed (null observations e.g. along foot or vehicle transects), are excluded from observational datasets.

In this study, we reviewed information on locations where surveys had been conducted. As far as the authors are aware, only one other study has used survey data, as opposed to observational data, to conduct a spatial survey gap analysis (Eco Logical Australia 2006), but that study was restricted to point data, representing floristic plots. The present gap analysis incorporated all survey techniques to conduct a complete gap analysis to calculate area-weighted survey effort across the south-west forest.

We set out to not only identify poorly surveyed locations, but also areas with high biodiversity and where there was an opportunity to improve the reserve system by contributing to a Comprehensive, Adequate and Representative Reserve System (JANIS 1997). We employed multi-criteria modelling, which is a quantitative means of integrating spatial information and is considered effective for the decision making needed to address the complex problems relating to natural resource and forest management (Chakroun and Bernie 2005; Mendoza and Martins 2006; Diaz-Balteiro and Romero 2008).

The model showed that although survey effort was relatively low on the eastern margins of the forest management area, species richness and the extent and conservation status of vegetation were relatively high in the northern central and south eastern parts of the forest.

The resulting model identified Northern Sandy Depression, Yornup Wilgarup Perup, Southern Hilly Terrain, Southern Swampy Plain and Redmond Siltstone Plain as the highest priority Landscape Conservation Units for additional biodiversity survey. Second priority LCUs for additional survey were Northern Upper Plateau, Monadnocks Uplands and Valleys, Northern Karri, Frankland Unicup Muir Complex, Strachan Cattaminup Jigsaw, South Eastern Upland and Southern Dunes.

Inclusion of a risk factor that represented disturbance arising from built up areas, roads and mines altered the priority for some LCUs. The Central Jarrah, North Western Jarrah, Margaret Plateau, Eastern Dissection and North Eastern Dissection were assigned a lower priority for additional survey when risk was included in the analysis. Extensive bauxite mining operations take place in the Central and Northern Jarrah LCUs, and the Northern Jarrah LCU also adjoins the Perth metropolitan area. The influence of mining for other minerals also affected the risk rating for the Margaret Plateau, Eastern Dissection and North Eastern Dissection. The priority for further survey increased for the Blackwood Plateau and the Frankland Muir Unicup Complex when risk was included, because these LCUs were modelled as having a relatively low risk of disturbance from built up areas, roads and mines.

This report has provided scientists with the quantitative spatial analysis on which to base decisions for the selection of biodiversity survey sites in the south-west forest of Western Australia. These data can be combined with finer scale analyses, such as those in Appendix 1 and by Hopkins *et al.* (1996) and Havel and Mattiske (2000) to maximise return per unit of survey effort and to maximise the opportunity to expand the existing reserve system for the purposes of effective biodiversity conservation.

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Appendix 1 Predictors for survey effort

Forest ecosystem	Frequency	Total frequency	Probability
Jarrah - Blackwood Plateau		25,342	0.34072
Jarrah - North West		11,769	0.15823
Jarrah - North East		10,554	0.14190
Jarrah - South		6,524	0.08772
Jarrah - Sandy Basins		4,274	0.05746
Shrub, herb, and sedgelands		4,110	0.05526
Western Wandoo forest		3,200	**0.04302**
Karri - Main Belt		1,803	**0.02424**
Western Wandoo woodland		1,324	**0.01780**
Jarrah woodland		1,110	**0.01492**
Karri - West Coast		873	**0.01174**
Peppermint and coastal heathland		806	**0.01084**
Jarrah - Mt Lindesay		636	**0.00855**
Rocky outcrops		602	**0.00809**
Whicher Scarp		528	**0.00710**
Jarrah - Unicup		325	**0.00437**
Swamps		214	**0.00288**
Karri/Yellow Tingle		142	**0.00191**
Karri/Red Tingle		83	**0.00112**
Jarrah/Yellow Tingle		56	**0.00075**
Darling Scarp vegetation		25	**0.00034**
Sand dunes		23	**0.00031**
Bullich and Yate		16	**0.00022**
Jarrah - Leeuwin Ridge		16	**0.00022**
Jarrah/Rates Tingle		14	**0.00019**
Karri - South Coast		4	**0.00005**
Karri/Rates Tingle		3	**0.00004**
Jarrah/Red Tingle		1	**0.00001**

Seasonal rainfall	Frequency	Total frequency	Probability
Winter dominant (more than 800mm)		50,150	0.63406
Winter dominant (500 - 800mm)		25,936	0.32791
Winter (500 - 800mm)		3008	**0.03803**

