Gnangara Sustainability Strategy

An across-government initiative

Groundwater – Biodiversity – Land use

ECOLOGICAL LINKAGES WITHIN THE PINE PLANTATIONS ON THE GNANGARA GROUNDWATER SYSTEM

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Department of Environment and Conservation

June 2009

GOVERNMENT OF WESTERN AUSTRALIA

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Ecological Linkages within the Pine Plantations on the Gnangara Groundwater System

Report for the Department of Environment and Conservation and Gnangara Sustainability Strategy

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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

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Executive Summary

The State Government has indicated that the three pine plantations on the Gnangara groundwater system will be cleared by 2029 and replanted to native woodlands. The Gnangara Sustainability Strategy has recommended that only a portion of the cleared land be restored to native vegetation, due in part to the belief that parklands will increase water recharge and the high cost of total rehabilitation. However, through strategic ecological linkages, connectivity can be maintained, whilst also allowing for areas in which maximum water recharge can occur.

Within the pine plantations, patches of remnant vegetation remain that were not planted with pine, and it is these pine bushland patches which form the backbone of the proposed ecological linkages in this report. Each pine bushland patch was assessed for condition, landform, percentage burnt and wildings. This was combined with patch size, perimeter to area ratio, and proximity to remnant vegetation so that each patch could be ranked, allowing those that are likely to have greater ecological value to be identified. Proposed ecological linkages were then delineated to include the larger patches with the highest ranking score whilst also incorporating vegetation complexes which are poorly represented on the Swan Coastal Plain.

Native vegetation still persists within pine compartments as well as those where the pine has already been clear felled. This native vegetation was assessed for almost 25% of the plantation area and blocks with greater than 10% understorey or overstorey cover were considered ‘good quality’. By combining the areas of remnant vegetation and the areas with ‘good quality’ native vegetation, the area within each proposed ecological linkage requiring complete rehabilitation could be determined as well as an approximate cost.

In total, 19 ecological linkages have been proposed, covering 15 500 hectares with approximately 60% of this area requiring complete rehabilitation. The rehabilitation establishment techniques and costing is still to be determined, and the management of the linkages will require further research and development with government agencies. Once this has been finalised, these post-pine linkages will complement the regional ecological linkages which are proposed for the remainder of the Gnangara groundwater system.

Introduction

An indication has been made by the State Government that the three pine plantations within the Gnangara Sustainability Strategy (GSS) study area will be cleared of pine in accordance with the *Wood Processing (Wesbeam) Agreement Act 2002,* which commits the State to providing wood from the Gnangara Mound plantations until 2029. An announcement was made by the Western Australian State Government that the commercial pine plantations on the Gnangara Mound would be replanted to native woodlands once the pine is cleared (Department of Conservation and Land Management 1999). However, the cost of returning 23 000 ha of degraded land back to native bushland would be extremely expensive and there area also a range of competing land uses on the urban interface of metropolitan Perth. Whilst cost is one reason the plantations will not be completely rehabilitated, the driving reason not to replant all cleared areas is the requirement of groundwater recharge, as it is believed that parklands may increase groundwater recharge. One way to retain ecological connectivity across the landscape is through strategic linkages, rather than rehabilitating broadscale areas, thus reducing costs substantially.

The three plantations within the GSS study area, from south to north are, Gnangara, Pinjar and Yanchep, all of which are planted predominantly with *Pinus pinaster* on sandy and nutrient poor soils. Based on land use and groundwater hydrology, the GSS has separated the Gnangara groundwater system into 30 subareas, with the commercial pine plantations located across the Gnangara, West Gnangara, West Pinjar and East Yanchep subareas (Figure 1).

This study identifies the extent and condition of regionally important ecological linkages across the 23 000 ha of pine plantation in the GSS study area. The report only refers to potential ecological linkages within the boundary of the four designated GSS subareas that contain pine plantations. These linkages were designed to provide connectivity of vegetation and habitats primarily in an east-west direction as well as to conserve patches of remnant vegetation with vegetation complexes which are poorly retained and/or reserved within the GSS study area. This study complements other work being done by the Department of Environment and Conservation (DEC) GSS team on ecological linkages through the other 26 GSS subareas (Brown *et al.* 2009).

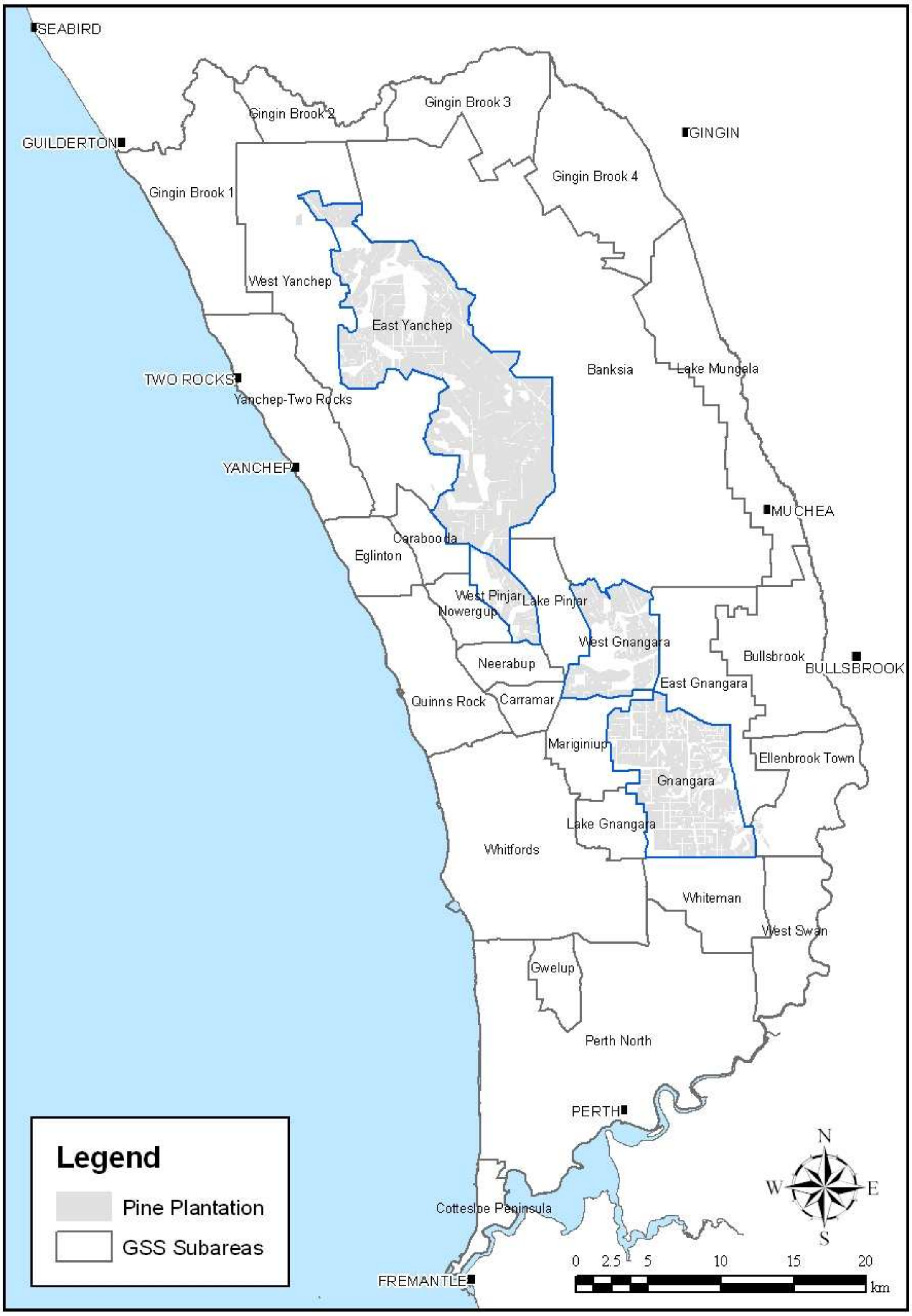

Figure 1: The Gnangara Sustainability Strategy study area and associated subareas. Those which are relevant to in this report are outlined in blue.

Landscape Connectivity and Spatial Characteristics of Remnant Patches

With habitat loss and fragmentation recognized as the two primary causes of species loss in Australia's southern temperate zone (Morton 1999), and a major threatening processes for the Swan Coastal Plain (Department of Environment and Conservation 2009) it is important that landscape connectivity is maintained through functional connections such as ecological linkages. Fragmentation often creates small isolated populations which are vulnerable to decline however this can be minimised by enhancing landscape connectivity through the presence of continuous corridors or ecological linkages and stepping-stones. This then allows for the movement of individuals, and thus genes, through the environment therefore supplementing declining populations, enhancing genetic diversity and assisting in recolonisation (Bennett 2006).

Ecological linkages have multiple functions including conservation of habitats for flora and fauna in human-dominated environments, retention of ecological processes (Bennett 1999) and aiding the movement of fauna. It is recognized that fauna need to move between habitat and resource patches if their effective long-term conservation is to be achieved (Bennett 1999; Hobbs 1992) and ecological linkages provide a means to do this. Bennett (2006) recognised that "a linked system of multiple remnants among which species or propagules can disperse will be more effective for long-term conservation than a system of isolated remnants and populations."

Landscape characteristics that have been found to impact on utilisation of corridors include corridor size and shape, the topographic location of the corridor and the size of connected patches have all been found to be influential. Additionally utilisation will depend on vegetation attributes within the corridor and the food resource availability. To ensure utilisation and success of ecological linkages it is essential to consider management to maintain or apply appropriate disturbance regimes, control invasive species, predators, competitors and minimize ecosystem threatening processes have been identified as essential to their success.

Whilst landscape connectivity is considered to be beneficial to biodiversity conservation, providing such connectivity is not as simple as providing structural connectivity, as the success of an ecological linkage in facilitating movement of an individual depends on the dispersal and colonisation success of the species as well as the spatial arrangement of their habitat. Landscape connectivity is species specific as a given landscape may be perceived simultaneously as both connected and disconnected by two species that differ in dispersal characteristics. The movement responses of a species to landscape structure, such as dispersal range and movement rates through different landscape elements, as well as how those responses differ as a function of broader-scale influences, need to be taken into consideration when designing a connected landscape (Taylor *et al.* 2006).

Whilst structural connectivity may not provide functional connectivity, e.g. if a target species does not use the linkage, the reverse is also true in that habitat does not necessarily need to be structurally connected to be functionally connected (Taylor *et al.* 2006). Some organisms are capable of linking resources across an uninhabitable or partially inhabitable matrix, through their gap-crossing abilities (Dale *et al.* 1994; Pither and Taylor 1998).

Landscape connectivity cannot be defined by an index of landscape pattern; it must be determined by the organisms' perception and interaction with the structure and heterogeneity of the landscape (Taylor *et al.* 2006). Assessment of such connectivity, both prior to, and after management modifications such as ecological linkages, begins with determining the movement and interaction of target organisms with the structural heterogeneity of the resulting landscape (With and Crist 1995). In addition to these species specific interactions with the environment, landscape connectivity is influenced by the matrix and the size and arrangement of resource patches (Taylor *et al.* 2006).

