Gnangara Sustainability Strategy

An across-government initiative

Groundwater – Biodiversity – Land use

CRITERIA AND RANKING OF BIODIVERSITY ASSETS IN THE GSS STUDY AREA

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September 2009

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Report to the Department of Environment and Conservation and Gnangara Sustainbility Strategy

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September 2009

This document has been commissioned/produced as part of the Gnangara Sustainability Strategy (GSS). The GSS is a State Government initiative which aims to provide a framework for a whole of government approach to address land use and water planning issues associated with the Gnangara groundwater system. For more information go to www.gnangara.water.wa.gov.au

Acknowledgements
The Department of Environment and Conservation – Gnangara Sustainability Strategy would like to thank the following for their contribution to this publication: Barbara Wilson and Paul Brown.

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Introduction

The ranking of biodiversity assets is an essential step in the process of formulating conservation priorities alongside identifying the risks that threatening processes pose to these assets. A number of biological, social, political and economic factors need to be considered when ranking and prioritizing biodiversity assets and natural areas. Therefore conservation planners are often faced with multi-criteria decision problems involving a large number of criteria. A number of multi-criteria decision analysis methods and tools have been developed that can assist planners (Moffett and Sarkar 2006; Smith and Theberge 1987). The objectives of this project were to assess the effectiveness of two multi-criteria evaluation models to rank the biodiversity assets across the GSS study area.

Background

Criteria

When ranking natural areas criteria are employed so an assessment of the values of each area can be undertaken with respect to each criterion (Smith and Theberge 1986). The assessment can be either quantitative or qualitative and can be prepared at a range of scales such as local, regional or at the national scale (Smith and Theberge 1986; 1987). Criteria used to rank natural areas fall into one of four generic types:

- Biotic/Abiotic (sometimes referred to as biodiversity pattern) – relate to biotic and abiotic characteristics by itself and not their potential use by humans though any criteria will always involve human value judgments (Smith and Theberge 1986);
- Biodiversity Process – the ecological, evolutionary and genetic mechanisms which are necessary to generate genetic diversity and the isolating mechanisms required for speciation (Smith et al. 1993);
- Sociopolitical – can relate to how humans use the landscape or value the landscape as a resource (Smith and Theberge 1986; Moffett and Sarkar 2006). Examples include recreational criteria and criteria relating to cultural resources (such as

historical and archaeological sites), future economic value of the land or industrial resource use;

- Planning and management – matters which are of importance from a planning and management perspective such as management costs (Smith and Theberge 1986).

A summary of commonly used classes of criteria used to rank natural areas is provided in Table 1. Additional information on these criteria including a definition, importance to biodiversity conservation and examples of the criteria use in regional planning across the Swan Coastal Plain is provided in Appendix A. The majority of the criteria listed are abiotic and biotic criteria.

Table 1: Commonly used Criteria used in the Ranking of Natural Areas. See the Appendix A for more detailed information for each criteria listed.

Criteria
Rarity
Diversity
Representativeness
Maintenance of ecological processes
Productivity
Fragility/Stability
Importance for Wildlife
Size
Shape
Condition
Threat
Naturalness
Educational value
Historical significance
Scientific Value/Research Investment
Recreational Value
Ecosystem Services
Icon species or ecological communities

Where possible specific criterion should be developed that relate to the primary attributes of ecosystems including composition, structure and function (Noss 1990). Criterion also need to be targeted at the multiple levels of organization and different spatial and temporal scales (Margules and Pressey 2000; Noss 1990). The hierarchy concept proposed by Noss (1990) provides a framework for this. When ranking biodiversity assets, ideally criterion should be selected that cover the regional/landscape, community/ecosystem and population/species levels of organization proposed by Noss (1990).

The nature of the criterion, used to rank natural areas, is very much dependent on the availability of regional spatial data relating to biotic, abiotic and biodiversity processes. Generally reliable regional datasets of the spatial distributions of species and populations do not exist (Ferrier 2002; Margules and Pressey 2000; Pressey 2004). Biodiversity conservation planners therefore utilize surrogate measures of biodiversity (Margules and Pressey 2000). Surrogates generally relate to the community/ecosystem level of organization (eg. vegetation types). The advantages with these types of surrogates are that data is readily available at the regional scale, they integrate biodiversity process and empirical studies have found that these broad environmental variables are good indicators of spatial patterns of species (Margules and Pressey 2000). The disadvantages are they lose biological precision (Margules and Pressey 2000).

When ranking natural areas often higher order surrogates (often referred to as a coarse filters), such as vegetation types, are used in combination with other criteria and datasets that relate to fine filter biodiversity features (Higgins *et al.* 2005; Lieberknecht *et al.* 2008; Margules and Pressey 2000; Moffett and Sarkar 2006). Examples of these include the location of threatened species or ecological communities, endemic species or special habitats which are not adequately represented by the higher order surrogates (Lieberknecht *et al.* 2008; Margules and Pressey 2000). The advantage of this approach is that these fine filter datasets provide a greater degree of precision thereby refining the coarse filter assessment.

Previous regional conservation planning exercises across or within the Swan Coastal Plain IBRA Region have generally used a combination of coarse filter and fine filter criterion and surrogates to identify areas of high biodiversity value (see Appendix A; Government of Western Australia 2000; Del Marco *et al*. 2004; Hill *et al*. 1996; Leprovost *et al*. 1987; Strelein *et al*. 2008). Criteria relating to the level of representation of vegetation complexes or wetland groups are often used as the coarse filter whilst criteria relating to rarity, diversity, maintenance of ecological processes, productivity, size, shape and condition provide the fine filter. Like most regions a lack of adequate data on species distributions at a regional scale limit how the population/species level of organization can be considered. The majority of previous conservation planning exercises in the Swan Coastal Plain also included a number of sociopolitical criteria in their rankings (see Appendix A; Government of Western Australia 2000; Del Marco *et al*. 2004; Hill *et al*. 1996; Leprovost *et al*. 1987). These have not been used to determine the regional biodiversity significance of the natural area but have been used to rank natural areas which have similar biodiversity values/levels of significance (Government of Western Australia 2000).

Evaluation Methods for Ranking Natural Areas

A number of multi-criteria evaluation methods can be used to combine the scores relating to individual criterion into a single composite index which can then be used to rank natural areas (Moffett and Sarkar 2006; Smith and Theberge 1987). The development of composite indices have a number of benefits including reducing the large amount of information relating to biodiversity features to a single measure thereby providing new perspectives on biodiversity pattern and process, and also making information on biodiversity value more accessible to non-specialists (Smith and Theberge 1987).

Any evaluation method used to rank natural areas must have ecological and mathematical validity (Smith and Theberge 1987). The scale of measurement used to assess the criteria will determine what evaluation methods can be used. A number of evaluation methods can be utilized when criteria are measured using quantitative data however there are more limitations when only qualitative data is available (Moffett and Sarkar 2006; Smith and Theberge 1987). A number of assumptions specific to each evaluation method may have to be met such as independence of criteria (Moffett and Sarkar 2006 appendix 1; Smith and Theberge 1987).

In regional conservation planning two of the most commonly used evaluation methods are Additive Weighting, which ranks alternatives based on the sum of the criterion scores (Smith and Theberge 1987), and the Maximax decision model, which ranks alternatives based on the highest score across all criterion (Hwang and Yoon 1981). Requirements and assumptions for both of these models are listed below under 'Databases and Methods Used'.

Databases and Methods Used

Two multi-criteria evaluation methods were tested:

1. Summed Weighted Rank Model (SWRM) – based on the additive weighting evaluation method;
2. Highest Weighted Rank Model (HWRM) – based on the Maximax decision model.

The methods used in each of the models are summarised in Table 2 and the criterion used in each model are listed in Table 3. For both models expert input from DEC personnel was sought during the development of the criteria, the scaling, scoring and weighting of criterion and the definition of significance categories (Eco Logical Pty Ltd 2008). In both models a combination of coarse filter criterion (eg. representation of vegetation complexes or conservation status of wetland) and fine filter criterion (eg. presence of threatened flora, fauna and TEC's) were employed to rank biodiversity assets which meant that some of the criterion were not independent. The rankings for both models were based on readily available spatial data on biodiversity assets (these are listed in the footnotes to Table 3). The SWRM model was developed first and was undertaken by Eco Logical Pty Ltd (Eco Logical Pty Ltd 2008). The HWRM model was developed internally by DEC GSS. Prior to the development of the HWRM the criteria from the SWRM were reviewed and updated as were a number of the biodiversity asset spatial datasets. Therefore the criteria and spatial data used in the HWRM model were different to that used in the SWRM model and these differences are outlined in Table 3.

Table 2: Summary of methods and scoring used in each model.