Soil unit	Soil type	Frequency	Total frequency	Probability
Tc5	Dissected plateau at low elevation of gently undulating to low hilly relief and characterized by extensive block laterite and lateritic (ironstone) gravels; some swamps: chief soils on slopes and undulating areas generally are hard acidic yellow mottled soils (Dy3.61) containing small to very large amounts of ironstone gravels. Associated are: (KS-Uc2.12), (KS-Uc2.2), and (Uc2.12) soils underlain by block laterite on the less dissected areas devoid of stream channels; acid grey earths (Gn2.94) sometimes containing ironstone gravels in shallow flat-bottomed valleys; (Uc2.32 and Uc2.33) soils on		27,190	0.34413

Soil unit	Soil type	Frequency	Total frequency	Probability
	slopes below laterite-capped ridges and on flat areas at various levels (some areas have a clay substrate at depth); areas of unit MT8; small areas of (Dr2.61) soils containing ironstone gravels and often intimately associated with the (Dy3.61) soils; some (Gn2.22) soils containing ironstone gravels in colluvial sites; some (Dy) and (Uc2) soils in swamps; and minor areas of other soils.			
JZ2	Dissected plateau having a gentle to moderately undulating relief, and with broad swampy drainage-ways and basins. It is characterized by lateritic gravels and block laterite: the chief soils are ironstone gravels with sandy and earthy matrices (KS-Uc4.2), (KS-Uc4.11), (KS-Gn2.24), and (KS-Uc2.12). They overlie duricrusts of recemented ironstone gravels and/or vesicular laterite, and/or mottled-zone and/or pallid-zone material. These soils cover ridges and slopes where some (Dy3.81 and Dy3 .82) soils containing ironstone gravels also occur. Leached sands (Uc2.2 and Uc2.3) are a feature of the drainage-ways and basins. Areas of (Dy5.41) and (Dy5.82) soils occur on pediments in some areas of this unit where it merges with unit Tf3.		17,038	0.21564
JZ1	Dissected plateau having a strongly undulating relief, and with some moderately incised valleys. The unit comprises much of the western part of the Darling Range south of the Swan River. It is characterized by lateritic gravels and block laterite. The chief soils are ironstone gravels with sandy and earthy matrices; the (KS-Uc4.2), (KS-Uc4.11), (KS-Uc2.12), and (KS-Gn2.24) soils blanket the slopes and ridges extending down into the upper ends of the minor valleys. They overlie duricrusts comprising recemented ironstone gravels, and/or vesicular laterite, and/or mottled-zone and/or pallid-zone material. Some (Dy3.81 and Dy3.82) soils containing ironstone gravels in the surface horizons may occur on some of the steeper slopes. Yellow loams (Um5.5), (Dy2.51) soils, and (Uc5.22) soils, all overlying pallid-zone clays and/or ironstone gravels at shallow depths (12-18 in.), occupy the swampy valley floors. Gravelly yellow earths (Gn2.2) are found downslope from granite bosses.		11,250	0.14239
Tf5	Dissected lateritic plateau of a generally hilly relief: chief soils on the slopes are hard acidic, and also neutral, yellow mottled soils (Dy3.81 and Dy3.82), (Dy3.61 and Dy3.62) containing moderate		4,380	0.05544

Soil unit	Soil type	Frequency	Total frequency	Probability
	to large amounts of ironstone gravels. Associated are block laterite, gravelly and bouldery (Dy5.81) and (KS-Uc4.2) soils on ridge tops; leached sands (Uc2.3), some on deposits containing water-worn stones; and small areas of soils of adjoining units.			
Tf6	Undulating to hilly portions of dissected lateritic plateau at moderate elevation: chief soils are hard acidic and neutral yellow mottled soils (Dy3.81 and Dy3.82), (Dy3.61 and Dy3.62) containing small to large amounts of ironstone gravels; possibly the (Dy3 .8) soils are more common in the eastern and the (Dy3.6) soils in the western portions. Associated are leached sands (Uc2.33) and sometimes (Dy5.42) soils in the flatter valleys; (Dy5.81) soils containing ironstone gravels adjacent to areas of unit Cd22, small areas of which are included also; small swampy areas of unit Cb43 soils; and valley side slopes of unit Ta9 soils where dissection is incised below the laterite. This unit merges with unit Cd22.		3,156	**0.03994**
Cd22	Flat to gently undulating portions of lateritic plateau at moderate elevation, occasional low hills, some tors: chief soils are leached sands (Uc2.12) and (Uc2.21), some only 6 in. thick, underlain by thick ironstone gravel and boulder layers and mottled kaolinitic clays at depths below 2-5 ft. Associated are: (Dy5.81) soils containing ironstone gravels and other soils of unit Tf6 on slopes; flats of leached sands (Uc2.33), some small areas of yellow (Gn2) soils containing ironstone gravel; small swampy areas of unit Cb43 soils; and minor areas of unit Ta9 soils where dissection is incised below the laterite. This unit merges along its southern boundaries with unit Cb42.		3,090	**0.03911**
Cb42	Plains with a succession of swampy flats broken by low sandy, or ironstone gravelly, knolls and hillocks: chief soils are leached sands (Uc2.33), some of which have thin peaty surface horizons. Associated are leached sands (Uc2.2 and Uc2.3) on sandy knolls; soils of units Tf6 and Cd22 on ironstone gravelly knolls and hillocks; and some acid peats (O) in lower-lying sites. This unit merges along its northern boundaries with unit Cd22.		2,025	**0.02563**
Uc1	Steep hilly to hilly dissected lateritic plateau with steep valley side slopes: chief soils are hard, and also sandy, neutral, and also acidic, yellow and yellow mottled soils (Dy3.62), (Dy5.62), (Dy2.82),		1,811	**0.02292**