The size of remnant habitat is a critical determinant of species richness and population abundance (MacArthur and Wilson 1963; Rosenzweig 1995). The theory that species richness and individual abundance will decrease with reduced patch size has been supported by studies world wide (Dunstan and Fox 1996; Fahrig 2001) and significant relationships have been shown in Australia for birds, mammals, reptiles and less frequently, for plants (Howe 1984; Kitchener and How 1982; Lyon 1987; Prober and Thiele 1995; Suckling 1982). However, it is important to remember that although some species may require larger areas for survival; this is not always as important as other factors such as connectivity and the impacts of urbanisation on dispersal.

The shape of the remnant vegetation is also important as it determines the impacts from edge effects which influence the diversity and integrity of remaining biota (Rosenzweig 1995). Such edge effects include disturbance and degradation from increasingly frequent fires, altered light levels and weed invasions (Hobbs 1993). The proportion of a patch or reserve which is exposed to these effects increases as the perimeter to area ratio increases. Small remnant patches with an irregular shape will have a high perimeter to area ratio, and thus a larger amount of the patch will be exposed to edge effects than a large patch which is more circular in shape (Buchanan 1979; Saunders *et al.* 1991).

Past Regional Linkage Studies

There have been two regional studies over the past 10 years that have identified potential ecological linkages across metropolitan Perth – Bush Forever (Government of Western Australia 2000b) and the Perth Biodiversity Project (Del Marco *et al.* 2004). These two studies describe conceptual regional linkages as bands 500 m wide, linking major patches of regionally important bushland. They do not show where bushland is protected, or should be protected, and expect further planning work to determine the actual boundary of each ecological linkage. Additionally, the Gnangara Park Concept Plan (Department of Conservation and Land Management 1999) designated four potential corridors through the plantation areas which link them to large areas of remnant bushland. A range of Local Government “local corridors” have also been designated for the City of Wanneroo, City of Swan, Shire of Chittering and Shire of Gingin. These Local Government corridors vary in width from 100 – 500 m wide. All proposed regional linkages and local corridors are shown for the Gnangara Sustainability Strategy (GSS) study area in Figure 2.

Existing proposals for linkages across the four GSS subareas incorporating the pine plantations in the GSS study area are shown in Figure 3. Bush Forever (Government of Western Australia 2000a) designated five regionally significant linkages which traverse the plantations. The Perth Biodiversity Project (Del Marco *et al.* 2004), building on the work done for Bush Forever, added six regional linkages through the plantation areas.

The existing studies have highlighted the need to provide ecological linkages (Figure 4) between:

- Whiteman Park and the bushland in the East Gnangara subarea;
- Whiteman Park, Lake Gnangara and Lake Jandabup;
- East Gnangara subarea and Lake Jandabup;
- Gnangara and West Gnangara subareas;
- Lake Pinjar and East Gnangara;
- West Pinjar subarea, Lake Pinjar and Yanchep National Park;
- Yanchep National Park and the Banksia subarea; and
- Banksia subarea and the proposed Wilbinga reserve complex

Whilst areas have been identified for linkage, no assessment of the bushland within the pine plantations was undertaken and no final boundaries were determined. The linkages through the pine plantations, proposed by previous studies, were not always based on the presence of large remnant patches, and did not assess the patches to determine those likely to have the highest ecological value. Additionally they may not have taken into account the future removal of pines, and therefore the large area of State forest which may be available for restoration and inclusion in linkages.

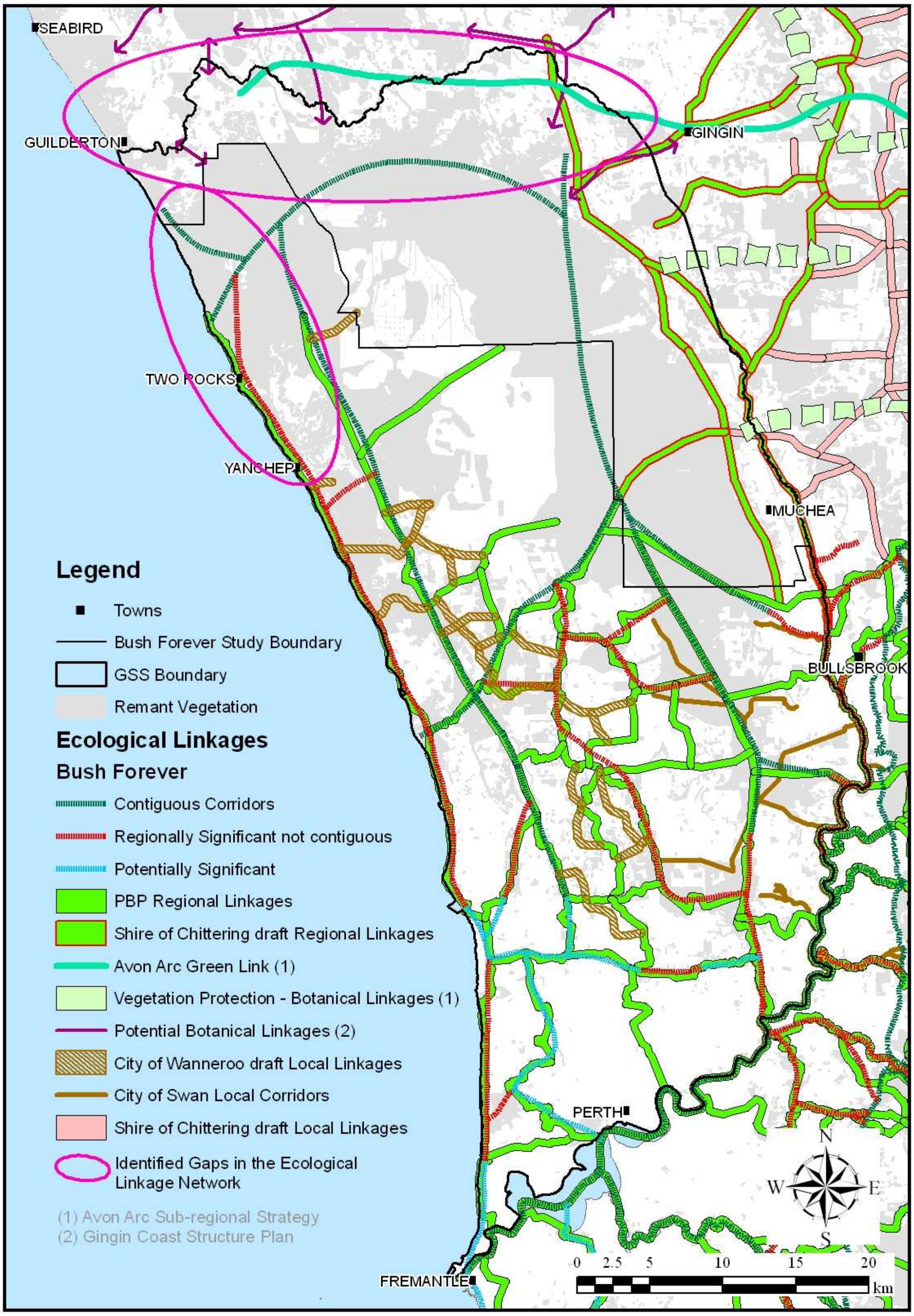

Figure 2: Ecological Linkages across the GSS study area from previous studies

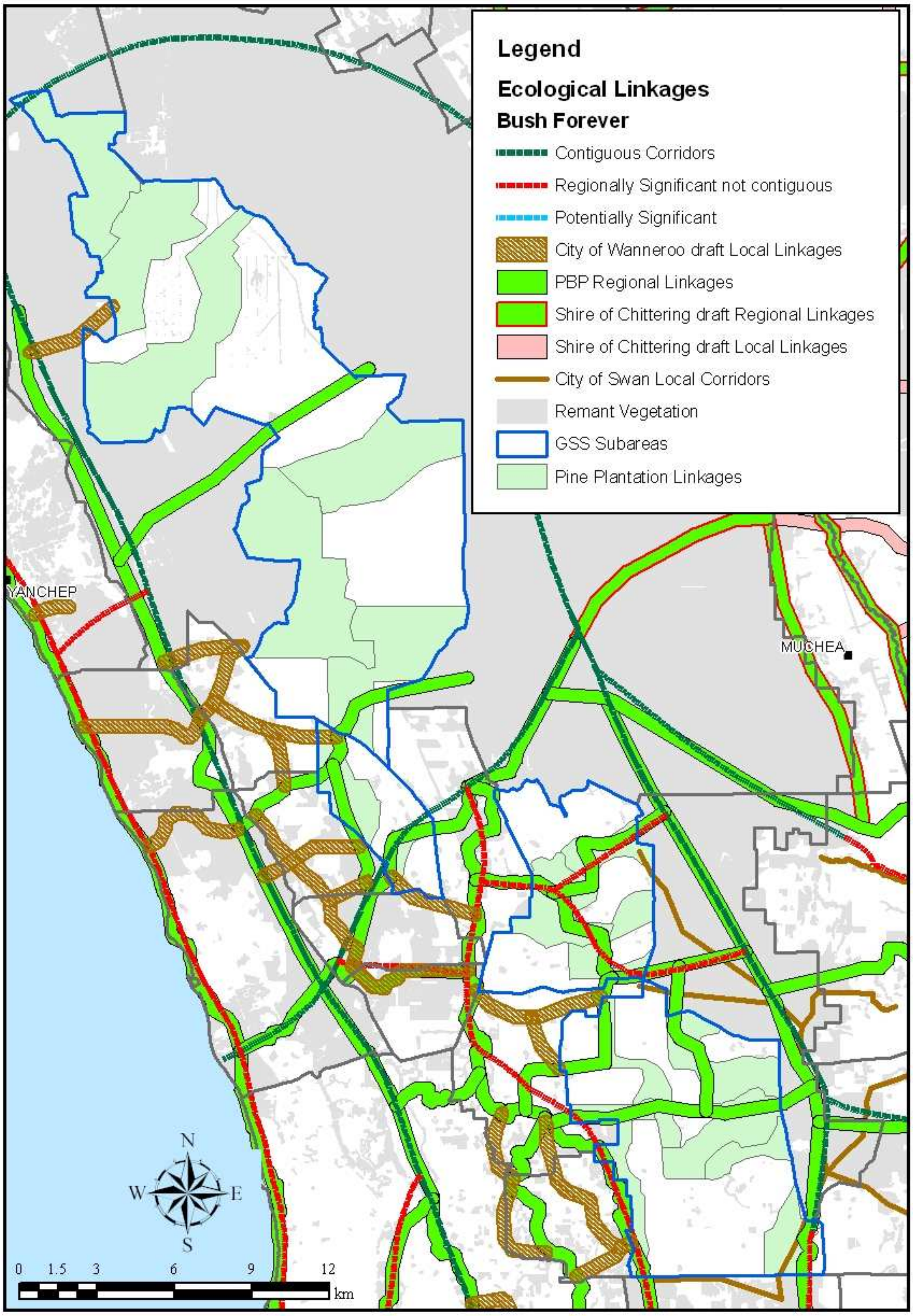

Figure 3: Proposed ecological linkages for the four subareas of interest. Linkages from previous studies are shown overlaying the proposed linkages defined by this study.