	Summed Weighted Rank Model (SWRM)	**Highest Weighted Rank Model (HWRM)**
Measurement scales of biodiversity asset data	Interval	Interval
Brief description of ranking procedures undertaken in the GIS.	Analysis undertaken in a vector based GIS. Data layers for each asset were combined within a GIS into a single vector layer and attributed to indicate what assets were present in each polygon and the final rank for each polygon. More details are provided in Eco Logical (2008)	Analysis undertaken in a raster based GIS. Data layers for each asset was converted to a 100 m grid using the Spatial Analyst extension in ArcView 9.1. The Spatial Analyst Cell Statistics function (maximum) was then used to calculate the final rank for each 100 m grid cell.
Evaluation Method	Additive weighting	Maximax (Smith and Theberge 1987; Moffett and Sarkar 2006)
Requirements and Assumptions	Taken from Smith and Theberge (1987) 1. Measurement of criteria is on an interval or ratio scale 2. Measurements of different criteria are comparable 3. Criteria are independent 4. Weights can be defined	Each criterion induces a weak linear ordering on the planning units (alternatives) which in this case are the 100 m grid cells (Moffett and Sarkar 2006)
Criterion Score Range	1 (lowest) – 5 (highest) The weightings (scores) reflect the significance that the experts place on the asset (Eco Logical 2008).	1 (lowest) – 10 (highest) The weightings (scores) reflect the overall value that the experts place on the asset.
Final Rank Score Range	Final scores ranged between 0 (no assets) – 33 (highest).	Final scores ranged between 1 (lowest) – 10 (highest).
Significance Categories	The final scores were summarised into 6 significance categories.	The final scores were summarised into 5 significance categories.

Table 3: Summary of criteria and criteria scores (numbers in brackets) used in each model. Information in brackets under the GSS Criteria Group refers to the broad criterion class covered by the GSS Criteria Group as per Table 1 and the Appendix A. Maps showing Input Spatial Data of biodiversity assets for the SWRM are available in Eco Logical Pty Ltd (2008). Maps and tables of Input Spatial Data of biodiversity assets for the HWRM are shown in Appendices B – F.

GSS Criteria Group	**Summed Weighted Rank Model (SWRM) Criteria**	**Highest Weighted Rank Model (HWRM) Criteria**
Ecological Community Status (rarity and representativeness)	[7]Within a buffer area of a TEC[1] that is: • Critically Endangered (5) • Other (Endangered and Vulnerable TEC[1]; PEC[2]) (3)	[8]Within a buffer area of a TEC[1] that is: • Restricted to GSS (10) • Not restricted to GSS (9)
		[8]Within a buffer area of a PEC[2] (8)
	[9,10]Vegetation Community (Complex) Status ([11]VC asset dataset version 1) • < 10 % retained over SCP or is on the Eastern side of the Swan Coastal Plain (Pinjara Plain and Gingin Scarp) (4) • < 30 % retained over SCP or < 400 ha remain across the SCP or > 60 % of pre-European extent occurs in the GSS study area (3) • 30 % retained over SCP and < 30 % is protected in the GSS study area (2) • > 30 % retained over SCP and > 30 % protected in the GSS and no additional protection is (1)	[9,10]Vegetation Community (Complex) Status ([11]VC asset dataset version 2) • Vegetation Complexes with < 10 % retained across SCP or with < 10 % in the SCP portion of the Perth Metro Region (9) • Vegetation Complexes with < 30 % retained across SCP or with < 400 ha retained across the SCP or with > 60 % of pre-European extent is within the GSS (8) • Vegetation Complexes with < 30 % protected within the GSS (6) • Vegetation Complexes that have adequate levels of retention and no additional protection required (2)
Terrestrial Flora Rarity and Endemicity (Rarity)	[12]Within 500 m of an existing threatened (DRF[3] and Priority) flora record (4)	[12]Within 500 m of an DRF that is: • Locally[4] endemic (10) • Regionally[5] endemic (9) • non – endemic (8)
		[12]Within 500 m of Priority Flora that is: • Locally[4] endemic (6) • Regionally[5] endemic (5) • non – endemic (4)
Fauna Rarity and Endemicity (Rarity)	[13]Within habitat for the critically endangered Western Swamp Tortoise (4)	[13]Within habitat for the critically endangered Western Swamp Tortoise (10)
	[13]Within the critically endangered Western Swamp Tortoise EPP[6] Policy area (2)	[13]Within the critically endangered Western Swamp Tortoise EPP Policy area (9)
Wetlands (Representativeness, Productivity, Importance For Wildlife, Condition, Ecosystem services, Icon Ecological Communities)		[14]Ramsar Wetlands (none in the GSS) (10)
	[15,17]Wetlands of National Importance or Conservation Category Wetlands (5)	[15]Wetlands of National Importance (9)
		[16]Conservation Category Wetlands (8)
	[16]Resource Enhancement Wetlands (3)	[16]Resource Enhancement Wetlands (6)
	[16]Multiple Use Wetlands (2)	[16]Multiple Use Wetlands (5)
Bush Forever Sites (all criteria)	[18,20]Bush Forever site or Northern Crown Reserve (for areas outside of the Bush Forever study area) (2)	See linkage criterion

GSS Criteria Group	Summed Weighted Rank Model (SWRM) Criteria	Highest Weighted Rank Model (HWRM) Criteria
Remnant Vegetation Patch Size (Size)	[10]Patch size • >1000ha (5) • 250-1000 ha (4) • 100-250 ha (3) • 20-100 ha (2) • <20ha (1)	
Connectivity/ Ecological Linkages (Maintenance of Ecological Processes, Size)		[10,17]Remnant vegetation cover over a 2 km^2 area • 100 % (9) • 80 % - 99 % (7) • 60 % - 79 % (5) A recent study (Brooker et al. 2008) of the landscape requirements of sensitive avifauna species on the Swan Coastal Plain was used when setting this threshold. In this study a threshold of 60 % total vegetation cover within a 2 km area for the most sensitive species (Scarlet Robin) was identified.
		[17,18]Bush Forever sites associated with GSS Conceptual Linkages (8)
		[10,17]Remnant Vegetation within 1 km of a GSS Conceptual Linkage (7)
		[10,17]Remnant Vegetation within 1 km of a designated Area for Conceptual Linkage (7)
	[19]Plantation Linkage (2)	[10, 19]Post Pine Linkage site: • remnant vegetation (3) • cleared areas (1)

[1] Threatened Ecological Community
[2] Priority Ecological Community
[3] Declared Rare Flora
[4] Local endemic – refers to a species or community which is only found within the Swan Coastal Plain IBRA region.
[5] Regional endemic – refers to species or community which is only found within the South West Australian Floristic Region (SWAFR)
[6] Environmental Protection Policies
[7] Spatial data: Threatened and Priority Ecological Community Sites, boundaries and buffers in WA. Accessed July 2008. WA Department of Environment and Conservation, Perth
[8] Spatial Data: Threatened and Priority Ecological Community Sites, boundaries and buffers in WA. Accessed Feburary 2009. WA Department of Environment and Conservation, Perth.
[9] Heddle et al. (1980); Kinloch *et al.* (2009)
[10] Spatial Data: Swan Coastal Plain Remnant Vegetation mapping (1:20,000). Department of Agriculture and Food of Western Australia, Perth, WA. Extent of remnant vegetation mapping is based on December 2005/January 2006 ortho-photos for the PMR portion of the GSS and the date of the ortho-photos is unknown for other areas.
[11] VC asset dataset version 1 was undertaken prior to the completion of Kinloch *et al.* (2009) so criteria and weightings are slightly different to VC asset dataset version 2.
[12] Spatial Data: Threatened Flora Database (DEFL). Accessed July 2008. WA Department of Environment and Conservation, Perth.
[13] Government of Western Australia (2003).
[14] Spatial Data: RAMSAR Sites in Western Australia. Accessed August 2008. WA Department of Environment and Conservation, Perth.
[15] Spatial Data: Environment Australia 2001.
[16] Spatial Data: Geomorphic Wetlands, Swan Coastal Plain. Accessed June 2008. WA Department of Environment and Conservation, Perth.
[17] Brown *et al*. 2009a.
[18] Spatial Data: Bush Forever 2000 - Site Boundaries. WA Department for Planning and Infrastructure
[19] Brown et al. 2009b
[20] Spatial Data: Spatial Cadatral Database. Landgate, Midland, Western Australia, www.landgate.wa.gov.au

Results

Summed Weighted Rank Model

The ranking of the biodiversity assets using the SWRM reveal that 15.2 % of the study area has biodiversity assets rated as being of extremely high or very high significance and 28 % as being of high significance (Table 4 and Figure 1). These areas have been identified as being significant as they scored highly in regard to criterion relating to Ecological Community Status, Terrestrial Flora Rarity, Fauna Rarity, Wetlands and Remnant Vegetation Patch Size (Eco Logical Pty Ltd 2008).

The majority of areas ranked as being of high significance are located in the north and central areas of the study area where there has been limited, agricultural or industrial development (Figure 1; Eco Logical Pty Ltd 2008). However, small usually isolated pockets of land ranked as being of high significance do occur in the developed areas in the south and east (Figure 1). Even though these areas are surrounded by cleared areas they often represent one of the last remaining areas for a particular species or ecological community and therefore are significant.

Limitations of a number of the spatial datasets used in this ranking are creating some artificial boundaries to the significance classes. These include the circular or uniform buffers for threatened flora and ecological communities and straight line (tenure) boundaries that divide contiguous vegetation (Figure 1).

Table 4: Extent and proportion of land area in each of the significance categories for the SWRM.

Significance Category	**Total Area of the Gnangara Mound (ha)**	**Proportion of the Gnangara Mound (%)**
No Assets	69537	32
Very Low (score 1 – 2)	24402	11
Low (score 3 – 4)	13457	6
Moderate (score 5 – 6)	15023	7
High (score 7 – 9)	60162	28
Very High (score 10 – 19)	31837	15
Extremely High (score 20 – 28)	421	0.20
Total	**214839***	**100**

* Note: this analysis was undertaken by consultants prior to the boundary of the GSS study area being finalised. Therefore the total area of the Gnangara Mound reported for this model is slightly smaller than that reported in Table 5. The small areas not included are along the Swan River (open water) and coast.