Soil unit	Soil type	Frequency	Total frequency	Probability
	(Dy3.21), with conspicuous but relatively smaller areas of red earths (Gn2.15 and Gn2.14). Associated are areas of block laterite, gravelly and bouldery (Dy5.81) and (KS-Uc4.2) soils on tops of rises and their colluvial slopes; some areas of leached sands (Uc2.34); some (Dr2.21) soils on slopes; some (Um5.2) soils on terraces of major streams; and areas of unit Wd8.			
Tc6	Dissected lateritic plateau of hilly relief at moderate elevation: chief soils of the dissected hilly areas are hard acidic yellow mottled soils (Dy3.61), (Dy3.71), and (Dy3.81) with some hard acidic red mottled soils (Dr3.21) and brown earths (Gn2.45), all containing ironstone gravels; some (Um5.2) soils on major stream terraces. Associated are (Dy3.42), some (Dy3.43) and (Ug5) soils often with massive ironstone pavements, in the broad flat drainage-ways; and block laterite, gravelly and bouldery (Dy5.81) and (KS-Uc4.2) soils on the tops of rises and their colluvial slopes, together with some areas of leached sands (Uc2.3).		1,360	**0.01721**
Cb43	Plains--swampy flats with shallow swamps and lakes, some lunettes: chief soils are various leached sands, especially (Uc2.33) which may have thin peaty surface horizons and (Uc2.35) with various (Dg) and (Dy) soils such as (Dg4.13), (Dy5.82), and (Dy5.42). Associated are lunettes of (Uc1.2) soils and other (Uc) soils, some with ironstone gravels, in colluvial sites. As mapped, areas of units Cd22 and Tf6 are included.		1,030	**0.01304**
Tf3	Low hilly to hilly terrain that occupies a zone flanking unit JZ2. It comprises valleys that are frequently narrow and have short fairly steep pediments, along with breakaways, mesas, and occasional granite tors. Included also are undulating areas representing elements of unit JZ2: chief soils are hard acidic yellow mottled soils (Dy3.81) along with sandy acidic yellow mottled soils (Dy5.41) and (Dy5.81), all of which contain moderate to large amounts of ironstone gravels in their surface horizons. Ironstone gravels (KS-Uc4.2) occur on the ridge crests and on the fine gravel deposits of the gently undulating parts of the unit, along with leached sands (Uc2.21).		914	**0.01157**
A14	Coastal dunes: chief soils are calcareous sands (Uc1.11) on the strongly undulating slopes of the dunes. Associated are small areas of other soils including (Uc6.12) on		892	**0.01129**

Soil unit	Soil type	Frequency	Total frequency	Probability
	limestone and (Dr2.61) on gneissic outcrops.			
Mw31	Deeply incised, steep scarp and valley side slopes of the Darling scarp and its more deeply incised tributary valleys: chief soils of the steep scarp and valley side slopes, on which massive rock outcrops are a feature, seem to be acid red earths (Gn2.14) on the colluvial slope deposits. Associated are (Dr2.21) and (Dy3.21) soils on moderate to steep upper slopes with some (Uc4.11) soils containing ironstone gravel on spurs and ridge tops.		889	**0.01125**
JK10	Undulating low slopes of coastal dunes with aeolianite outcrops, caves, and sink holes: chief soils are brown sands (Uc4.2). Associated are small areas of other soils, probably including (Uc1.22) and (Uc2.21).		707	**0.00895**
MT8	Gently undulating terrain of broad shallow valleys and low ridges with moderate amounts of laterite and lateritic (ironstone) gravel: chief soils of the broad shallow valleys are acid grey earths (Gn2.94) sometimes containing ironstone gravels and possibly with some (Dy5.81) and/or (Dy5.41) soils also. Associated are leached sands (Uc2.2 and Uc2.3) in valley deposits and outwash areas; (Dy3.61) and (Dr2.61) soils containing ironstone gravels on ridges and their slopes and areas of block laterite; and minor areas of various soils such as (Um4.2), (Dr2.21), and (Dy3.21) on river terraces. As mapped, areas of unit Tc5 may be included.		653	**0.00826**
Ta10	Steep hilly to hilly terrain with rock outcrops and steep-sided valleys, some with swampy floors: chief soils seem to be hard acidic and neutral yellow mottled soils (Dy3.21 and Dy3.22) and hard acidic red soils (Dr2.21) some varieties of each of these have dark duffy Ao horizons. Associated on colluvial slopes are acid and neutral red earths (Gn2.14 and Gn2.15); (Uc2.34) and (Dy5.41) soils on quartzites; and leached sands (Uc2.33) and possibly acid peats (O) in valley flats and swamps. As mapped, areas of adjoining units are included.		525	**0.00664**
Ca19	Low-lying poorly drained plains: chief soils are leached sands (Uc2.2 and Uc2.3) the latter more common in the flatter, wetter sites and the former in the better-drained marginal areas. Associated are a variety of soils in shallow depressions and swampy drainage-ways, including acid peats (O); (Dy5.41) and (Uc2.12) soils overlying block laterite.		376	**0.00476**
Ca20	Coastal dunes and plains: chief soils are		340	**0.00430**