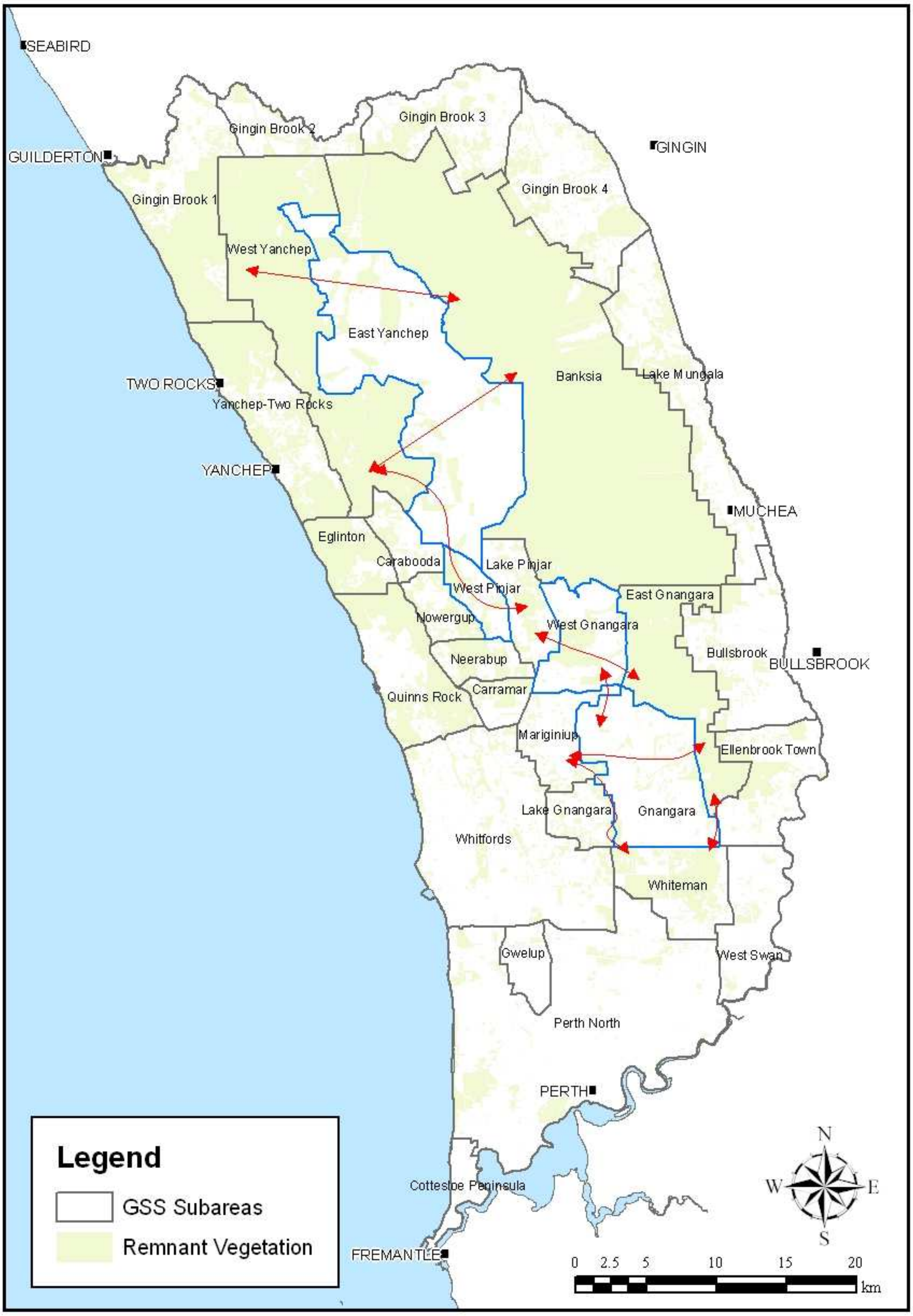

Figure 4: Requirements for additional ecological linkages are indicated by red arrows. The subareas which are relevant to in this report are outlined in blue.

Therefore the primary aim of this study was to identify 500-1 000 m wide ‘ecological linkages’, thus gaining connectivity, through the pine plantation network on State forest on the Gnangara groundwater system that:

- Link the largest and best condition remnant bushland patches;
- Maximises the proportion of existing bushland and areas of good native understorey and overstorey within the linkage area therefore minimising the area within the linkage that has degraded native vegetation to completely cleared areas, which require extensive rehabilitation and revegetation; and
- Contains Heddle vegetation complexes not adequately represented in the conservation estate on the Swan Coastal Plain.

Methods

Study Site

The study site was the 23 000 ha of State forest under the Gnangara, Pinjar and Yanchep Pine Plantations on the Swan Coastal Plain north of metropolitan Perth. These plantations fall within the GSS subareas Gnangara, West Gnangara, West Pinjar and East Yanchep which cover almost 31 000 ha of the GSS study area (Figure 1). All commercial pine is planted on land owned by the State Government and vested as State Forest with the WA Conservation Commission and managed by the Department of Environment and Conservation. The Forest Products Commission (FPC) own and manage the pine trees and all timber products within the plantations.

The plantations were planted by the State Government in the 20th century (1929 to 1995) and are to be cleared over a 25 year period (2002 to 2027). They occur on the sandy soils of the Spearwood and Bassendean Dune Systems and were established by clearing native vegetation (woodlands and wetlands) on appropriately selected soils. Depending on when the section of plantation was established, some areas of either very deep sand dune or wetland were not cleared and planted to pine as they were unsuitable. These unplanted remnant vegetation patches, within the plantation matrix, as well as the persisting and regenerated native understorey following pine establishment, form the basis for the selection and shape of the proposed ecological linkages in this study.

Adjoining the plantations are large areas of native woodlands on conservation estate – *Banksia* woodland to the north and east; tuart woodlands to the north-west in Yanchep National Park; and mixed *Banksia*-Marri Woodlands to the south in Whiteman Park.

Bushland Extent and Condition Survey

The existing DEC and FPC maps of the Gnangara, Pinjar and Yanchep Plantations were used to identify possible remnant vegetation 'patches' within the plantation that were not planted to pine. Roads were not assessed unless the associated reserve was 'unusually wide' (> 30 m width). The remnant patches in the main block of the Gnangara Plantation (between Gnangara and Neaves Roads) were surveyed in October to December 2007. The site visits to the remnants for the remainder of Gnangara, Pinjar and Yanchep Plantations were completed in February-March 2008. Each patch was examined using a rapid assessment (5 – 15 min) primarily by the senior author to determine:

- whether the landform and vegetation is upland or wetland;
- if the patch was burnt in any of the past four years (visual assessment only);
- if it represents either bushland or cleared breaks;
- the visual condition of the vegetation [broadly following the Keighery (1994); bushland condition rating scale (table 1)];
- the relative amount of pine wildings (ranked 1-5); and
- any comments about the site.

Phytophthora dieback was not visually assessed during these field visits and thus not used in the vegetation condition rating.

Table 1: Keighery condition scale from Keighery (1994)

Pristine Pristine or nearly so, no obvious signs of disturbance
Excellent Vegetation structure intact; disturbance affecting individual species; weeds are non-aggressive species
Very Good Vegetation structure altered; obvious signs of disturbance. For example, disturbance to vegetation structure caused by repeated fires; the presence of some more aggressive weeds; dieback; logging; grazing.
Good Vegetation structure significantly altered by very obvious signs of multiple disturbances. Retains basic vegetation structure or ability to regenerate it. For example, disturbance to vegetation structure caused by very frequent fires; the presence of some very aggressive weeds at high density; partial clearing; dieback; grazing.
Degraded Basic vegetation structure severely impacted by disturbance. Scope for regeneration but not to a state approaching good condition without intensive management. For example, disturbance to vegetation structure caused by very frequent fires; the presence of very aggressive weeds; partial clearing; dieback; grazing.
Completely Degraded The structure of the vegetation is no longer intact and the area is completely or almost completely without native species. These areas are often described as ‘parkland cleared’ with the flora comprising weed or crop species with isolated native trees or shrubs.

Bush Forever (Government of Western Australia 2000a and 2000b) defined bushland as native vegetation in good or better condition based on the Keighery (1994) condition scale. Therefore, non-pine plantation areas completely cleared of native vegetation and those with ‘degraded’ native vegetation were excluded from the analysis of ‘bushland’ remnants.

A shapefile was created for the remnant patches within and directly adjoining the three plantations based on aerial photographs, the existing plantation plans and site visits. A map of bushland extent and condition was then prepared.

Determining Representativeness of Vegetation

Heddle *et al.* (1980) mapped the vegetation complexes across the Swan Coastal Plain. Janine Kinloch used the Heddle vegetation complexes and the Department of Agriculture and Food Western Australia (DAFWA) 2006 remnant vegetation mapping to assess the pre-European and current extent of complexes found in the GSS study area. A separate technical report outlines the findings of this study including their level of retention and the priority for additional protection within the GSS (Kinloch and Valentine in prep).

Ranking of Bushland Patches

In order to rank the bushland patches, a series of scores, based on attributes of the bushland remnants (condition, area, perimeter to area ratio, vegetation complex, and proximity to remnant vegetation), were allocated to each pine bushland patch. All scores, except proximity to remnant vegetation, were totalled for each discrete patch, with a higher score indicating a greater ecological function. Once these total scores were calculated the patches with the highest scores had a proximity score added to it so as to further rank them according to proximity to remnant vegetation. Each attribute is outlined below, with details on how each of the scores were allocated.

Condition Score

The condition rating attributed to each patch during the bushland extent and condition survey was assigned a score (Table 2), following Keighery (1994), with ‘Excellent’ being given the highest score and ‘Good-Degraded’ the lowest.

Table 2: Condition Score

Condition Rating	**Score**
Excellent	6
Excellent – Very Good	5
Very Good	4
Very Good – Good	3
Good	2
Good - Degraded	1

Area Score

The area was calculated for each discrete bushland patch and these were then divided into five classes. If a bushland patch consisted of more than one polygon (i.e. there was a division due to vegetation condition, wilding score or an arbitrary division) then both polygons were given the same area score, from the composite patch, as they contribute to this patch. The classes and their associated scores are listed in Table 3 below, with the highest score attributed to the largest patches.

Table 3: Area classes and score

Patch Size	**Score**
>350 ha	5
100.1 – 350 ha	4
10.1 – 100 ha	3
1.1 – 10 ha	2
0 – 1 ha	1

Perimeter to Area Ratio Score

The perimeter to area ratio was calculated for each discrete patch however, as with the area score the same value was attributed to all polygons which contributed to that patch, if multiple polygons existed. The ratios were then divided into classes with equal intervals, and assigned a score as displayed in Table 4. Those with a smaller ratio were given a higher score as they had a greater internal area.

Table 4: Perimeter to area ratio classes and scores

Perimeter to Area ratio	**Score**
0 – 0.02	8
0.021 – 0.04	7
0.041 – 0.06	6
0.061 – 0.08	5
0.081 – 0.1	4
0.101 – 0.12	3
0.121 – 0.14	2
0.141 – 0.16	1

Vegetation Complex Score

Using the analysis of the Heddle vegetation complexes, each vegetation complex was assigned a score depending on its restriction, retention and reservation (degree of protection under DEC-managed estate) (Table 5). This gave greater priority to those vegetation types which are rare within the landscape. Where a patch consisted of more than one vegetation status, it was assigned the score of the vegetation complex which made up the majority of the patch.