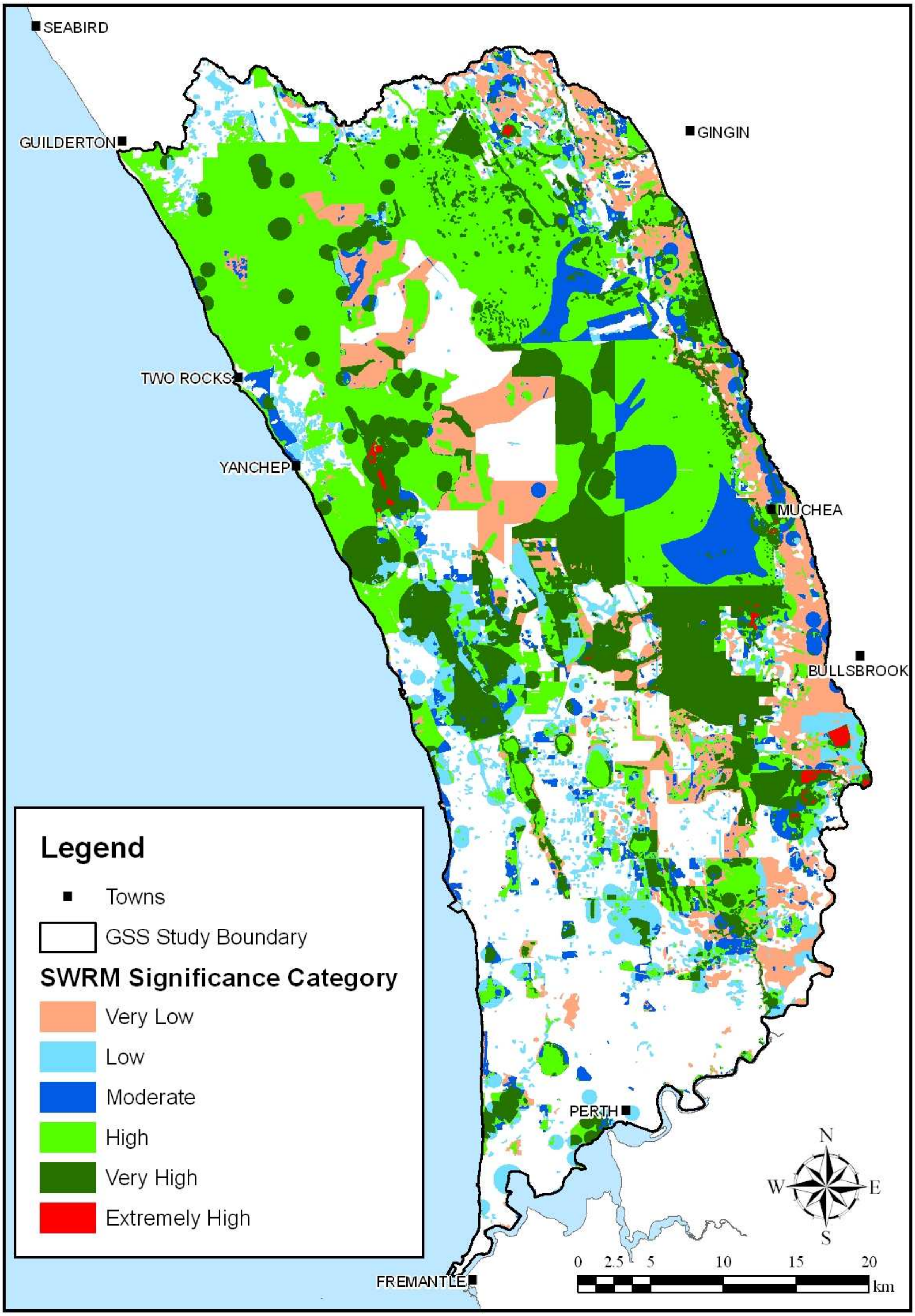


Figure 1: Ranking of biodiversity assets across the Gnangara Mound using the Summed Weighted Rank Model (SWRM)

Highest Weighted Rank Model

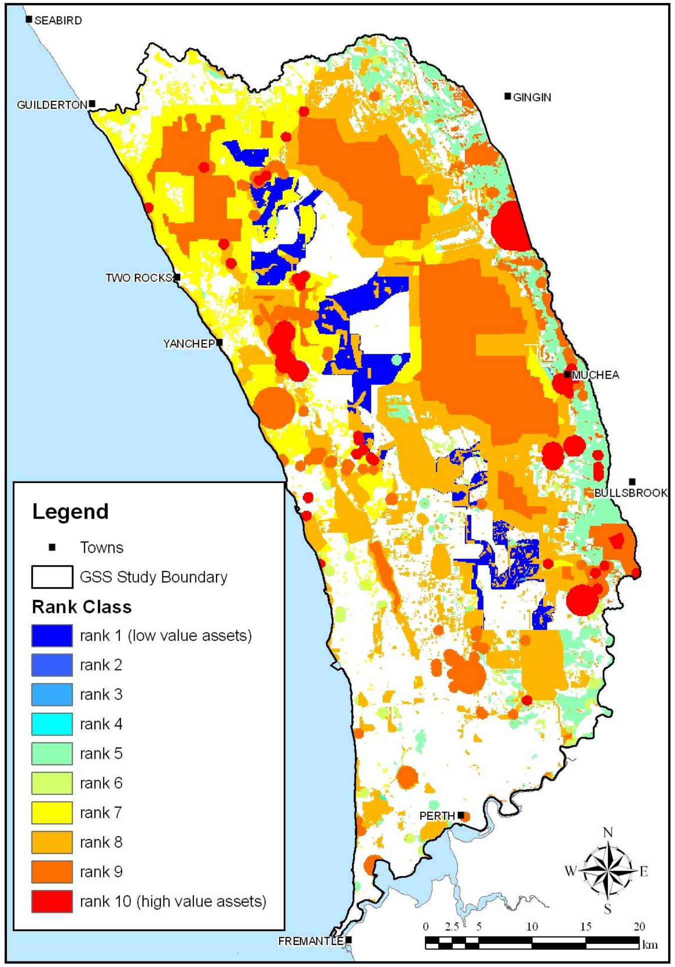
The ranking of the biodiversity assets using the HWRM revealed the majority of biodiversity assets were ranked 7 or higher (Figure 2a; Table 5). In total 43 % of the Gnangara Mound has biodiversity assets which are rated as being of very high or extremely high significance (Table 5and Figure 2b). These areas have been identified as being significant as they scored highly in regard to criterion relating to Ecological Community Status, Terrestrial Flora Rarity and Endemicity, Fauna Rarity and Endemicity, Wetlands and Connectivity/Ecological Linkages.

The spatial distribution of the areas ranked as being of very high or extremely high significance is similar to that of the first model with the majority of areas in the north and central areas of the Gnangara Mound with only small isolated pockets occurring in the developed areas in the south, east and far north (Figure 2b). This result was expected as the criteria used in both models are similar and the biodiversity assets used are either the same or very similar.

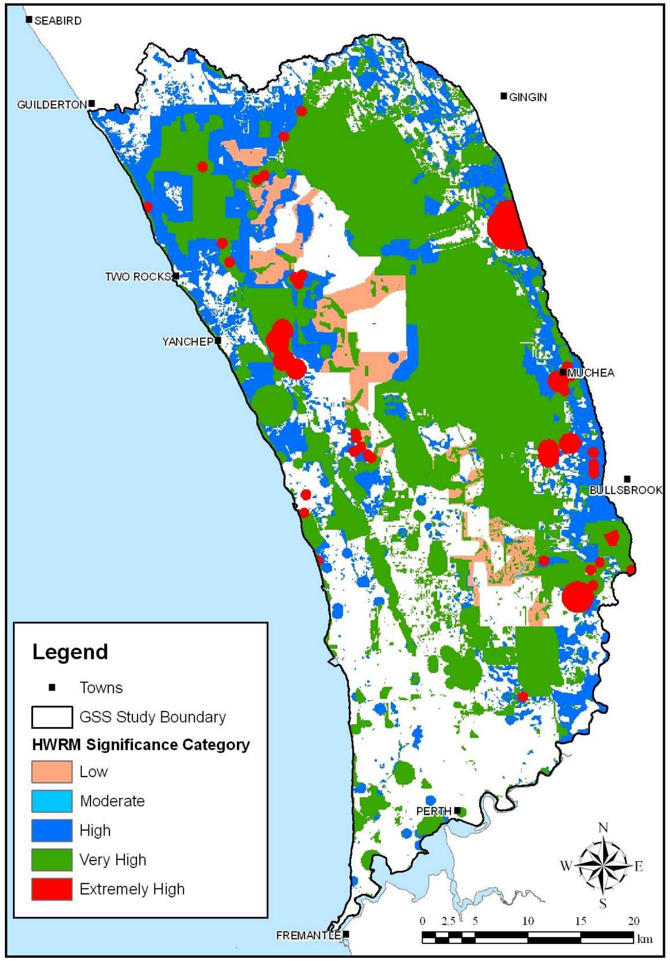
The limitations noted in the SWRM with the spatial datasets of threatened flora and ecological communities also apply here with the buffers producing a somewhat artificial line partitioning the ranks (Figure 2a&b). The problems of tenure lines within the remnant vegetation mapping causing artificial partitioning of ranks have been overcome though due to the analysis being undertaken in a raster environment using a fairly coarse grid size. Additionally patch size was not included in the criteria for the HWRM rather the criterion relating to ‘Remnant vegetation cover over a 2 km^2 area’ was used to distinguish those parts of the landscape which have high remnant vegetation retention and connectivity (Table 3).