Soil unit	Soil type	Frequency	Total frequency	Probability
	leached sands (Uc2.21) of the inland dunes where there are swampy interdune flats of leached sands (Uc2.34). Associated are unconsolidated dunes of calcareous sands (Uc1.11) and a plain also of calcareous sands (Uc1.11) with small freshwater swamps fronting the coast. The dunes of leached sands are underlain by calcareous sandy materials at depths of 3-7 ft.			
Qb31	Hilly to steep hilly terrain of rather broken relief: chief soils are hard neutral red soils and acidic red soils (Dr2.22 and Dr2.21) with hard neutral, and also acidic, yellow mottled soils (Dy3.22 and Dy3.21). Associated are colluvial slump areas of (Gn2.45) and other soils on the slopes; narrow terrace and mass movement deposits of (Gn2.15 and Gn2.14) soils, and possibly other soils similar to those of unit Mu12, along some valleys; some siliceous sands (Uc1.21) on dunes in the main valleys; and remnants of the main soils of units Tf5 and JZ1 on some interfluve ridges. As mapped, areas of adjoining units are included.		265	**0.00335**
Tc7	Knolls and hillocks--islandsof (Dy) and (Gn) soils separated by swampy plains of (Uc) soils: chief soils of the knolls and hillocks are hard, and sandy, acidic yellow mottled soils (Dy3.61) and (Dy5.81) with some red earths (Gn2.15), all frequently containing ironstone gravels. Associated are leached sands (Uc2.2 and Uc2.3) of the swampy plains that vary in size from narrow drainage-ways to plains on which only a few hillocks occur.		221	**0.00280**
JJ14	Steep granitic ranges and hills with bare rock walls: chief soils are shallow sands (Uc4.11) and leached sands (Uc2.2) in colluvial positions. As mapped, areas of units JZ1 and JZ2 are included.		175	**0.00221**
Cb44	The Collie basin area, generally flat to strongly undulating land with many sandy flats and swamps: chief soils seem to be leached sands (Uc2.33) in the lower and more swampy sites and (Uc2.21), often containing ironstone gravels, on flat to gently sloping areas. Associated are (Dy3.61 and Dy3.62), (Dy3.8), and (Dy5.8) soils all containing ironstone gravels on the undulating areas. As mapped, areas of the adjoining units may be included.		87	**0.00110**
Cb40	Swampy plains: chief soils are leached sands (Uc2.33), some of which have a thin peaty surface horizon. Associated are small hummocks of leached sands		79	**0.00100**