Table 5: Vegetation status and score

Vegetation status	**Score**
<30% retained over SCP and GSS study area or >60% of pre-European extent occurs in the GSS study area	3
<30% of current extent is protected in the GSS study area	2
No additional protection required	1

Proximity to Remnant Vegetation Score

The proximity of each pine bushland patch to another patch of remnant vegetation, either within, or outside the pine plantations, was determined by buffering the remnant vegetation shapefile at a distance of 50 m. This allowed the proximity of any patch to its closest remnant vegetation patch to be determined to within 50 m. The proximity ranged from 0 to 1250 m. The distances were again divided into classes and scored (Table 6). Those with patches in close proximity were given the highest score so as to give weighting to connectivity of patches.

Table 6: Proximity classes and scores

Proximity to nearest remnant vegetation (within 50m)	**Score**
0 – 49 m	6
50 – 99 m	5
100 – 199 m	4
200 – 299 m	3
300 – 499 m	2
> 500 m	1

Native Vegetation Assessment under Pine

The identification of the extent (percentage cover and species diversity) of the native overstorey and understorey in planted pine compartments is a second component of this study. In 2004, the DEC Swan Coastal District let two tenders to evaluate the native vegetation across the south eastern part of the Gnangara Plantation. However, by mid-2007 the report for the first half of the work was only in draft form and the DEC had not received the second draft report nor any of the GIS data. The GSS team, through Tracy Sonneman, followed up with the consultants to complete the work and to have the DEC District (through Clayton Sanders) and the GSS (through Paul Brown) provide feedback on the draft documents. The two consultant reports were completed and GIS data provided to the DEC and the GSS Taskforce in 2008.

Woodman Environmental Consulting (2005; 2008) were contracted to identify, describe and map areas of persistent native vegetation present underneath pines within the eastern half of the GSS Gnangara subarea, (east of Centre Way and Silver Road). Each pine compartment was surveyed for native flora persisting under pines with a list of species generated for each compartment. A range of vegetation types under pines were recorded and mapped. Cover values for native understorey and overstorey were visually estimated in the field, and given as a percentage cover range. These percentage cover ranges were: 0-2%; 2-10%; 10-30%; 30-70% and 70-100%.

In the remainder of the GSS Gnangara subarea, as well as the West Gnangara and West Pinjar subareas which had not surveyed by Woodman Environmental Consulting, DEC staff drove tracks and roads to visually estimate and map the total percentage cover values of native overstorey and understorey. This was undertaken between July and November 2008 for all pine compartments within the West Gnangara and West Pinjar subareas and for the pine compartments within the proposed ecological linkages and the northwest corner of the Gnangara subarea.

A contract has been tendered by the DEC GSS team to evaluate the within pine compartment native overstorey and understorey in a portion of the East Yanchep subarea. This data was not available for this report (Woodman Environmental Consulting in prep). However, transect based native understorey density has indicated that the native vegetation in East Yanchep is diverse, dense and still widespread (Department of Conservation and Land Management 2002).

The results from the previous surveys were analysed to determine the relative distribution of the percentage cover ranges. This indicated that areas with understorey or overstorey within the two highest percentage cover ranges were scarce, and would therefore not prove to be useful in differentiating the compartments. As we were limited by the ranges previously supplied, determining categories for the percentage cover that could be considered representative of ‘good quality’ vegetation was challenging. We therefore made the subjective judgement that areas within the 10-30% and above (i.e. greater than 10%) range of understorey or overstorey provided sufficient cover to distinguish whether areas contained ‘good quality’ native vegetation or not. This was based on the field assessment that these areas could clearly be identified as having comparatively ‘significant’ native vegetation, and the fact that this threshold enabled us to map areas in large enough blocks to be of use in calculating the possible impact of persisting native vegetation on the placement of linkages and their rehabilitation requirements. Furthermore, the location of these “good quality’ areas suggested that the presence of more than 10% vegetation cover may indicate some innate characteristic or past management practice that allowed native vegetation to remain (e.g. wetland soils), and therefore allow us to distinguish areas where previous disturbance of native vegetation may have been minimal.

The use of ecological thresholds, such as the 10% described above, is gaining popularity in land use policy (Lindenmayer and Luck 2005). There is also an increasing amount of research that supports the theory of ecological thresholds (Radford *et al.* 2005). A local example which employed thresholds was site identification for Bush Forever, which used representation and retention of vegetation complexes as a key criterion. Inherent in the planning process was a general presumption against clearing any complex with less than 10% remaining in the Perth Metropolitan Region portion of the Swan Coastal Plain (Government of Western Australia 2000b).

Using the 10-30% range as a minimum vegetation cover for classifying areas as ‘good quality’, involves the assumption that such areas will require less rehabilitation than those without this level of native vegetation. This does not mean these areas do not require further rehabilitation, however with a greater chance of internal recruitment, supplemented with recruitment from surrounding remnant bushland patches, it is assumed that less restoration effort will be required.

Given the decision to use the 10-30% range as the minimum value, the following two criteria were used to produce shapefiles of areas of ‘good quality’ native vegetation within pine compartments:

- Total cover of native overstorey (if present) – greater than 10%; and/or
- Total cover of native understorey (if present) – greater than 10%

Delineating Ecological Linkages

Boundaries of potential ecological linkages were hand drawn across the four GSS subareas that visually met the following criteria:

- Meets the regional linkage objectives for the broader GSS project;
- Links the best condition and largest bushland remnants together in a 500 - 1 000m wide linkage across a section of the subarea;
- Includes areas of ‘good quality’ native vegetation in pine compartments; and
- Targets the vegetation complexes that have not been adequately protected.

Boundaries of linkages were adjusted and refined based on GIS analysis, expert input and field assessment. We then calculated the following for each ecological linkage:

- area (ha)
- maximum length (m), mean width (m)
- the proportion of each Heddle Vegetation Complex
- the proportion of "Bushland", defined as native vegetation in good or better condition based on the Keighery (1994) condition scale;
- total cover of native overstorey and/or native understorey – greater than 10%;
- remaining area that requires complete rehabilitation to native woodland
- approximate cost of rehabilitation based on $10 000 a hectare.

Results

Bushland Extent and Condition Survey

Bushland Patch Extent, Distribution and Size

A total of 6 100 ha of non-pine, and therefore potentially remnant native vegetation, was identified in 352 patches which were visited and assessed in the four GSS subareas. However 214 ha, or 27 patches, of these were found to be completely cleared of native vegetation and four hectares in four patches were exotic Eucalyptus arboretums. Bush Forever (Government of Western Australia 2000a and 2000b) defined bushland as native vegetation in good or better condition based on the Keighery (1994) condition scale. Thus a further 78 ha in 54 patches were assessed as 'Degraded', so not included in the subsequent analysis of 'bushland' remnants (85% of the non-pine areas designated Degraded were in the Gnangara subarea).

The attributes of the remaining 5 804 ha, in 267 bushland patches, ranged in size from 0.08 to 940 ha with variation between subareas (Figure 5). East Yanchep contained the second largest patches with West Gnangara containing the largest patch. This range in size has resulted in an average perimeter distance of 1 895 m and an average perimeter to area ratio of 0.046, with a standard deviation of 0.033, for all four subareas (Table 7).

Table 7: Broad characteristics of bushland remnants across the four GSS subareas.

GSS subarea	Gnangara	West Gnangara	West Pinjar	East Yanchep	Total
Total area (ha) of the subarea	7 666	4 096	1 663	17 525	**30 951**
No of discrete patches	135	48	23	61	**267**
Total area of patches (ha)	1 252	1 317	652	2 583	**5 804**
Mean area (ha)	9	27	28	42	**22**
Area of smallest bushland patch	0.08	0.11	0.43	0.10	**0.08**
Area of largest bushland patch	177	940	309	448	**940**
Average Perimeter (m)	1 492	1 923	2 306	2 610	**1 895**
Average Perimeter to Area Ratio	0.049	0.047	0.030	0.044	**0.046**

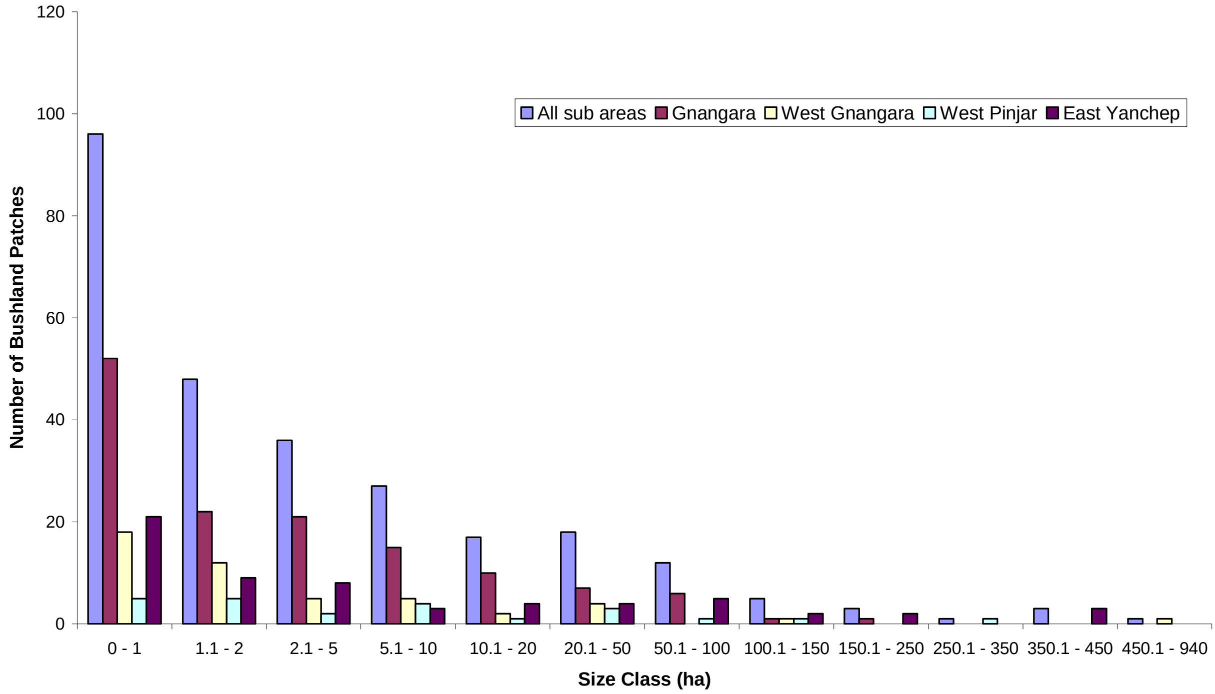

Figure 5: The distribution of patch areas across the four subareas and the study site as a whole.

The pine bushland patches were generally not evenly distributed between or within the subareas. The greatest number of bushland patches occurred in the Gnangara subarea and within this subarea they were biased to the north and east of the plantation (except for a few bushland blocks on the western edge of the plantation). There was also little bushland in the southwest quarter of the plantation and what did remain was only in Good condition. Similarly, West Gnangara has the largest number of patches to the east, with most stretching across the plantation and one large patch in the centre. In contrast, West Pinjar appears to be more uniform and East Yanchep has fewer individual patches with generally larger areas that are more prevalent to the west in the southern half of the subarea.

West Gnangara has the second highest proportion of pine bushland out of all the subareas surveyed, with West Pinjar containing the highest. Gnangara and East Yanchep have almost the same component of pine bushland patches in each subarea.

Vegetation Condition in Bushland Remnants

Overall there were a greater number of bushland patches rated as Excellent (67%) than any other class. The condition Excellent-Very Good had the second largest area attributed to it (15%) and the total area within each condition rating then continued to decrease as the condition declined (Figure 6).