Table 5: Extent and proportion of land area in each of the Rank Classes for the HWRM.

Rank Class	Total Area of the Gnangara Mound (ha)	Proportion of the Gnangara Mound (%)	Significance Category	Proportion of the Gnangara Mound (%)
no assets	72400	34	N/A	34
Rank 1	9838	5	Low	5
Rank 2	18	0.008	Moderate	0.024
Rank 3	33	0.015		
Rank 4	16	0.008	High	19
Rank 5	13425	6		
Rank 6	3222	1		
Rank 7	23110	11		
Rank 8	44386	21	Very High	40
Rank 9	41745	19		
Rank 10	6704	3	Extremely High	3
Total	**214896**	**100**		**100**



a)



b)

Figure 2: Ranking of biodiversity assets across the Gnangara Mound using the HWRM: (a) Rank Classes and (b) Significance Categories

Discussion

A direct comparison of the ranking of biodiversity assets resulting from the two different evaluation methods, applied in these multi-criteria models, is not possible. Not only were the evaluation methods different so were the criteria and some of the base asset datasets had been more fully developed for the HWRM (undertaken last). Despite this, some of the differences in the rankings can be directly related to the type of evaluation model used highlighting the strengths and weaknesses of each. The SWRM has been found to be more effective than the HWRM at discriminating areas which contain multiple high value biodiversity assets from those areas which contain only one (significance category of extremely high in Figure 1). These high value biodiversity assets are generally though not exclusively fine filter criterion and include threatened flora, threatened ecological communities, habitat for the critically endangered Western Swamp Tortoise, Wetlands of National Importance and Conservation Category Wetlands. The adding of the criterion scores in this evaluation method means that these types of areas will always rank very highly. In the HWRM those areas with multiple high value assets cannot be distinguished from those which have only one high value asset. These areas are all clumped together in the rankings (Rank 10 in Figure 2a). It must be noted that for the SWRM the assumption of independence of criterion has not been met since a combination of coarse and fine filter criterion has been used (Table 2). Good examples of this lack of independence are the criterion relating to the Western Swamp Tortoise, Wetlands of National Importance and Conservation Category Wetlands (Table 3; Appendix D; Appendix E). Independence of the criteria is not a requirement of the HWRM (Table 2) so using a combination of fine and coarse filter criterion is valid for the evaluation method used in this model.

Another drawback of the SWRM evaluation method is that potentially areas ranked in the very high or high significance categories may not be important in respect to any individual criteria. This is not a problem for the HWRM which basis the rank on the highest score for any criteria. Therefore we can be certain that those areas in the significance categories of very high or extremely high all have at least one high ranking biodiversity asset present. One more drawback of the SWRM evaluation method is that it is more susceptible to skewing the ranks towards those areas where there has been a greater amount of biological survey effort

One purpose in undertaking this type of evaluation is to reduce the large amount of information on biodiversity assets to a single rank or index. Another purpose is to provide new perspectives and insights into what areas have significantly high biodiversity values (Smith and Theberge 1987). Both models presented have been successful in achieving these aims and the analysis of the pros and cons of each above indicate that no one model has out performed the other. Rather both can provide valuable insights into the location, extent and significance of biodiversity values across the Gnangara Mound.

These analyses have illustrated that one of the drawbacks to multi-criteria evaluation models is that they are heavily dependent on expert input to weight scores both within and between criterion. This weighting process can be quite subjective in ecology (Smith and Theberge 1987) and this has proved to be the case with these models despite the fact that the same key people were involved for both models. It must be remembered that the development of these types of criteria is an iterative process so insights gained after each round of model development will improve our understanding and knowledge of the patterns of significance of biodiversity across the region and these insights will be fed into the next round of model development. This certainly happened in this case. For example the low final ranks of wetland vegetation on the eastern boundary of the Gnangara Mound were identified as a shortcoming of the criterion for the SWRM (Figure 1). This was rectified for the HWRM with the experts agreeing that the weighting applied to Multiple Use wetlands should be higher (Table 3).

Further development of these multi-criteria models is dependent on the further refinement of the criteria and some of the biodiversity spatial datasets (e.g. determining better ways of representing the extent of occurrences of threatened flora and threatened ecological communities for regional planning exercises such as these) and development of additional surrogate measures of biodiversity. In regard to the further development of the criteria consideration should be given to including criteria relating to the shape of remnant vegetation patches, using a index such as the perimeter to area ratio, especially in those areas where the remnant vegetation is highly fragmented (i.e., in those areas where there is < 60 % cover of remnant vegetation over a 2 km^2 area). The development of additional surrogate measures of biodiversity would certainly strengthen the criteria and models; especially those relating to both terrestrial and aquatic species and ecological community diversity, threats, productivity, condition and ecological processes (see below), but at this stage the lack of available spatial data prevent their inclusion. Surrogates based on spatial distribution models for species that have been developed using available location data from Museum or Herbarium records are increasingly been used in conservation planning (Margules and Pressey 2000) and in data poor regions modeling of collective properties of biodiversity is being considered (Ferrier 2002).

In more recent years there has been a greater recognition of the importance of conserving biotic processes required to produce and maintain pattern (Pressey 2004; Pressey *et al.* 2003; Smith *et al.* 1993). Therefore criteria relating to biodiversity processes are now being included in multi-criteria analyses that rank natural areas. A review undertaken by Pressey *et al.* (2003) found that four approaches had been used by recent conservation planning studies when considering biodiversity process: (1) incidental; (2) generic design criteria; (3) process-specific design criteria; (4) specific spatial attributes associated with process. These are further outlined in Table 6. In the models presented in this study and in previous multi-criteria biodiversity evaluations undertaken on the Swan Coastal Plain, biodiversity processes have been considered largely based on incidental and generic design criteria. Biodiversity pattern has been considered through levels of representation of vegetation complexes and wetland types (Del Marco *et al.* 2004; Government of Western Australia 2000; Hill *et al.* 1996). Design criteria relating to the size of intact natural areas and connectivity of remnant vegetation or linked wetland systems have also been employed (Del Marco *et al.* 2004; Government of Western Australia 2000; Hill *et al.* 1996). To enable approaches based on process-specific design criteria and specific spatial attributes associated with processes to be used on the Gnangara Mound information will need to be compiled relating to these parameters, surrogate measures will then need to be identified and spatial datasets relating to these will need to be developed.

Table 6: Description of approaches of including biodiversity process in recent conservation planning studies. Taken from review by Pressey *et al.* (2003).

Approach	Description
Incidental	By considering only biodiversity pattern some processes, that do not need large areas, are likely to persist even when not explicitly targeted. This approach ignores important population and ecological processes.
Generic design criteria	E.g. size, shape, connectivity. The approach can assist to maintain processes such as disturbance regimes, but their effectiveness is limited by the fact they don't consider requirements of specific processes.
Process-specific design criteria	Parameterising the generic design criteria with quantitative requirements for persistence of specific processes. This requires adequate (functional) information. Parameters could be related to: natural disturbances (setting minimum size), spatial requirements for select species, defining core geographical range for species where persistence is more likely.
Specific spatial attributes associated with processes	Identifies locations defined by specific physical or climatic features, associated with processes of interest (e.g. refugia).

It is not possible to base the formulation of conservation objectives and priorities for the Gnangara Mound solely on the biodiversity asset rankings emanating from the two multi-criteria evaluation models presented. Whilst both models provide valuable insights into what areas have significantly high biodiversity values one flaw with them is that they score sites in isolation (Wilson *et al.* 2008) and therefore can not provide insights into what are the minimum number of sites required to represent all species and biodiversity features (Possingham *et al.* 2008). Alternatively they cannot evaluate the contribution that a site makes to the overall reserve network or to meeting regional biodiversity targets (Wilson *et al.* 2008). To answer these types of questions decision support software such as Marxan (Ball and Possingham 2000) will need to be used. Marxan draws upon mathematical optimization models to determine the optimum network of sites that complement each other and meet conservation objectives and can also explore the socio-economic costs to meeting conservation objectives (Possingham *et al.* 2008; Wilson *et al.* 2008; Martin *et al.* 2008). The development of biodiversity surrogates and spatial layers for these two models will act as good groundwork for any future Marxan analysis.

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Appendices

Appendix A: Review of commonly used criteria

Review of commonly used criteria used in the ranking of biodiversity assets or natural areas. Numbers in brackets indicate publications reviewed (see footnotes at end of table and full citations are listed in the Reference section above).