Soil unit	Soil type	Frequency	Total frequency	Probability
	(Uc1.21).			
Cb41	Low-lying wet plains with swamps and lakes, some estuarine areas: chief soils are leached sands (Uc2.33), some of which have thin peaty surface horizons. Associated are a variety of peat (O) and other soils in the swamps and depressions; some other leached sands such as (Uc2.32) on slopes; diatomaceous earths (unclassified); some granitic tors on slopes; and other undescribed soils. As mapped, areas of the ironstone gravelly soils of the adjacent units are included.		73	**0.00092**
MT7	Plain: chief soils are acid Fey earths (Gn2.94) often in fairly intimate association with leached sands (Uc2.22) that have a clay D horizon at depths of 3-8 ft. Associated are small areas of (Dy3.81) soils containing ironstone gravels.		64	**0.00081**
Sp2	Gently sloping bench or terrace--the Ridge Hill Shelf: chief soils are hard acidic yellow soils (Dy2.61) containing ironstone gravels. Associated are brown sands (Uc4.2) often containing ironstone gravels at depth and forming a western fringe to the bench; and some (Dy3.4) soils on dissected areas. As mapped, areas of units Wd6 and Gb16 may be included.		60	**0.00076**
Sd2	Rounded hills of the Darling scarp with gneissic rock outcrops; slopes are moderate to very steep: chief soils seem to be hard acidic, and also neutral, yellow and yellow mottled soils (Dy2.21 and Dy2.22) and (Dy3.21 and Dy3.22). Associated are hard acidic red soils and neutral red soils (Dr2.21 and Dr2.22) on the slopes; with some (Dy3.6) soils containing ironstone gravel and also small areas of unit JZ1 soils on ridge tops; and various unclassified soils in the narrow valleys. As mapped, areas of unit JZ1 may be included.		56	**0.00071**
Wd8	Gently undulating drainage divides developed on quartzite: chief soils are sandy acidic yellow mottled soils (Dy5.81) and (Dy5.41) with leached sands (Uc2.3) often associated with deep deposits of water-worn quartz sand and grit (Uc1.2). Sometimes ironstone gravelly (Dy5.81) and (KS-Uc4.2) soils are associated.		51	**0.00065**
NZ2	Shallow swampy flat valley floors at moderately high elevation: chief soils are sandy acidic gley soils (Dg3.81) and hard acidic gley soils (Dg2.81) and (Dg1.81). Associated are possibly some (Dy5.8) soils. As mapped, there are included areas of unit JZ2, particularly ironstone gravels		42	**0.00053**

Soil unit	Soil type	Frequency	Total frequency	Probability
	(KS-Uc4) and leached sands (Uc2.2 and Uc2.3).			
Wd6	Plain: chief soils are sandy acidic yellow mottled soils (Dy5.81), some of which contain ironstone gravel, and in some deeper varieties (18 in. of A horizon) (Uc2.22) soils are now forming. Associated are acid yellow earths (Gn2.24). Other soils include (Dy3.81) containing ironstone gravel; (Dy3.71); low dunes of (Uc2.33) soils; and some swamps with variable soils.		35	**0.00044**
Ta9	Valley side slopes, gentle to steep slopes where dissection has cut below the laterite level: the soils vary locally, although the hard yellow mottled soils such as (Dy3.21, Dy3.22, and Dy3.41) seem more common, with variable proportions of related (Dr) soils such as (Dr2.21, Dr2.22, and Dr2.41). Associated on the slopes are a great range of soils including (Gn3.12) and other (Dy) and (Dr) soils; and small flats and benches of unit Cd22 at the foot of the slope. As mapped, areas of unit Tf6 soils are included in upper slope positions.		19	**0.00024**
Ub96	Valley plains in which some salinity is usually present: chief soils are hard neutral, and also alkaline, yellow mottled soils (Dy3.42 and Dy3.43). Associated are small areas of many other soils including minor areas of sands as for unit Ub95. As mapped, areas of adjoining units may be included.		15	**0.00019**
Ph2	River levees and terraces: chief soils are hard acidic red soils (Dr2.81) on the levees. Associated are upper terraces of neutral red and yellow earths (Gn2.15) and (Gn2.25); lower terraces of (Um6.11) soils; and smaller areas of other soils.		14	**0.00018**
Qb29	Rolling to hilly with some steep slopes; gneissic rock outcrops common: chief soils are hard neutral red soils (Dr2.22) with others such as (Dr2.62) and (Dr3.42). Associated are (Dy3.42) soils on slopes; patches of (Ug5.37) and (Ug5.2) soils with some gilgai also on slopes; colluvial slopes of (Gn2) soils such as (Gn2.12) and (Gn2.45); and variable areas of other soils seem likely. As mapped, areas of unit Uf1 and small areas of unit Oc30 may be included.		14	**0.00018**
Qb32	Moderate to steep valley side slopes on basic igneous and associated rocks; gentle colluvial slopes and small to moderate valley floors; some rock outcrops: chief soils on the valley side slopes are hard neutral red soils (Dr2.22) and neutral red friable earths (Gn3.12) with some shallow		14	**0.00018**