Condition rating was not evenly distributed amongst the four subareas. The Gnangara subarea had the greatest number of patches in the Good to Very Good categories whilst the other subareas were predominantly Very Good to Excellent. For example, Gnangara was the only subarea with less than 80% of bushland remnants in Excellent condition (only 13% in Excellent condition). The East Yanchep subarea had 80% of the bushland remnants in Excellent condition and a further 15% as Excellent-Very Good. In comparison, the West Gnangara and West Pinjar subareas both had greater than 80% of bushland in Excellent condition, but had slightly smaller proportions in Excellent-Very Good condition, and unlike East Yanchep they did have a small percentage of remnants in Good and Good-Degraded conditions.

The vegetation in the largest 45 patches (over 25 ha in size) were all rated as Very Good to Excellent condition. Excluding these 45 patches, there was no correlation between bushland patch size (ha) and vegetation condition rating. This is consistent with studies conducted on the eastern side of the Swan Coastal Plain, which indicated that even small bushland patches, if not disturbed, can be very resilient to weeds and degradation

(Government of Western Australia 2000b; Keighery *et al.* 1997). Sites with heavy soils containing a high percentage of clay often display this resilience which Keighery *et al.* (1997) suggests is related to the following factors: density of cover of plant communities, seasonal inundation and the dry impenetrable nature of clay-based soils in summer.

The relationship between condition and landform revealed that the uplands were more frequently in Excellent condition than the wetlands. Of the uplands, 89% were rated excellent or Excellent-Very Good however only 37% of the wetlands fell within these condition rating categories.

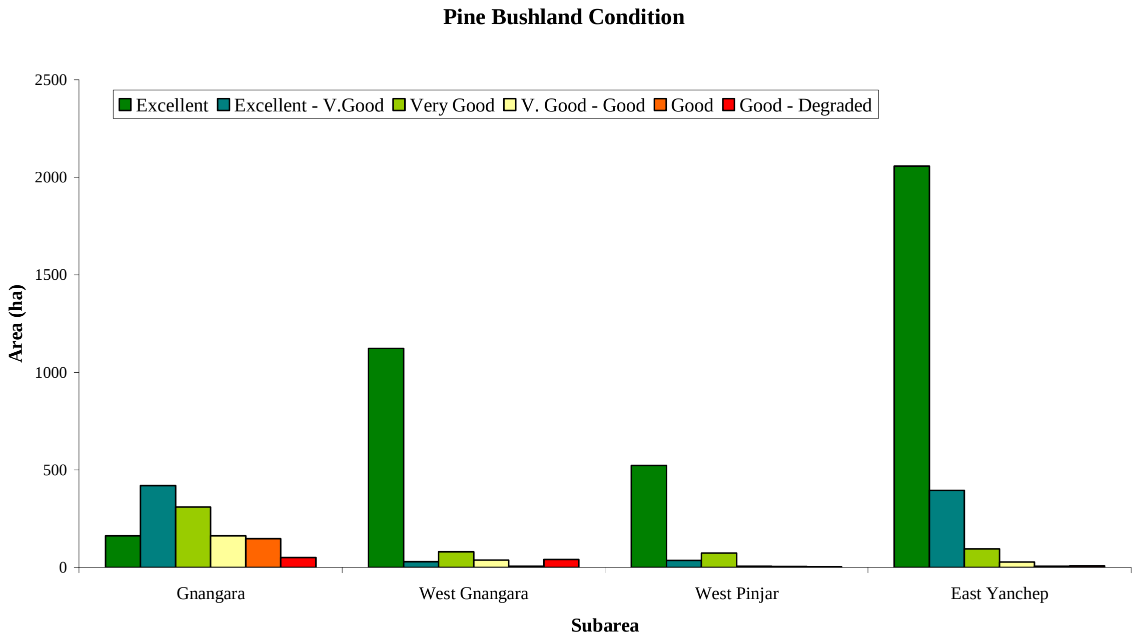

Figure 6: Attributes for bushland remnants in each of the Gnangara Sustainability Strategy subareas containing extensive areas of pine plantation.

Landform and Vegetation Type

Overall, uplands make up 86% of the total area surveyed; however wetlands are distributed unevenly across the four subareas. The bushland patches in the East Yanchep subarea are almost all uplands (99%) with only three wetlands present. The bushland patches in the West Pinjar subarea are also predominantly uplands (92%) with only four wetland patches. Whilst the patches in West Gnangara are predominantly upland (82%), if the one large patch (904 ha) is excluded then the percentage of uplands decreases to 48% thereby making wetlands predominant in this subarea. Within the Gnangara subarea, the majority of bushland patches were upland sites (61%), however, whilst the total area covered by wetlands in Gnangara is less than that of uplands the number of individual patches classified as wetlands outweighs that of uplands.

The wetland sites consisted predominantly of a *Melaleuca preissiana* overstorey whilst the majority of upland sites were *Banksia* woodlands or limestone heaths. Within the Gnangara and West Gnangara subareas, the upland patches were predominantly Banksia woodland on grey sands on Bassendean Dunes, and there was no evidence of limestone outcropping, yellow sands nor Spearwood vegetation types. West Pinjar and East Yanchep subareas are situated on Spearwood Dunes over a range of Heddle Vegetation Complexes. Thus they had greater diversity in the overstorey of upland patches with scattered eucalypts (Tuart, Blackbutt and Jarrah), Marri and Casuarina. Additionally, limestone outcropping was also common in these bushland remnants.

Impact by Fire and Pine Wildings

Few bushland remnants have been burnt in the past four years and it would appear many are long unburnt. Overall 70% of the pine bushland remnants are unburnt (in the last four years) with Gnangara having a considerable percentage of bush unburnt (95%). Records of prescribed burning by CALM / DEC in the Gnangara Plantation originally indicated that few bushland patches had been burnt in the last 10 years (Mike Cantelo, District Fire Coordinator pers. comm.) however a large amount of remnant vegetation was burnt in 2008/2009, particularly within the West Gnangara subarea. Both West Pinjar and East Yanchep have 75% of their pine bushland remnants unburnt whilst West Gnangara only has 32%.

Pine wildings were noted in the majority of patches, however in the larger patches this tends to be concentrated along the perimeter. Such edge effects are notable as the smaller patches of bush tend to have higher wildings ratings. The majority of bushland patches received the lowest pine wilding rating of 1 (76%) or 2 (19%) with only a few having more severe wilding infestation (leaving 5% with a rating 3-5). The majority were large saplings 3 – 4 m high, but there was a full range of pines from fully grown trees to small seedlings < 0.5 m high. Gnangara was the most affected by pine wildings with 60% of patches rated as 2 and the highest number of patches with a rating of 3 (13%). The other three subareas were not as badly infested as Gnangara with West Gnangara recording 91% of patches rated as 1, and West Pinjar and East Yanchep with 97% and 90% of their patches rated as 1 respectively.

Ranking

The total scores, without the proximity score, ranged from 6 to 22, with 22 being the maximum score achievable. Only two patches scored 22 with the majority scoring 16. The scores were divided into classes (Table 8) so that the proximity score could be added to those in the top two classes.

Table 8: Total scores without proximity and score classes

Score	Polygon Count	Polygon Count (%)	Score Classes
6	3	0.8	Very Low
7	2	0.5	
8	8	2.0	
9	6	1.5	
10	18	4.5	Low
11	26	6.6	
12	30	7.6	
13	30	7.6	
14	38	9.6	Moderate
15	33	8.3	
16	44	11.1	
17	39	9.8	
18	33	8.3	High
19	35	8.8	
20	29	7.3	
21	20	5.1	
22	2	0.5	

Once the proximity score was added the final score was again divided into classes as seen in Table 9.

Table 9: Total scores, with proximity added to the two highest classes, and their associated score classes

Score	Polygon Count	Polygon Count (%)	Score Classes
0	123	31.1	Very Low
16	7	1.8	Low
17	7	1.8	
18	15	3.8	
19	36	9.1	Moderate
20	33	8.3	
21	28	7.1	
22	28	7.1	
23	31	7.8	
24	25	6.3	High
25	24	6.1	
26	22	5.6	
27	15	3.8	
28	2	0.5	

This then indicated which patches may have higher ecological values by assigning them higher scores. Figures 7-9 show the four subareas and their associated bushland patches (coloured to show their final ranking). These figures also show the locations of the proposed ecological linkages.

Once ranked, almost all of the pine bushland patches within the high score class were located within one of the ecological linkages established by this study. Of the seven patches that were not within a linkage, four were located outside of the pine plantation (they are adjacent to remnant vegetation within the pine plantation) and hence outside of the subareas in which ecological linkages were designated. The percentage of patches outside of the linkages continued to increase for the moderate and low score classes then decreased slightly for the very low score class (Table 10).

Table 10: Statistical analysis of final rank score classes

Score Class	No. of polygons in Score Class	No. of polygons outside Ecological Linkages	% of polygons outside Ecological Linkages
High	88	4	5
Moderate	156	54	35
Low	29	20	69
Very Low	123	68	55

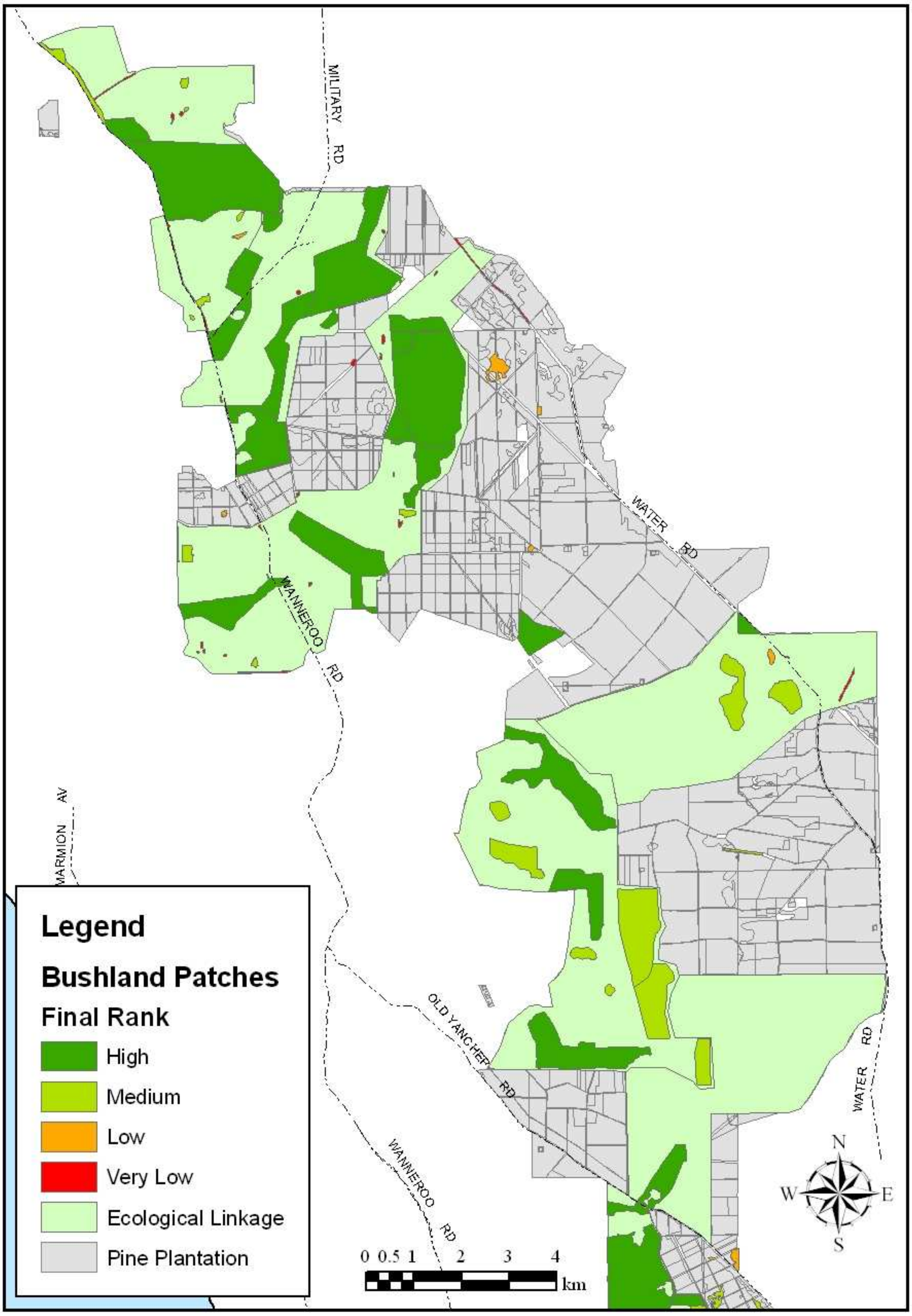

Figure 7: The East Yanchep subarea and its associated bushland patches (with final rank) and ecological linkages