Criteria	Definition	Generic Type of Criterion				Importance to Biodiversity Conservation	Examples of criteria's use in Regional Planning across the Swan Coastal Plain
		Biotic/Abiotic	Biodiversity Process	Planning and Management	Sociopolitical		
Rarity	"Rarity…is based on geographic (restricted area) and demographic (low numbers) criteria…"(1). It can apply to species or ecological communities. The evaluation of rarity is particularly dependent on the existence and syntheses of regional level information (2).	yes				Preservation of genetic diversity (2)	• Bush Forever – "considered from a ecological community and individual species perspective" (20) • Local Government Biodiversity Planning Guidelines for the PMR (12) • First – tier evaluation of wetlands in Wedge Island to Mandurah area (18 and 19)
Diversity	"the diversity of a community is …the number of its species (the community's species richness) and their relative abundance (called variously evenness, equitability or dominance)….. The term species is to be interpreted broadly, including the usual taxonomic definition but also classifications based on other criteria…." (3) Diversity is most commonly applied to assemblages of species but can also be applied to different taxonomic levels, vegetation communities or geological features (2)	yes				Diversity is important for several reasons: • "more for your money" or it is desirable to maximize the representation of species, communities or ecosystems (2); • 'special and distinctive' biodiversity features can only be maintained in a diverse protected area network (11) • there is a connection between diversity and stability though some authors dispute this connection (2); • link between diversity and genetic variability (4); • high vegetation diversity is more likely to provide a greater number of habitats that will meet the life cycle needs of a greater number of species (5).	• Bush Forever – "richness, diversity or complexity for their physical or biological attributes at the community, species or genetic level" (20) • Local Government Biodiversity Planning Guidelines for the PMR – considered in a general way only by considering upland and wetland structural plant communities (12) • First – tier evaluation of wetlands in Wedge Island to Mandurah area (18)

Criteria	Definition	Generic Type of Criterion				Importance to Biodiversity Conservation	Examples of criteria's use in Regional Planning across the Swan Coastal Plain
		Biotic/Abiotic	Biodiversity Process	Planning and Management	Sociopolitical		
Representativeness	This is better described as an approach to conservation rather than a single criterion (2). It seeks to represent within a protected area network the variation within biodiversity features be they species or habitats (2 and 10)	yes	yes			Biodiversity can potentially provide a range of environmental, social and economic benefits to society but these can only be supplied if the full range of biodiversity features can be maintained (11).	• Bush Forever - "representation of each floristic community type within each vegetation complex" and "each natural wetland group and wetland types within each wetland group" (20) • Local Government Biodiversity Planning Guidelines for the PMR (12) • First – tier evaluation of wetlands in Wedge Island to Mandurah area (18 and 19)
Maintenance of ecological processes	These criteria vary a great deal as they depend on the nature of the biotic, abiotic and threatening processes operating in ecosystems. Criteria relating to the maintenance of ecological processes have only recently been considered in conservation planning in only a general way and most examples of their use involve generic design criteria such as size , shape and connectivity (15).		yes			Preservation of biodiversity (ecological and evolutionary) processes which generate genetic diversity and drive speciation (14 and 15).	• Bush Forever - large areas with relatively intact natural processes (20). • Local Government Biodiversity Planning Guidelines for the PMR – considered in regard to connectivity (12) • First – tier evaluation of wetlands in Wedge Island to Mandurah area (18)
Productivity	"Productivity is a measure of rate at which communities of plants and animals bind energy into various kinds of organic material" (7)	yes	yes			Areas of high productivity are unusual or unique and often "provide the energetic basis for production over a larger area" (2)	• First – tier evaluation of wetlands in Wedge Island to Mandurah area (18 and 19)
Fragility/Stability	Vulnerability to a disturbance (2)	yes	yes			It implies that a species, feature or ecosystem has a high probability of extinction or damage therefore it needs protection from threatening processes (8). It is often correlated with rarity (2).	• Project Dieback uses susceptibility to *Phytophthora cinnamomii* (17).
Importance for Wildlife	"Identify areas that provide habitat for a certain, often large proportion of a wildlife population."(2). The notion of importance can relate to: • importance of different species (endangered vs widespread species) (2) • the importance of particular habitats to particular aspects of a species life cycle (eg., breeding) (2) • "the relative importance of site populations" (2)	yes	yes			See reasons listed in rarity and to maintain healthy, dynamic and sustainable populations (2)	• Bush Forever - fauna habitats specific for feeding/breeding/nursery functions, wildlife corridors and habitats for significant populations of migratory birds (20). • First – tier evaluation of wetlands in Wedge Island to Mandurah area (18 and 19)

Criteria	Definition	Generic Type of Criterion				Importance to Biodiversity Conservation	Examples of criteria's use in Regional Planning across the Swan Coastal Plain
		Biotic/Abiotic	Biodiversity Process	Planning and Management	Sociopolitical		
Size	The extent of a natural area.	yes	yes	yes		Size is important for a variety or reasons including: • playing a significant role in determining the many 'direct benefits' it can supply such as species richness or water yield (11); • each species has different range requirements so size needs to be considered to maintain viable populations (2); • natural areas should be "sufficiently large to be self – regulating, through the inclusion of all the interacting components ..."(6) including the maintenance of natural disturbance regimes (13); • larger natural areas have a greater capacity to resist disturbance and threatening processes (12)	• Bush Forever – lower size limit of 20 ha used though smaller areas were considered if a complex or community was threatened or poorly reserved (20) • Local Government Biodiversity Planning Guidelines for the PMR (12)
Shape	An assessment of how compact a natural area is.	yes		yes		The shape of a natural area has a large influence on the level of influence threats and disturbing processes have with compact shapes (such as circles or squares) being less impacted by edge effects and therefore having greater resilience (12).	• Bush Forever – compact shape is preferable to an irregular or an elongate shape (20) • Local Government Biodiversity Planning Guidelines for the PMR (12)
Condition	An assessment of the current ecological state of an ecosystem compared to what it would have been in pre European times or in the absence of human – induced disturbances (11). Benchmarks are often employed to enable this comparison.	yes	yes	yes		The condition of a natural area determines the "quality and presence of sensitive and vulnerable "(11) biodiversity features and biodiversity benefits. The "awe inspired by the grandeur" of natural landscapes is also dependent on the natural area being in good condition (11).	• Bush Forever – order of preference for remnants were those that were (summarized from 20): 1. largely undisturbed 2. basic vegetation structure intact 3. in lesser condition but able to be regenerated • Local Government Biodiversity Planning Guidelines for the PMR (12) • First – tier evaluation of wetlands in Wedge Island to Mandurah area (18)
Threat	Severity and imminence of threat (2) or susceptibility to threat.			yes		Threat is considered so the feasibility of being able to effectively manage an area is considered explicitly in the planning stages (2).	• Project Dieback – Autonomous spread of *P. cinnamomi*, proximity to infested areas, density of roads (17)
Naturalness	The absence of large-scale human modification but not the exclusion of sustainable traditional use of natural areas or the exclusion of natural disturbance regimes such as fire (2).	yes	yes			Reasons listed under Condition apply equally here. Undisturbed areas are also valuable in providing baseline information so we can assess the impact of disturbances in areas modified by humans (2).	• Bush Forever • Second – tier evaluation of wetlands in Wedge Island to Mandurah area (18)