Soil unit	Soil type	Frequency	Total frequency	Probability
	(Uc) and (Um) soils. Associated are various (Dy), such as (Dy5.8), and (Dr), such as (Dr3.32), soils on the colluvial slopes; and (Um5.5) soils on the valley floors with some clay flats of (Uf) or (Ug5.2) soils.			
Pb28	Incised valleys with moderate to steep hilly slopes, some narrow tributary valleys and valley basins; granitic rock outcrops common on slopes: chief soils seem to be hard acidic red soils (Dr2.21) and (Dr2.61) with hard acidic yellow mottled soils (Dy3.21) on the slopes. Associated are neutral red earths (Gn2.15) on colluvial fills; and some siliceous sands (Uc1.2) sometimes overlying ironstone gravels in the narrow tributary valleys. As mapped, areas of adjoining units are included.		12	**0.00015**
Wd9	Broad valleys and undulating interfluvial areas with some discontinuous breakaways and occasional mesas; lateritic materials mantle the area: chief soils are sandy acidic yellow mottled soils, (Dy5.81) containing much ironstone gravel in the A horizons, and (Dy5.84), both forming a complex pattern with each other and with lateritic sandy gravels (KS-Uc2.12). Associated are leached sands (Uc2.21) underlain by lateritic gravels and mottled clays that occur at a progressively greater depth down slope.		12	**0.00015**
Ta8	Incised valley side slopes of moderate to very steep relief: chief soils are hard acidic, and also neutral, yellow mottled soils (Dy3.21 and Dy3.22) with hard neutral yellow mottled soils (Dy3.62) containing ironstone gravels. Associated are (Dr2.22 and Dr2.21) soils on slopes; some dunes of siliceous sands (Uc1.21) along valleys; some flats of (Dy3.42) soils in the valleys together with swampy areas of undescribed soils; and some ridges of soils of the adjoining units.		10	**0.00013**
Uf1	Undulating terrain with ridges, spurs, and lateritic mesas and buttes: chief soils on the broad undulating ridges and spurs are hard, and also sandy, neutral, and also acidic, yellow mottled soils (Dy3.82 and Dy3.81), (Dy5.82 and Dy5.81), all containing ironstone gravels. Associated are a variety of soils on the shorter pediment slopes, including (Dr2.32), (Dr3.41), (Dy2.33), and others of similar form; and dissection products of the lateritic mesas and buttes. As mapped, small areas of unit Ms7 may occupy some drainage divides, unit Va63 traverse some drainage-ways, and unit Qb29 occur in		10	**0.00013**

Soil unit	Soil type	Frequency	Total frequency	Probability
	localities of deeper dissection.			
Mu11	River terraces: chief soils are neutral red earths (Gn2.15) and neutral yellow earths (Gn2.25) on the higher terrace. Associated are (Um6.11) soils on the lower terrace and some areas of (Dy3.4) soils.		9	**0.00011**
Ub97	Very gently undulating plain: chief soils are neutral, and also alkaline, yellow mottled soils (Dy3.42 and Dy3.43) overlying siliceous pans at depth.		8	**0.00010**
MT9	Undulating with long ridges: chief soils of the undulating areas are acid Fey earths (Gn2.94) sometimes containing ironstone gravels. Associated are ridges and knolls of (Dy3.61) and (Dr2.61) soils containing ironstone gravels and areas of block laterite; and smaller areas of other soils.		7	**0.00009**
Ub95	Valley plains with some sandhills, dunes, lateritic gravel areas, and swamps: chief soils are hard neutral and sandy neutral yellow mottled soils (Dy3.42) and (Dy5.42). Associated are leached sands (Uc2.21) and siliceous sands (Uc1.21) of the sandhills and dunes; some (KS-Uc) gravels on residual knolls and ridges; areas of the soils of units Ub96 and Va64; and undescribed swamp soils. As mapped, areas of adjoining units may be included. There are similarities with unit Ca22.		7	**0.00009**
Mu12	Terraced valley and its steep side slopes: chief soils seem to be neutral and acidic red earths (Gn2.15 and Gn2.14) on upper terraces and mass movement deposits. Associated are flat mid-terrace remnants of acid yellow earths (Gn2.24) in complex with low dunes of (Uc2.22) sands; some deep sand areas (Uc4.2) and (Uc2.2); some areas of (Um6.11) soils on lower terraces; and some (Dr) and (Dy) soils similar to those of unit Qb31 on the steeper side slopes. As mapped, the width of this unit is exaggerated.		6	**0.00008**
Tf4	Low hilly to hilly portions of dissected lateritic plateau with gently undulating ridge crests and narrow incised valleys: chief soils are hard acidic yellow mottled soils (Dy3.81) and (Dy3.61) containing moderate to large amounts of ironstone gravel. Associated are (KS-Uc4.2) ironstone gravels and (Dy5.8) soils containing ironstone gravels on ridge crests; valley side slopes of the soils of unit Ub90; and (Uc2.21), sometimes with ironstone gravels and boulders in colluvial situations. As mapped, inclusions of adjoining units are likely.		4	**0.00005**
Tf7	Flat and often swampy area: chief soils are hard acidic, and also neutral, yellow		4	**0.00005**