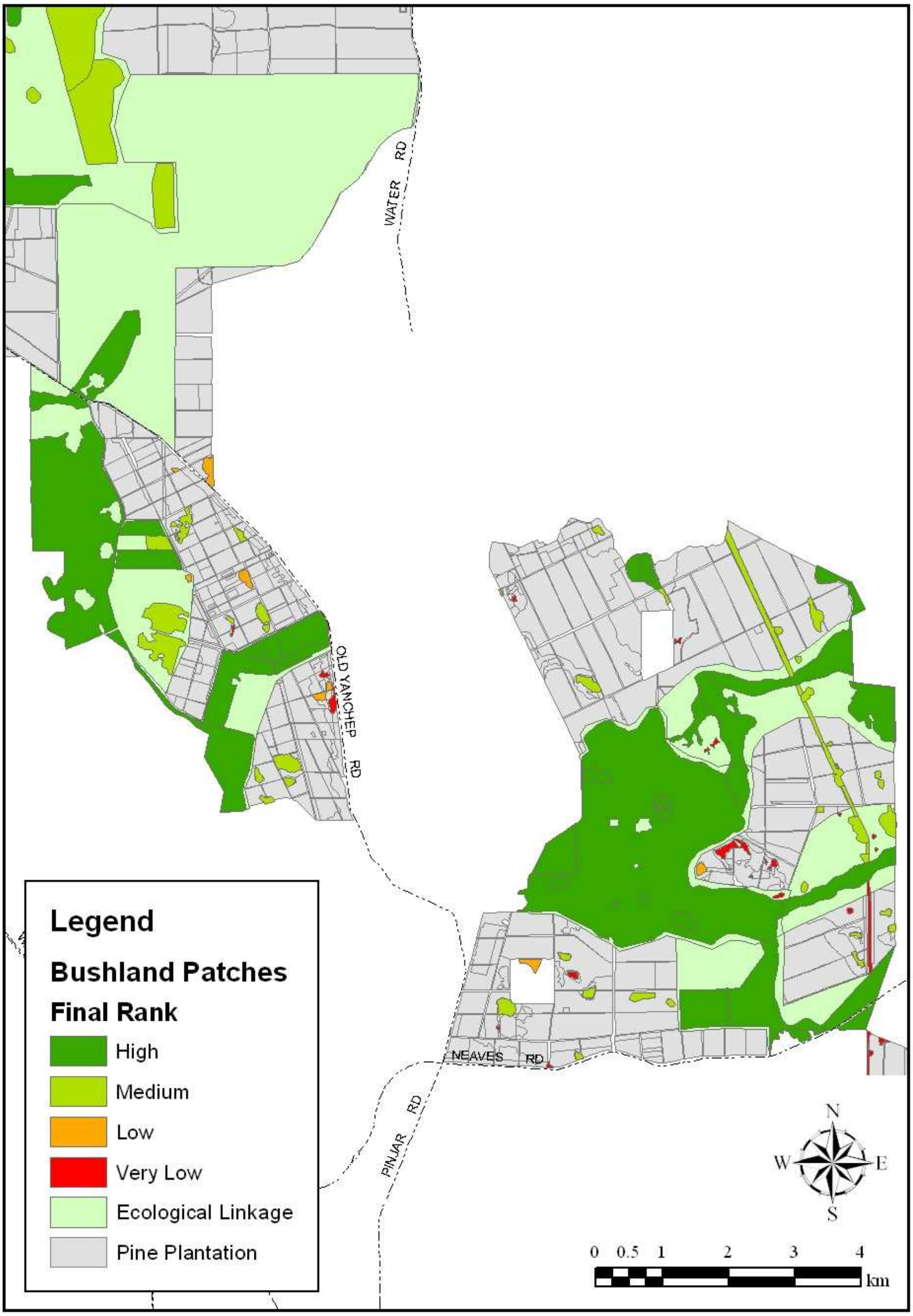

Figure 8: West Pinjar and West Gnangara subareas with their associated bushland patches (with final rank) and ecological linkages

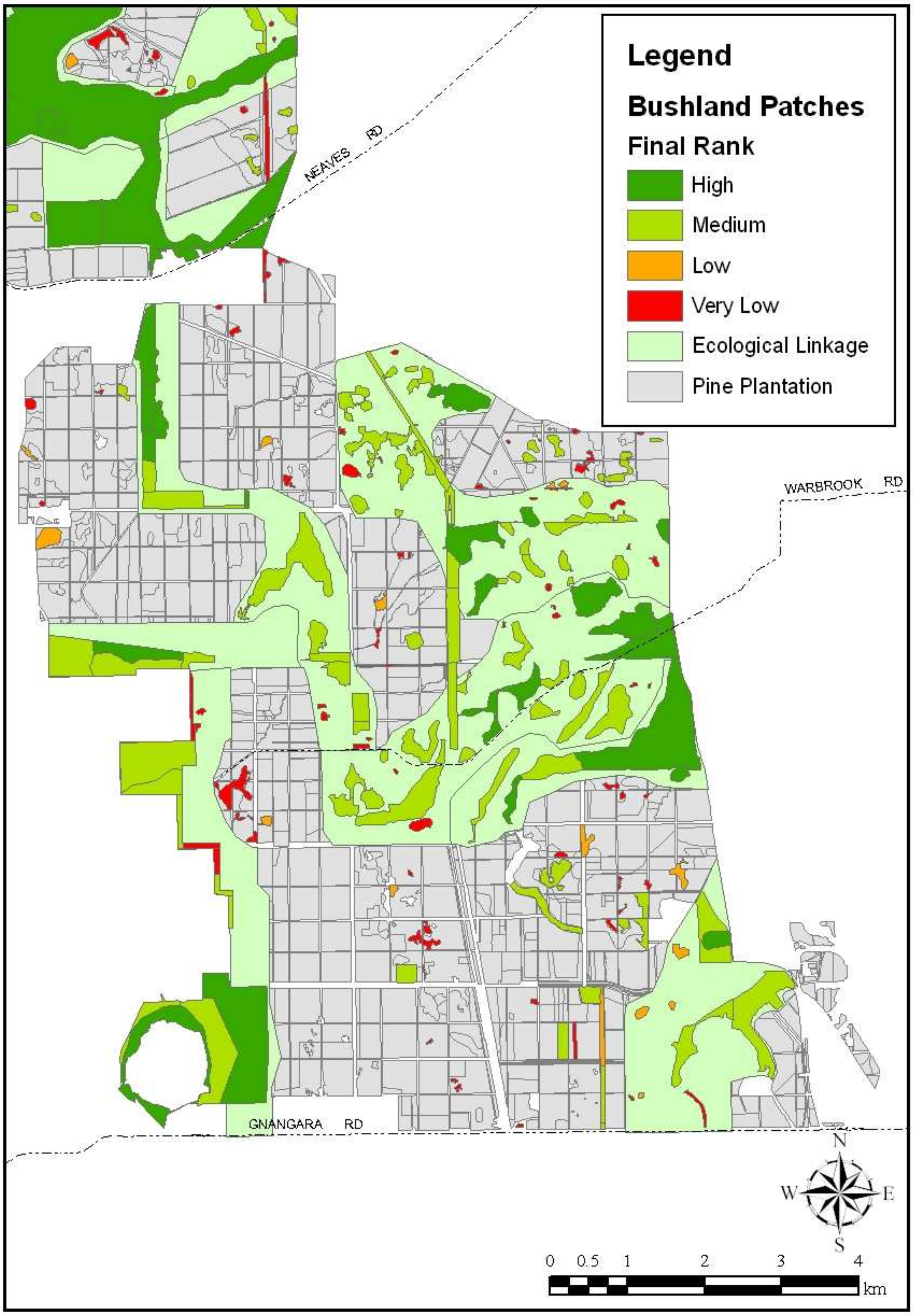

Figure 9: Gnangara subarea and its associated bushland patches (with final rank) and ecological linkages

Determining Representativeness of Vegetation

There are nine vegetation complex types represented within the four GSS subareas containing commercial pine plantation, most of which are poorly reserved within the GSS area and the Swan Coastal Plain (SWA2 bioregion) (Table 11). Previous work, by both the GSS and Ecological Australia (2008), allowed each vegetation complex in the GSS area to be assigned a vegetation complex score, of which there were four, however only three of these are present within the four subareas of interest (Figure 10). A vegetation complex with a score of 1 requires no additional protection, as outlined in the methods above.

The Bassendean Complex-North is largely restricted to the GSS study area (60% of pre-European extent within GSS) however it is well represented in the pine bushland patches and conservation reserves. Of the other two complexes which are largely restricted to the GSS study area, one is poorly represented within the pine bushland patches but is well reserved (Karrakatta Complex – North/Transition). The other, the Pinjar Complex, has inadequate levels of retention both on the Swan Coastal Plain and within the GSS study area with Jandabup Nature Reserve being the only reserved area. The Pinjar Complex comprises less than 1% of the total pine bushland patches (33 ha) with small remnants located within all four subareas, and only half has a condition rating of Very Good or above.

Whilst not being restricted to the GSS study area, there are three vegetation complexes, represented in the four subareas, which have inadequate levels of retention within the GSS area (i.e. there is less than 30% remaining on both the Swan Coastal Plain and in the GSS study area). The protected areas of the Karrakatta Complex-Central and South in the GSS study area are Woodvale Nature Reserve, Kings Park and areas of State Forest. The occurrence of this complex in State Forest, is pine all within bushland patches (303 ha) which comprise 5% of the remnants surveyed, the majority of which are within the West Pinjar subarea. Of these patches 143 ha are in Excellent condition with all other patches in a better than Good condition. Whiteman Park and State Forest are the only areas of Bassendean Central and South which are protected. Those in State Forest are pine plantation, with only 4% of all pine bushland patches comprising this vegetation complex. Of the 206 ha of this complex, only 40 ha is in Excellent-Very Good condition and 93 ha are in Very Good condition. All of these patches have been included in a proposed ecological linkage.