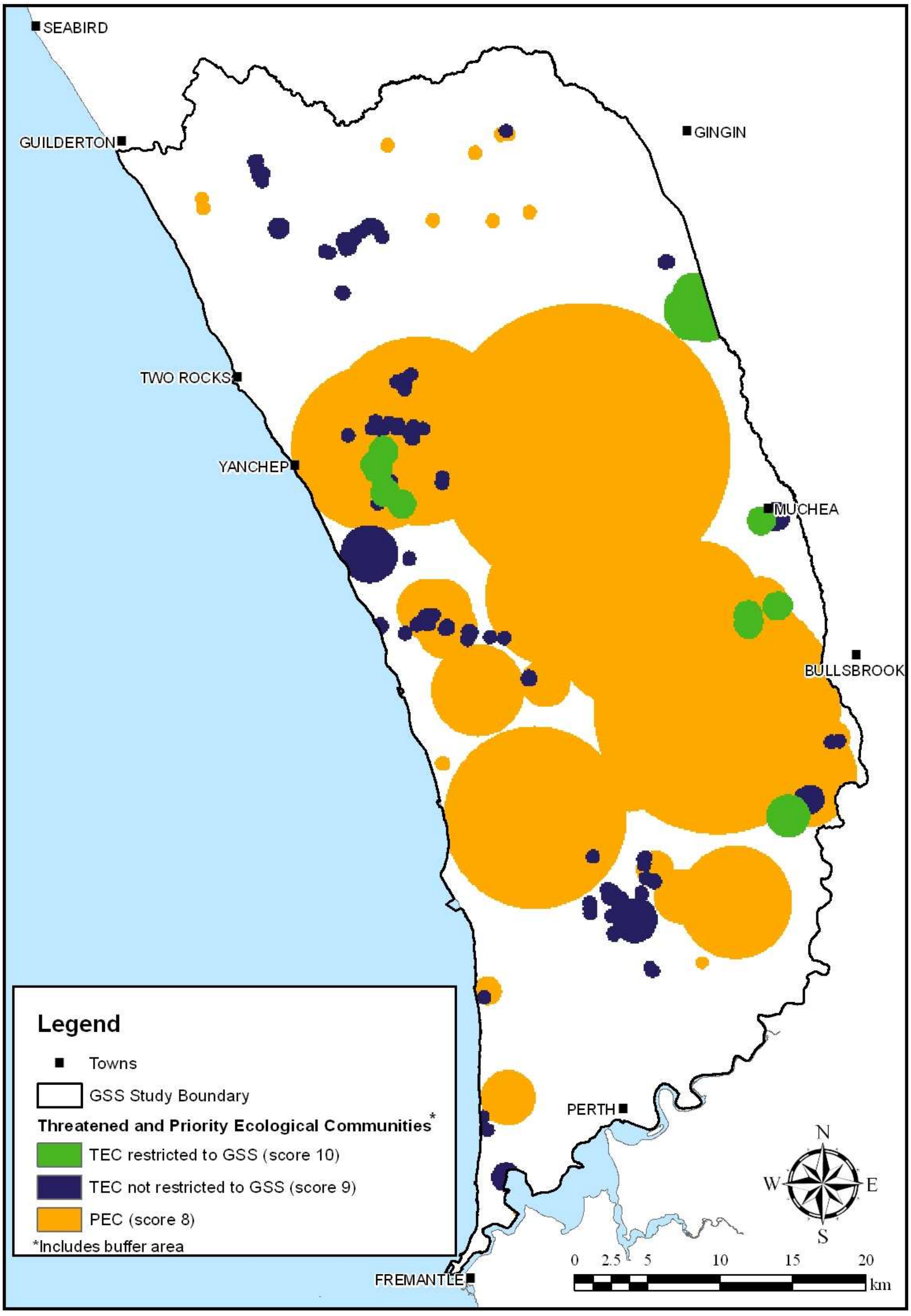
Criteria	Definition	Generic Type of Criterion				Importance to Biodiversity Conservation	Examples of criteria's use in Regional Planning across the Swan Coastal Plain
		Biotic/Abiotic	Biodiversity Process	Planning and Management	Sociopolitical		
Educational value	A natural area provides opportunities for the community to experience and learn about biodiversity and nature (12).				yes	On-going community and political support for biodiversity conservation initiatives is reliant on the community having a general understanding of why biodiversity is important.	• Local Government Biodiversity Planning Guidelines for the PMR (12) • First – tier evaluation of wetlands in Wedge Island to Mandurah area (18 and 19)
Historical significance	An area which contains "good examples of resources characteristic of a particular "prehistoric culture, historic tribe, period of time, or category of human activity" (9).				yes	To identify areas with cultural significance.	• Bush Forever (20) • Local Government Biodiversity Planning Guidelines for the PMR (12) • First – tier evaluation of wetlands in Wedge Island to Mandurah area (18 and 19)
Scientific Value/Research Investment	The further study of a site will help address current research questions in the biophysical, historical or archaeological fields (9) or is important site for the collection of baseline ecological data (2).				yes	Ongoing scientific research underpins many aspects of biodiversity conservation.	• Bush Forever – scientific or evolutionary importance (20) • Local Government Biodiversity Planning Guidelines for the PMR (12) • First – tier evaluation of wetlands in Wedge Island to Mandurah area (18 and 19)
Recreational Value	A natural area can be used for passive recreational use.				yes	One of the community benefits of protecting natural areas is that they can be used for passive recreational use (e.g. bushwalking) (12)	• Bush Forever - "area is a regional recreation resource" (20) • Local Government Biodiversity Planning Guidelines for the PMR (12) • First – tier evaluation of wetlands in Wedge Island to Mandurah area (18 and 19)

Criteria	Definition	Generic Type of Criterion				Importance to Biodiversity Conservation	Examples of criteria's use in Regional Planning across the Swan Coastal Plain
		Biotic/Abiotic	Biodiversity Process	Planning and Management	Sociopolitical		
Ecosystem Services	"Ecosystem services are transformations of natural assets (soil, water, air, and living organisms) into products that are important to humans" (16)	yes	yes		yes	Provision of ecosystem services are additional benefits that natural areas provide over and above the environmental benefits of protecting biodiversity.	• Bush Forever – wetlands are also recognized for the role they play in maintaining ecological functions associated with the hydrological cycle and river foreshores and coastal vegetation are recognized for the role they play in maintaining stability in these environments (20) • Local Government Biodiversity Planning Guidelines for the PMR (12) • First – tier evaluation of wetlands in Wedge Island to Mandurah area (18 and 19)
Icon species or ecological communities	These are criteria that relate to the protection of habitat for charismatic or easily recognizable flora, fauna or ecological communities that hold special significance to the local community or regional area (12).	yes			yes	The protection and promotion of an easily recognizable feature of the natural environment helps engage the local community in biodiversity conservation and promotes a sense of place (12).	• Local Government Biodiversity Planning Guidelines for the PMR (12) • First – tier evaluation of wetlands in Wedge Island to Mandurah area (18 and 19)

(1) Argus and White (1982) cited in Smith and Theberge (1986)
(2) Smith and Theberge (1986)
(3) Solomon (1979) cited in Smith and Theberge (1986)
(4) McKinnon (1982) cited in Smith and Theberge (1986)
(5) Environment Canada and Ontario Ministry of Natural Resources (1984) cited in Smith and Theberge (1986)
(6) Man and Biosphere Program (1974) cited in Smith and Theberge (1986)
(7) Peterson (1976) cited in Smith and Theberge (1986)
(8) Ratcliffe (1977) cited in Smith and Theberge (1986)
(9) Schiffer and Gummerman (1977) and Schiffer and House (1977) cited in Smith and Theberge (1986)
(10) Wilson et al. 2008.
(11) Stephens et al. 2002
(12) Del Marco et al. 2004
(13) Margules & Pressey 2000
(14) Smith et al. 1993
(15) Pressey et al. 2003
(16) Cork et al. 2001
(17) Strelein *et al.* (2008)
(18) Hill et al. 1996
(19) Leprovost et al. 1987
(20) Government of Western Australia 2000