Soil unit	Soil type	Frequency	Total frequency	Probability
	mottled soils (Dy3.81 and Dy3.82) in association with (Dy5.81) soils, all of which have some lateritic gravel at the junction of the A and B horizons. Other soils include leached sands (Uc2.21).			
Oc30	River terraces: chief soils are hard alkaline red soils (Dr2.33). Associated are some (Dy3.43) soils; and small areas of other soils are likely. As mapped, areas of soils of unit Qb29 may be included.		3	**0.00004**
X14	Swampy plain with some granitic tors in the south-western portion: chief soils are sandy neutral yellow mottled soils (Dy5.42) and leached sands (Uc2.33). Associated are low ridges of (Dy) soils containing ironstone gravel as for unit Ca23.		3	**0.00004**
Ub90	Generally rolling to hilly country with tors; lateritic mesas and buttes on some interfluve areas: chief soils are hard neutral and acidic yellow mottled soils (Dy3.42 and Dy3.41) sometimes containing ironstone gravels. Associated are variable areas of hard acidic and neutral red soils (Dr2.31), (Dr2.21), (Dr2.32), and (Dr2.22) on slopes; (Dy3.82 and Dy3.81) soils containing moderate to large amounts of ironstone gravels on ridges, crests of hills, and upper slopes; and many small areas of other soils. As mapped, areas of adjoining units may be included.		2	**0.00003**
Cb39	Subdued dune-swale terrain: chief soils are leached sands (Uc2.33) with (Uc2.22) and (Uc2.21) on the low dunes. Associated are small areas of other sand soils (Uc).		1	**0.00001**
LK21	Ranges of granites and granodiorites with some bare rock walls: chief soils on the steeper slopes seem to be shallow loamy soils (Um4.1), some with quite dark crumbly organic surface horizons. Associated are a variety of soils including acid red earths (Gn2.14) in colluvial pockets on the slopes (karri areas), where some (Dr4.22) and (Db3.22) soils are present; also areas of (Dy5.41) soils on the lower to mid slopes of the range; and areas of undescribed soils in other topographic positions.		1	**0.00001**
Ub92	Valley plains: chief soils are hard neutral yellow mottled soils (Dy3.42). Associated soils are not described. Salinity, including resalinized areas, is a feature.		1	**0.00001**
Vd6	Flat, fairly extensive valley floors: chief soils are hard alkaline yellow mottled soils (Dy3.33). Associated are (Dy3.43) soils along with areas of gilgai and cracking		1	**0.00001**

Soil unit	Soil type	Frequency	Total frequency	Probability
	clays (Ug5.37), as well as some (Dr3.33) and (Dr3.43) soils.			

Geology (Regolith)	Frequency	Total frequency	Probability
Residual or relict material, including ferruginous, siliceous, and calcareous duricrust		50,961	0.64432
Exposed rock, saprolite, and saprock		12,690	0.16044
Slope deposits, including colluvium and sheetwash		9,729	0.12301
Sandplain, mainly eolian, including some residual deposits		2,840	**0.03591**
Alluvium in drainage channels, floodplains, and deltas		2,366	**0.02991**
Lacustrine deposits, including lakes, playas, and fringing dunes		297	**0.00376**
Water		171	**0.00216**
Coastal deposits, including beaches and coastal dunes		39	**0.00049**

Vegetation complex	Frequency	Total frequency	Probability
Dwellingup		11,553	0.14611
Blackwood		9,151	0.11574
Pindalup		7,095	0.08973
Kingia		5,853	0.07402
Darradup		3,730	**0.04717**
Yalanbee		2,651	**0.03353**
Nillup		2,402	**0.03038**
Catterick		2,366	**0.02992**
Bidella		2,264	**0.02863**
Wilga		2,166	**0.02739**
Boonarie		1,997	**0.02526**
Jalbaragup		1,495	**0.01891**
Caldyanup		1,441	**0.01822**
Bevan 2		1,377	**0.01742**
Gracetown		1,228	**0.01553**
Telerah		1,089	**0.01377**
Mattaband 2		1,053	**0.01332**
Whicher Scarp		924	**0.01169**
Collis 1		898	**0.01136**
Murray 2		860	**0.01088**
Frankland Hills		829	**0.01048**
Corbalup 2		722	**0.00913**
Lindesay		722	**0.00913**
Keystone		696	**0.00880**
Cardiff		684	**0.00865**
Murray 1		676	**0.00855**
Leroy		625	**0.00790**
Coolakin		617	**0.00780**
Granite Valleys		610	**0.00771**
Grimwade		546	**0.00691**
Yarragil 1		487	**0.00616**
Cooke		471	**0.00596**
Collie		454	**0.00574**
Swamp		429	**0.00543**