The three remaining complexes which are poorly reserved in the GSS are in the Spearwood Dunes - the Cottesloe North, Cottesloe Central and South and Karrakatta North complexes. These complexes occur primarily within State Forest and Unallocated Crown Land, neither of which are secure conservation reserves, however a small portion of Cottesloe North is protected within Yanchep National Park. Cottesloe Complex-Central and South has less than 20% of its current extent within the GSS area protected, with Neerabup National Park being the major area protected. This complex comprises 16% of the pine bushland patches with remnants located within the West Pinjar and East Yanchep subareas and all of which are in Excellent condition. Only 15% of the pine bushland patches contain the vegetation type consist with the Cottesloe North complex, all of which are within the East Yanchep subarea. Similarly, all of the remnant patches of the Karrakatta complex occur within the East Yanchep subarea. The pine bushland patches for all of these complexes have been encompassed in a proposed ecological linkage.

Table 11: Area in hectares of each vegetation complex within each subarea with proportions (%) shown in brackets.

Vegetation Complex	**Gnangara**	**West Gnangara**	**West Pinjar**	**East Yanchep**	**Grand Total**
Bassendean Complex-Central And\South*%	206 (16)				206 (4)
Bassendean Complex-North+%	717 (57)	1145 (87)		6 (0.2)	1868 (32)
Bassendean Complex-North-\Transition	319 (26)	157 (12)			476 (8)
Cottesloe Complex-Central And\South%			385 (60)	544 (21)	929 (16)
Cottesloe Complex-North%				864 (33)	864 (15)
Karrakatta Complex-Central And\South*%	0.02		260 (40)	43 (2)	303 (5)
Karrakatta Complex-North%				1122 (43)	1122 (19)
Karrakatta Complex-North-\Transition+				3 (0.1)	3 (0.05)
Pinjar Complex+*%	9 (1)	17 (1)	1 (0.2)	5 (0.2)	33 (1)
Grand Total	1251	1319	646	2588	5804

"+ largely restricted to the GSS study area (>60% of pre-European extent within GSS)

* inadequate levels of retention (< 30 % SCP and < 30 % GSS)

% poorly reserved - less than 30 % of their current extent within the GSS protected

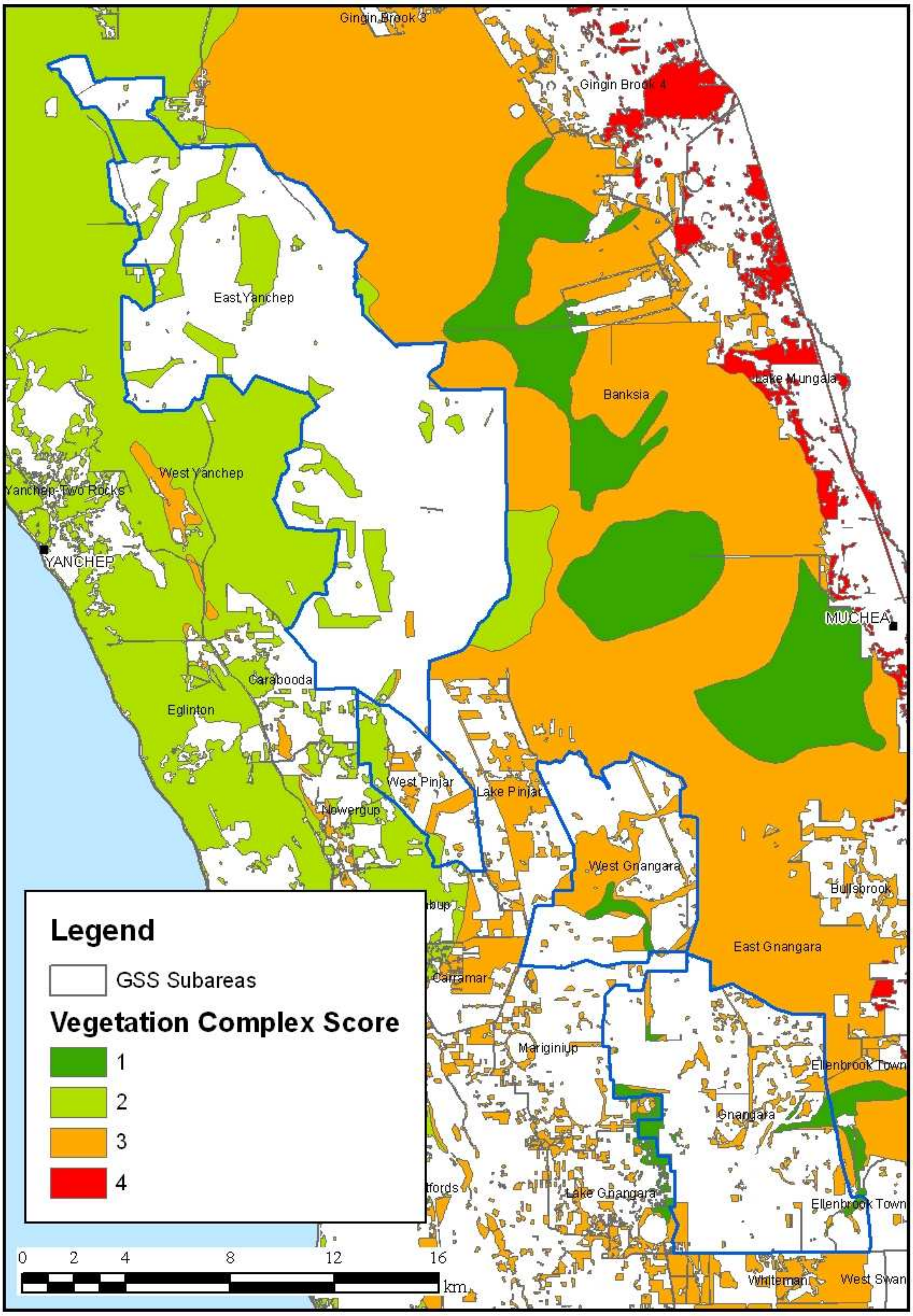

Figure 10: Remnant vegetation and its associated vegetation complex score within the four subareas.

Once the proposed ecological linkages have been rehabilitated the area of remnant vegetation within each vegetation complex will be increased. For seven of the nine complexes, the area of remnant vegetation within each subarea (listed in Table 11) will double (Table 12). Of these complexes, four will be increased more than two-fold. The Karrakatta complex North\Transition will increase from 3 ha to 164 ha. The Karrakatta complex Central and South, which has inadequate levels of retention and is poorly reserved, will increase from 303 ha to 1222 ha. Of the two complexes which will not experience a two-fold increase, the Pinjar complex will have only a portion of its occurrence within the pine plantations incorporated in an ecological linkage (7 ha). The majority of this vegetation complex occurs on the boundary of State forest in very small isolated patches which are not in close proximity to other pine bushland patches, therefore making it difficult to include.

Table 12: Vegetation complex composition of each proposed ecological linkage, once rehabilitated (hectares).

Ecological Linkage	**Bassendean Complex-Central And\South**	**Bassendean Complex-North**	**Bassendean Complex-North-\Transition Vegetation Complex**	**Cottesloe Complex-Central And\South**	**Cottesloe Complex-North**	**Karrakatta Complex-Central And\South**	**Karrakatta Complex-North**	**Karrakatta Complex-North-\Transition Vegetation Complex**	**Pinjar Complex**	**Grand Total**
Gnangara – 9		755	0							756
Gnangara – 6B		165	115							281
Gnangara – 6A		699	36							736
Gnangara – 4	126	82	189							397
Gnangara – 8		151	59						4	213
Gnangara – 7		420	52							472
Gnangara – 1	312	68	58							438
West Gnangara – 5C		212								212
West Gnangara – 5A		707	121						4	832
West Gnangara – 5D		259	45							303
West Gnangara – 5B		399								399
East Yanchep – 2		9		399		747	306			1461
East Yanchep – 4				1201	748	57				2006
East Yanchep – 6		23		149			1101	164		1437
East Yanchep – 8		12			1233		912			2157
East Yanchep – 10					517		779			1296
East Yanchep – 11					668		599			1267
West Pinjar – 21				64		174				238
West Pinjar – 23				354		244				599
Grand Total	438	3960	676	2168	3166	1222	3698	164	7	15499

Native Understorey and Overstorey Assessment

Of the 7 364 ha of pine plantation assessed for native understorey and overstorey 3 152 ha, or 43%, had a cover greater than 10% for either understorey or overstorey. West Gnangara had the highest percentage (66%) of assessed plantation with native understorey and overstorey greater than 10%, followed by West Pinjar (50%). The Gnangara subarea had the lowest percentage (26%) of assessed area with an understorey or overstorey greater than 10%. It is expected that East Yanchep will be similar to Pinjar and West Gnangara in terms of its persistent native vegetation.

Determining Ecological Linkage Locations

Within each subarea approximately half of the pine plantation has been proposed to be included within an ecological linkage. The area of remnant vegetation, 'good quality' understorey and/or overstorey and the percentage of each linkage requiring complete rehabilitation are displayed in Table 13 below, with the details for the remaining areas displayed in Appendix 1. This shows that within the 19 proposed ecological linkages (Figures 7-9) which cover 15 500 hectares, only 9 314 hectares, or 60% of the total linkage area, requires complete rehabilitate. Table 14 outlines some brief spatial characteristics of each of these proposed linkages (see Appendix 2 for the linkage associated with each ID).

While the percentage of each subarea designated as an ecological linkage is similar, the area of each of these linkages which require rehabilitation is variable between subareas. The Gnangara and West Gnangara subareas have the smallest portions (43%) assigned to ecological linkages however Gnangara requires far more rehabilitation of its linkages, with 53% requiring rehabilitation, whilst West Gnangara only requires 10% of the linkages to be completely rehabilitated. West Pinjar has a slightly higher portion assigned to linkages (50%), followed by East Yanchep (55%). Again they differ in the amount of rehabilitation required within these areas. West Pinjar only needs 21% of the area designated as a linkage rehabilitated, whilst East Yanchep requires 75%, at this stage of analysis.

Appendix 3 provides a list of the strengths and weaknesses for each of the 19 proposed ecological linkages on the ex-pine plantation lands on the Gnangara groundwater system.

Table 13: Basic statistics on each ecological linkage including the area requiring complete rehabilitation.