Appendix B: HWRM Input Spatial Data – Ecological Community Status

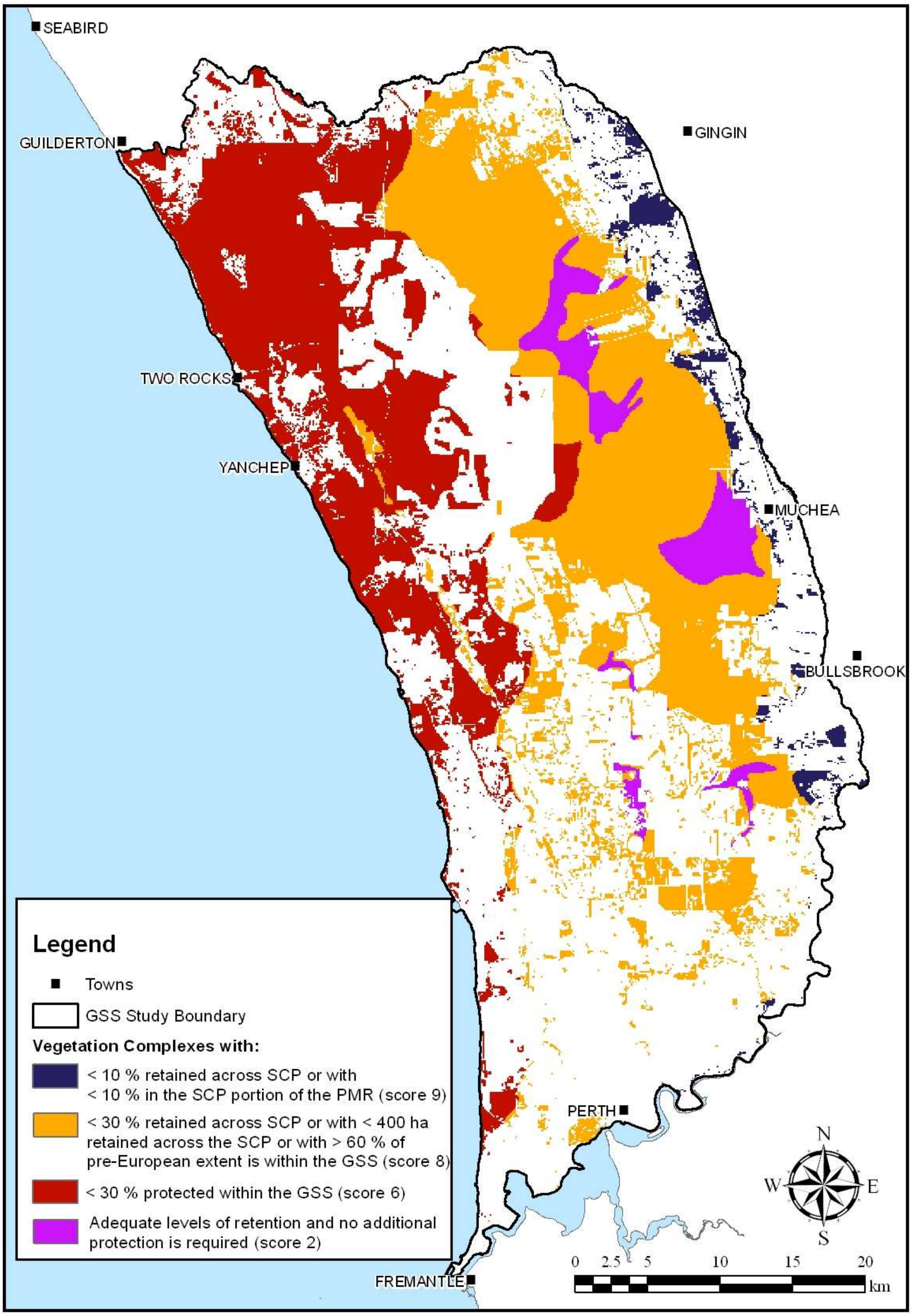
Threatened Ecological Communities



Identifier	Community Name	Criteria Score	Conservation Status	Endemism*
CAVES SCP01	Aquatic Root Mat Community Number 1 of Caves of the Swan Coastal Plain	10	Critically Endangered	Local
Mound Springs SCP	Communities of Tumulus Springs (Organic Mound Springs, Swan Coastal Plain)	10	Critically Endangered	Local
NTHIRON	Perth to Gingin Ironstone Association	10	Critically Endangered	Local
SCP19b	Woodlands over sedgelands in Holocene dune swales of the southern Swan Coastal Plain (original description; Gibson et al. (1994).	9	Critically Endangered	Regional
Limestone ridges (SCP 26a)	Melaleuca huegelii - Melaleuca acerosa (currently M. systena) shrublands on limestone ridges (Gibson et al. 1994 type 26a)	9	Endangered	Regional
Muchea Limestone	Shrublands and woodlands on Muchea Limestone	9	Endangered	Regional
SCP20a	Banksia attenuata woodland over species rich dense shrublands	9	Endangered	Regional
SCP07	Herb rich saline shrublands in clay pans	9	Vulnerable	Regional
SCP15	Forests and woodlands of deep seasonal wetlands of the Swan Coastal Plain	9	Vulnerable	Regional
SCP30a	Callitris preissii (or Melaleuca lanceolata) forests and woodlands, Swan Coastal Plain	9	Vulnerable	Regional
SCP22	Banksia illicifolia woodlands	8	Priority 2	Not asssessed
SCP21c	Low lying Banksia attenuata woodlands or shrublands.	8	Priority 3	Not asssessed
SCP23b	Banksia attenuata - Banksia menzeisii woodlands	8	Priority 3	Not asssessed
SCP24	Northern Spearwood shrublands and woodlands	8	Priority 3	Not asssessed
SCP25	Southern Eucalyptus gomphocephala-Agonis flexuosa woodlands	8	Priority 3	Not asssessed
SCP29a	Coastal shrublands on shallow sands	8	Priority 3	Not asssessed
SCP29b	Acacia shrublands on taller dunes	8	Priority 3	Not asssessed
SCP30b	Quindalup Eucalyptus gomphocephala and/or Agonis flexuosa woodlands	8	Priority 3	Not asssessed

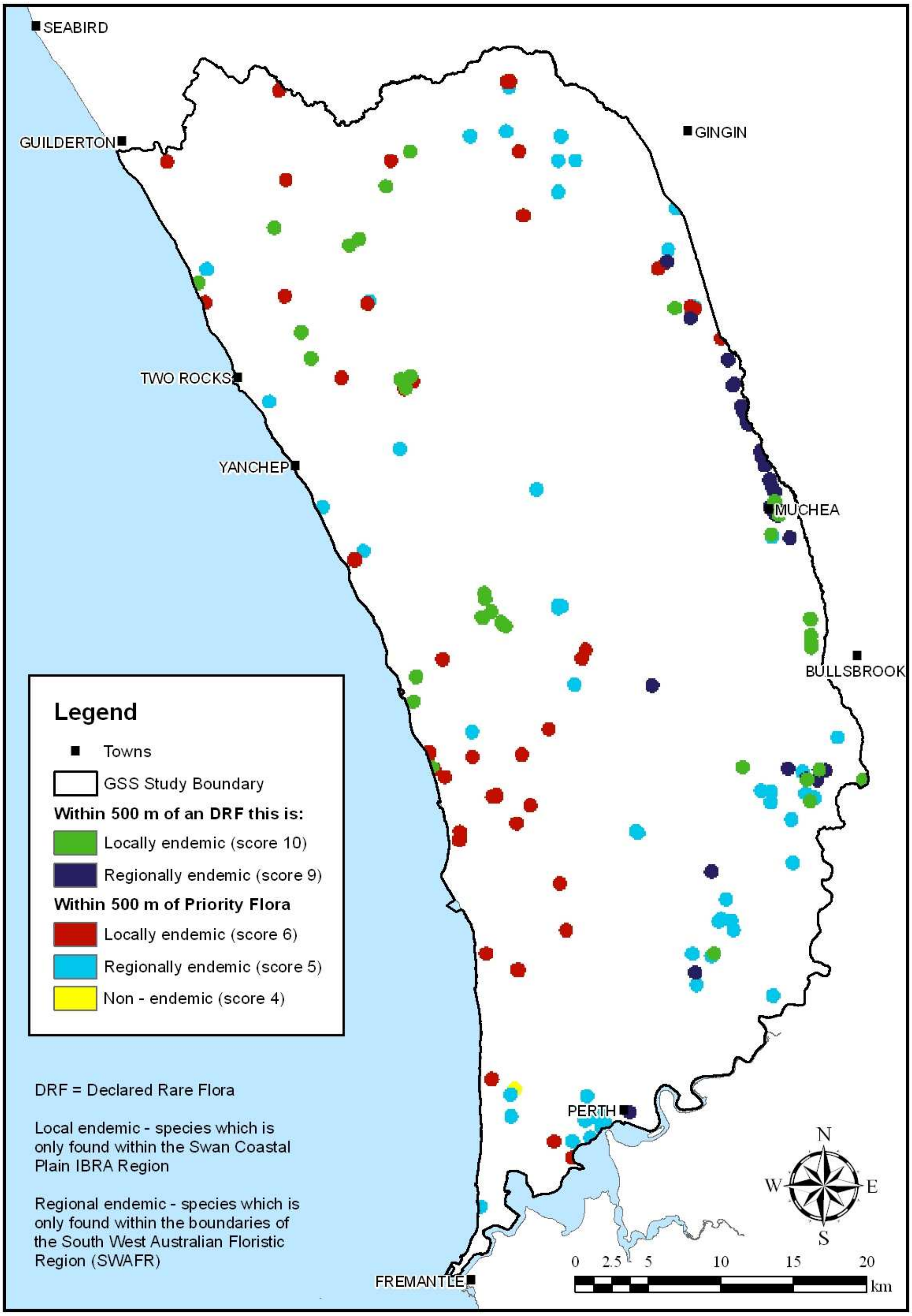
* Local – refers to a species or community which is only found within the Swan Coastal Plain IBRA region; Regional – refers to species or community which is only found within the South West Australian Floristic Region (SWAFR)

Vegetation Complexes



Vegetation Complex	Criteria Score	< 10 % SCP	< 10 % in the SCP portion of the PMR (2)	< 30 % retained SCP (3)	< 400 ha retained SCP (3)	> 60 % of pre-European extent is within the GSS (3)	< 30 % protected GSS (4)	no additional protection required (9)
Quindalup	6						x	
Cottesloe -Central And\South	6						x	
Cottesloe -North	6						x	
Karrakatta -Central And\South	8			x			x	
Karrakatta -North	6						x	
Karrakatta -North-\Transition	8					x		
Vasse	6						x	
Herdsman	8			x			x	
Pinjar	8			x		x	x	
Moore River	6						x	
Bassendean -Central And\South	8			x			x	
Bassendean -Central And\South-Transition	8					x		x
Bassendean -North	8					x	x	
Bassendean -North-\Transition	2							x
Caladenia	6						x	
Southern River	8			x			x	
Beermullah	9	x	x	x			x	
Guildford	9	x	x	x			x	
Swan	9		x	x			x	
Yanga	9		x	x		x	x	
Coonambidgee	9		x				x	