Vegetation complex	Frequency	Total frequency	Probability
Balingup		413	**0.00522**
Pemberton		408	**0.00516**
Unicup		396	**0.00501**
Goonaping		373	**0.00472**
Scott		360	**0.00455**
Coate		353	**0.00446**
Bevan 1		329	**0.00416**
Wheatley		310	**0.00392**
Warren		302	**0.00382**
D'Entrecasteaux		296	**0.00374**
Mattaband 1		294	**0.00372**
Yarragil 2		290	**0.00367**
Crowea		289	**0.00366**
Wilyabrup		263	**0.00333**
Helena 2		261	**0.00330**
Corbalup		252	**0.00319**
Kilcarnup		235	**0.00297**
Quagering		209	**0.00264**
Yerraminnup		194	**0.00245**
Lakes and Open Water		193	**0.00244**
Quindabellup		169	**0.00214**
Rosa		159	**0.00201**
Yanmah		152	**0.00192**
Hester		141	**0.00178**
Angove		139	**0.00176**
Donnelly		136	**0.00172**
Mattaband		135	**0.00171**
Collis 2		132	**0.00167**
Milyeanup		111	**0.00140**
Michibin		106	**0.00134**
Blackwater		104	**0.00132**
Bevan 3		97	**0.00123**
Water		89	**0.00113**
Trent		73	**0.00092**
Carbunup		71	**0.00090**
Forrestfield		69	**0.00087**
Darling Scarp		67	**0.00085**
Helena 1		67	**0.00085**
Quininup		60	**0.00076**
Abba		57	**0.00072**
Scott Scarp		57	**0.00072**
Muja		52	**0.00066**
Meerup		45	**0.00057**
Collis		41	**0.00052**
Stratton		34	**0.00043**
Preston		31	**0.00039**
Yelverton		31	**0.00039**
Treeton		30	**0.00038**
Cartis		25	**0.00032**
Camballup		24	**0.00030**
Williams		24	**0.00030**
Beermullah		20	**0.00025**
Fernley		19	**0.00024**
Kordabup		18	**0.00023**

Vegetation complex	Frequency	Total frequency	Probability
Yornup		18	**0.00023**
Guildford		16	**0.00020**
Layman		16	**0.00020**
Qualeup		16	**0.00020**
Jangardup		15	**0.00019**
Lowdon		15	**0.00019**
Pingerup		15	**0.00019**
Cowaramup		14	**0.00018**
Hazelvale		11	**0.00014**
Valley Terrace		11	**0.00014**
Bindoon		10	**0.00013**
Wishart		10	**0.00013**
Kirup		9	**0.00011**
Shallow Valleys		9	**0.00011**
Mitchell		7	**0.00009**
Dempster 1		6	**0.00008**
Glenarty Hills		6	**0.00008**
Mogumber		6	**0.00008**
Sedimentary Valleys		6	**0.00008**
Owingup		5	**0.00006**
Wannamal		5	**0.00006**
Condinup		4	**0.00005**
Jasper		4	**0.00005**
Reagan		4	**0.00005**
Bevan		3	**0.00004**
Bridgetown		3	**0.00004**
Darkin 2		3	**0.00004**
Darkin 5		3	**0.00004**
Darkin 5f		3	**0.00004**
Hawk		3	**0.00004**
Newgalup 1		3	**0.00004**
Nooning		3	**0.00004**
Sandalwood		3	**0.00004**
Boscabel		2	**0.00003**
Broad Swamps		2	**0.00003**
Burnett		2	**0.00003**
Gnowergerup		2	**0.00003**
Moondah		2	**0.00003**
Mumballup		2	**0.00003**
Saline Terraces		2	**0.00003**
Sidcup		2	**0.00003**
Barlee		1	**0.00001**
Boulongup		1	**0.00001**
Broad Valleys		1	**0.00001**
Cattaminup		1	**0.00001**
Cleave		1	**0.00001**
Cormint		1	**0.00001**
Dalmore 1		1	**0.00001**
Dalmore 2		1	**0.00001**
Darkin 3		1	**0.00001**
Darkin 4		1	**0.00001**
Dempster		1	**0.00001**
Donnybrook		1	**0.00001**
Kapalarup		1	**0.00001**

Vegetation complex	Frequency	Total frequency	Probability
Lukin 1		1	**0.00001**
Newgalup 2		1	**0.00001**
Southampton		1	**0.00001**
Swan		1	**0.00001**
Toponup		1	**0.00001**
Walpole		1	**0.00001**
Wilgarup		1	**0.00001**
Wingewelup		1	**0.00001**

Fire frequency (Number of times burnt between 1937 and 2012)	Frequency	Total frequency	Probability
6		10,127	0.12804
8		10,013	0.12660
9		10,006	0.12651
7		8,277	0.10465
5		7,489	0.09468
10		6,560	0.08294
11		5,806	0.07341
4		4,700	0.05942
12		3,275	**0.04141**
13		2,393	**0.03026**
3		2,356	**0.02979**
0		2,144	**0.02711**
2		2,018	**0.02551**
14		1,559	**0.01971**
1		1,221	**0.01544**
15		669	**0.00846**
16		314	**0.00397**
17		125	**0.00158**
18		41	**0.00052**
20		1	**0.00001**