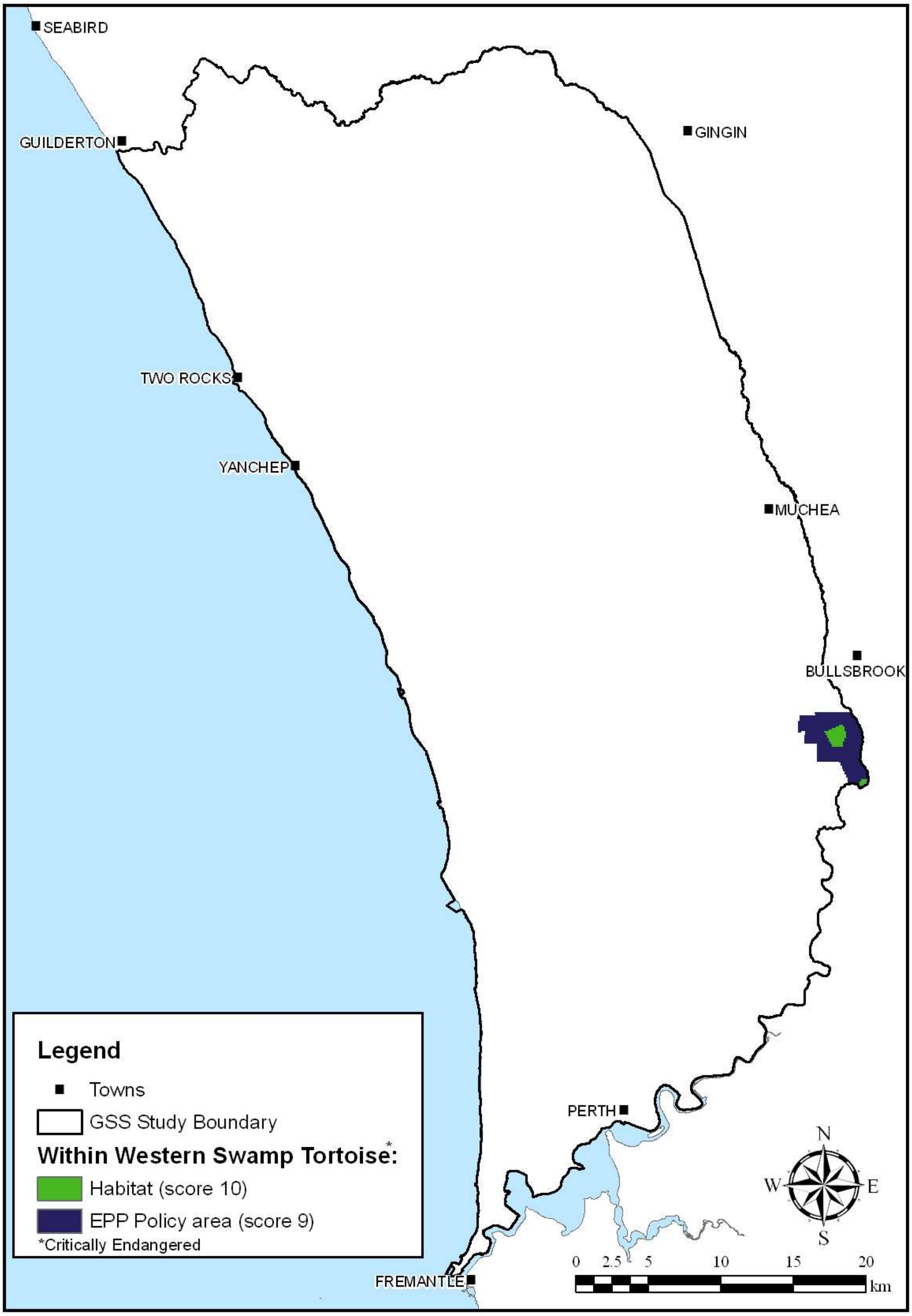
Appendix C: HWRM Input Spatial Data – Terrestrial Flora Rarity and Endemicity



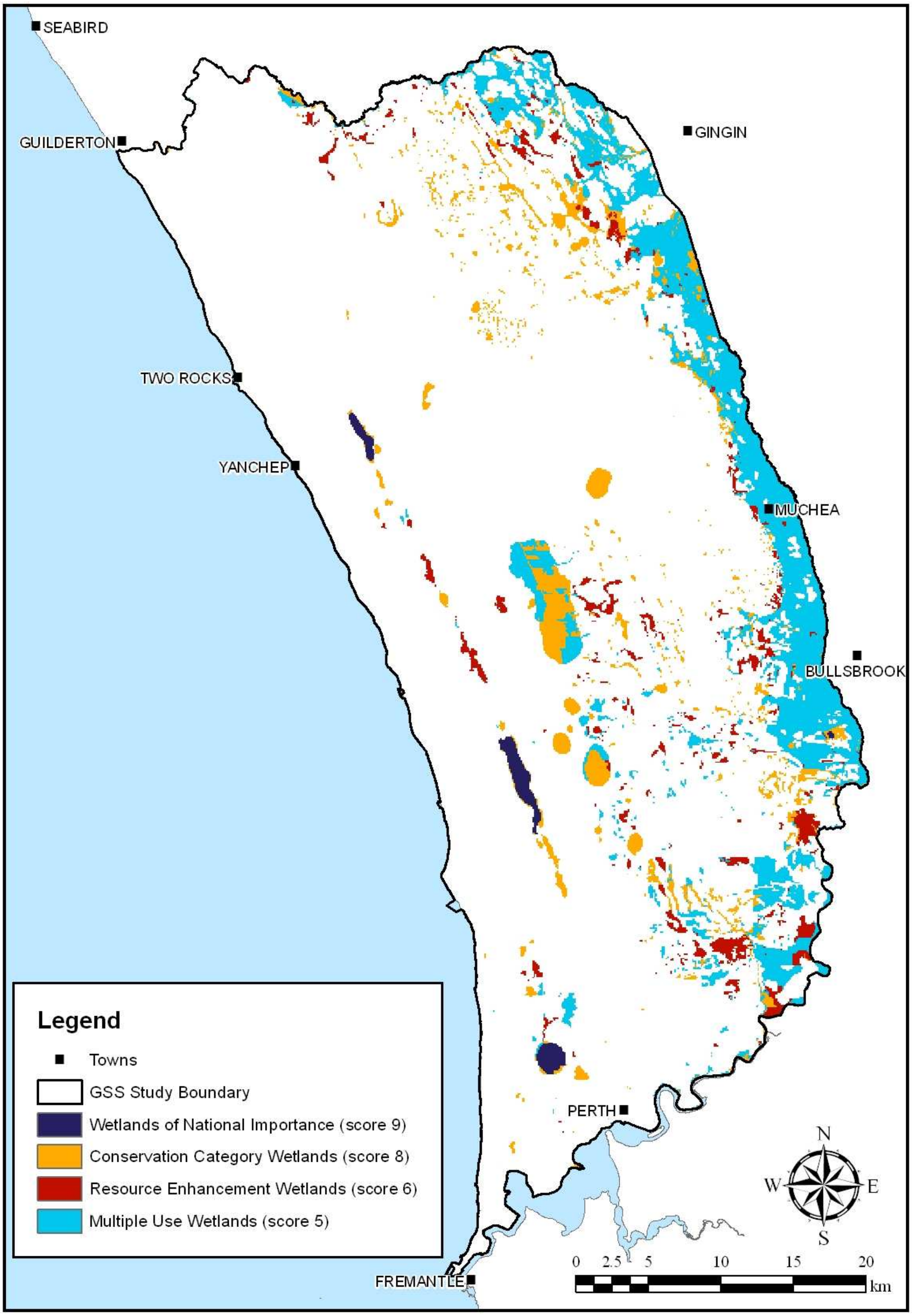
Scientific Name	**Criteria Score**	**Conservation Code[+]**	**Endemism[*]**
Caladenia huegelii	9	R	Regional
Darwinia foetida	10	R	Local
Drakaea elastica	10	R	Local
Eleocharis keigheryi	9	R	Regional
Epiblema grandiflorum var. *cyaneum*	10	R	Local
Eucalyptus argutifolia	10	R	Local
GRegionalvillea curviloba subsp. *curviloba**	10	R	Local
GRegionalvillea curviloba subsp. *incurva**	9	R	Regional
Trithuria occidentalis	10	R	Local
Marianthus paralius	10	R	Local
Anthotium junciforme	5	4	Regional
Conostylis pauciflora subsp. *pauciflora*	6	4	Local
Conostylis pauciflora subsp. *euryrhipis*	6	4	Local
Dodonaea hackettiana	5	4	Regional
Drosera occidentalis subsp. *occidentalis*	5	4	Regional
GRegionalvillea thelemanniana	5	4	Regional
Jacksonia sericea	6	4	Local
Schoenus natans	5	4	Regional
Stachystemon axillaris	5	4	Regional
Verticordia lindleyi subsp. *lindleyi*	5	4	Regional
Adenanthos cygnorum subsp. *chamaephyton*	5	3	Regional
Angianthus micropodioides	5	3	Regional
Aotus cordifolia	5	3	Regional
Beyeria cygnorum	4	3	Not Endemic
Blennospora doliiformis	5	3	Regional
Conostylis bracteata	6	3	Local
Cyathochaeta teRegionaltifolia	5	3	Regional
Dillwynia dillwynioides	6	3	Local
Haemodorum loratum	5	3	Regional
Haloragis (now Meionectes) tenuifolia	5	3	Regional
Hibbertia spicata subsp. *leptotheca*	6	3	Local
Lasiopetalum membranaceum	5	3	Regional
Myriophyllum echinatum	5	3	Regional
Rhodanthe pyRegionalthrum	5	3	Regional
Sarcozona bicarinata	6	3	Local
Stylidium longitubum	5	3	Regional
Stylidium maritimum	5	3	Regional
Acacia benthamii	6	2	Local
Anigozanthos humilis subsp. *badgingarra* (S.D. Hopper 7114)	5	2	Regional
Fabronia hampeana	5	2	Regional
Isotropis cuneifolia subsp. *glabra*	6	2	Local
Calectasia sp. Pinjar (C. Tauss 557)	6	1	Local
CaRegionalx teRegionalticaulis	5	1	Regional
Eucalyptus x mundijongensis	6	1	Local
GRegionalvillea evanescens	6	1	Local
Lechenaultia magnifica	5	1	Regional
Tripterococcus paniculatus	5	1	Regional

[*] Local – refers to a species or community which is only found within the Swan Coastal Plain IBRA region; Regional – refers to species or community which is only found within the South West Australian Floristic Region (SWAFR).
[+] 1: Priority One - Poorly known Taxa; 2: Priority Two - Poorly Known Taxa; 3: Priority Three - Poorly Known Taxa; 4: Priority Four - Rare Taxa; and R: Declared Rare Flora - Extant Taxa

Appendix D: HWRM Input Spatial Data – Fauna Rarity and Endemicity



Appendix E: HWRM Input Spatial Data – Wetlands



Appendix F: HWRM Input Spatial Data – Connectivity/Ecological Linkages