Subarea and Linkage ID	**Area of Bushland (ha)**	**Area Cleared (ha)**	**Total area of linkage (ha)**	**% as Rem Veg**	**Total area OS > 10 % (ha)**	**Total area US > 10 % (ha)**	**Total area with OS or US > 10 %**	**% assessed with good US or OS**	**Area requiring rehab (ha)**	**% of linkage requiring rehabilitation**	**Cost to rehabilitate ($millions)**
Gnangara – 9	169	586	756	22%	0	202	202	38%	384	51%	3.84
Gnangara – 6B	131	149	281	47%	0.1	0.7	0.8	1%	148	53%	1.48
Gnangara – 6A	229	507	736	31%	0	153	153	34%	353	48%	3.53
Gnangara – 4	171	226	397	43%	18	20	37	20%	189	48%	1.89
Gnangara – 8	72	141	213	34%	0	22	22	20%	119	56%	1.1
Gnangara – 7	147	325	472	31%	7	81	82	30%	242	51%	2.42
Gnangara – 1	106	332	438	24%	10	31	32	13%	300	69%	3
West Gnangara – 5C	61	151	212	29%	14	109	110	79%	41	19%	0.41
West Gnangara – 5A	756	75	832	91%	12	38	38	73%	37	4%	0.37
West Gnangara – 5D	158	145	303	52%	0	61	61	47%	84	28%	0.84
West Gnangara – 5B	181	218	399	45%	46	198	198	98%	21	5%	0.21
East Yanchep – 2	52	1409	1461	4%					1409	96%	14.09
East Yanchep – 4	682	1324	2006	34%					1324	66%	12.34
East Yanchep – 6	102	1335	1437	7%					1335	93%	13.35
East Yanchep – 8	675	1482	2157	31%					1482	69%	14.82
East Yanchep – 10	545	751	1296	42%					751	58%	7.51
East Yanchep – 11	348	919	1267	27%					919	73%	9.19
West Pinjar – 21	176	61	238	74%	28	23	34	71%	28	12%	0.28
West Pinjar – 23	382	216	599	64%	39	65	68	65%	148	25%	1.48
All proposed eco linkages	**5143**	**10352**	**15500**	**33%**	**174**	**1004**	**1038**	**40%**	**9314**	**60%**	**92.15**

Table 14: Maximum length and mean width for each ecological linkage

Subarea and Linkage ID	Maximum Length (metres)	Mean Width (metres)
Gnangara – 9	5 542	1 386
Gnangara – 6B	3 358	930
Gnangara – 6A	5 328	1 488
Gnangara – 4	6 091	741
Gnangara – 8	3 236	688
Gnangara – 7	5 748	700
Gnangara – 1	3 560	1 550
West Gnangara – 5C	1 880	1 060
West Gnangara – 5A	3 950	2 422
West Gnangara – 5D	2 945	1 110
West Gnangara – 5B	2 962	1 141
East Yanchep – 2	5 668	3 216
East Yanchep – 4	7 355	2 113
East Yanchep – 6	6 458	2 263
East Yanchep – 8	10 508	2 194
East Yanchep – 10	5 740	2 260
East Yanchep – 11	6 492	1 915
West Pinjar – 21	3 585	536
West Pinjar – 23	4 360	1 286

Discussion

Condition of Wetlands

A greater proportion of uplands were assessed to be in Excellent or Excellent-Very Good condition than that of wetlands. This may be because the wetlands are in poorer condition due to the drying climate and decreasing water table or because the majority of the wetlands occur in the Gnangara subarea, which has the lowest area of bushland with an Excellent condition category. These wetlands may still be viable as wetland habitat as once they are released from dense pine plantings it has been observed that the groundwater table recovers locally and wetland vegetation tends to regenerate well. Alternatively, in an increasingly drying climate with declining groundwater levels, as proposed by the modelling undertaken by the GSS (Government of Western Australia 2009), this may not be the case. The composition of wetland vegetation may experience a shift towards species more tolerant of drier condition (terrestrialisation) (Groom *et al.* 2001).

Impact of Fire on Bushland Remnants

Often when the plantations are clear felled, most of the surrounding bushland remnants are severely burnt in the subsequent hot clearing burn. This practice is considered to be a threatening process to the species diversity and vegetation condition of the bushland remnants. Burning these patches of remnant vegetation is likely to cause degradation which will be difficult to reverse due to the fragmented nature of the patches. Whilst there was a large proportion of unburnt patches (within four years) at the time of assessment, this has since increased. It is vital that these patches be protected from any further burning.

Bushland Ranking and Ecological Linkages

Ranking of all bushland patches has confirmed the location of the proposed ecological linkages through ex-pine plantation, as they include the most highly ranked bushland patches. However, further local refinement of linkage boundaries could include some more of the ‘unprotected’ bushland patches, if necessary. While the majority of patches which scored very low in the final ranking were outside the ecological linkages there were still many included in these linkages. Where poorer ranked bushland patches occur on, or near the boundary of a linkage, and if the persisting native vegetation is low surrounding them, there is the possibility of deleting them from the linkage. This will only be undertaken if the linkage can still maintain a minimum width of 500 m, and only if this is required financially, due to rehabilitation costs.

Native Vegetation Assessments

By assessing the native vegetation which has persisted within the pine plantations we have been able to improve not only the location of the ecological linkages but also the likely requirements of rehabilitation. Due to the pre-determined cover ranges and the impact this had on determining the threshold for ‘good quality’ native vegetation, there will still be variation in the degree to which areas with ‘good quality’ understorey and overstorey regenerate and therefore the requirements of rehabilitation in these areas. Additionally, the varied diversity of species within these areas, and the possible impacts of clearfelling and burning on the vegetation will affect the rehabilitation requirements of these ‘good quality’ areas.

If the persistent native vegetation is to provide recruitment, and therefore a reduced rehabilitation effort it is important that it is conserved, particularly during pine removal. Care will need to be taken to ensure that disturbance is minimal, particularly for individual trees, to facilitate the rehabilitation process back to native vegetation (Woodman 2008). These trees and other native vegetation will contribute to vegetation structure, enabling residency of fauna species, and act as a source of seed if they are maintained (Woodman 2008).

Determining the restoration techniques most applicable for areas with 'good quality' native vegetation will depend on the species present, the desired rehabilitation outcomes and the treatment of these areas during, and immediately after removal of pine. The diversity of species within each area of 'good quality' native vegetation varies, which is likely to impact on the rehabilitation requirements. Where only a few species are present, the structural diversity and the range of possible species recruitment is limited. In these cases, infill planting will be required.

For native vegetation in pine compartments which still require harvesting, the disturbance from fire, as well as harvesting itself, is likely to disturb much of the vegetation. Fire is needed to minimise the reoccurrence of pine, and to remove pine litter, which combined with the impact from clearfelling, means that the techniques used in restoring these areas may be similar to sites without 'good quality' native vegetation (Maher 2009). However, if seed remains in the soil after these treatments, it is highly likely that a greater number of species and/or seedlings may recruit after restoration activities have been carried out (Maher 2009).

In compartments which have already been cleared of pine there is also uncertainty about the restoration techniques most applicable. Those with satisfactory levels of native vegetation (e.g. 'good quality' areas) could be retained, at least in the short term (Maher 2009). If it is decided that the species diversity needs to be increased, infill planting may be utilised, or alternatively a full suite of restoration efforts may need to be considered, depending on the desired outcome and the level of difficulty of applying these efforts whilst also preserving the current vegetation. If a full suite is required, the compartment may require burning and treatment as for other sites (Maher 2009).

Whilst East Yanchep is currently estimated to require 75% of the areas designated as ecological linkages to be completely rehabilitated, this is likely to change upon further assessment. Once the native understorey and overstorey has been assessed, and factored in to the calculations for rehabilitation, it is highly probable that this percentage will decrease to a level more consistent with other subareas. While this information is not currently available, it will be incorporated once received and, if required, the boundaries of the ecological linkages may be moved to further enhance the linkage as well as reduce the area requiring rehabilitation.

Evaluation of Rehabilitation Techniques

DEC has established rehabilitation trials using direct seeding across cleared plantation compartments annually since 2001. The success of these trials has recently been assessed by Murdoch University (Maher *et al.* 2008). This included assessing which species established and the success of their establishment as well as the effect of fire and rainfall on establishment rates. Additionally, the impact of weeds on establishment was recorded.

Maher *et al.* (2008) found that although rates of establishment and density for each species were variable, many species had good establishment rates with 19 of the 44 species planted at three or more sites, successfully establishing at more than 75% of the sites ion which they were sown. There were five species which failed to establish at any of the sites at which they were sown and three species which had low establishment rates (<35%). The success and density of establishment for most species varied considerably among sites however factors such as burning treatments and broad soil type did not explain this variation.

Whilst rainfall did not appear to have an effect on the vegetation assemblages that established, weed cover explained some of the variation observed in species establishment and density among sites. Maher *et al.* (2008) found that higher levels of weed cover reduced the percentage of species establishment and density of *Banksia attenuata* and *Eucalyptus todtiana* that established within the trial plots. For this reason it was recommended that reducing weed cover should be a primary goal of restoration activities.

Further work has been undertaken to determine the appropriate native species selections, establishment techniques and the costs of rehabilitation for the disturbed areas within the ecological linkages, post-pine clearing. This was recently completed by the University of Western Australia (Maher 2009). This report provides preliminary recommendations for seed species lists and discusses possibilities for restoration, including the use of topsoil from nearby sites under development.

Management between Ecological Linkages

Outside of proposed ecological linkages and the blocks on the edge of State forest targeted for excision, it has been proposed that cleared plantation areas should be managed to protect the groundwater resource and to increase recharge around bore fields for public water supply. There are numerous issues to clarify before the light coverage of native vegetation mixed with agricultural grasses and broadleaf weeds can be managed sustainably and without adversely impacting the remnant bushland in the ecological linkages and surrounding bushland blocks. This analysis forms part of another study by the GSS lead by the Water Corporation and the Department of Agriculture and Food.

Management Actions

There is a need to prepare a policy document and associated prescriptions relating to the ongoing management and maintenance of ecological linkages and their incorporated bushland blocks through the ex-pine plantations. We have listed a few appropriate management actions in Appendix 4 as a start to these discussions. These will need to address a whole range of threatening processes and conservation issues, including:

- *Phytophthora* dieback hygiene, survey, control and reducing impact.
- Prescribed burning, fire access and wildfire response methods.
- Removal and relocation of tracks and roads
- Response to proposals for linear developments through linkages (roads, powerlines, pipelines)
- Weed control
- Public access and off road vehicles.

Funding the Establishment and Management of Linkages

Our preliminary estimates for the rehabilitation of ex-pine sites on the Gnangara groundwater system using direct seeding of native flora is $8 000 to $10 000 per ha. Further clarification of these costs will occur once the prescriptions and rehabilitation techniques suggested by Maher (2009) are finalised for each individual area requiring restoration. If we were to rehabilitate all the cleared ex-pine in our study area (23 000 ha) it would cost up to $230M over 25 years. There are no land purchase costs as all commercial pine plantations on the Gnangara groundwater system are on State forest vested in the Conservation Commission and managed by DEC.

Through the process of targeted ecological linkages proposed in this paper, 19 linkages would require partial rehabilitation over a total of 9 314ha (42% of the total pine plantation) thus reducing gross cost by 60% or almost $137M. However, this would still cost approximately $93M based on preliminary estimates of $10 000 a hectare. There are several potential sources of this substantial funding.

1. Additional budget allocation to DEC from State Government
2. Allocation of sale price, to linkage rehabilitation, from identified areas on the edge of Crown land with the view to their excision for urban deferred or industrial development to provide employment generating land for strategic employment categories.
3. Offsets from developments adversely impacted environmental values on the Swan Coastal Plain.
4. Funding sources

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Appendix 1

Table 1: Basic statistics on all areas assessed including proposed ecological linkages (green).

Subarea and Linkage ID	Corridor Priority	Upland	Wetland	Not Assessed Bush	Total Area of Bush	Cleared	Total area of linkage	% as Rem Veg	Area OS > 10 %	Area US > 10 %	Area with OS or US > 10 %	Total area of linkage assessed for OS and US	% of area assessed with good US or OS	Area requiring rehab	% requiring rehab
Gnangara - 9	1	8	161	0	169	586	756	22%		202	202	537	38%	384	51%
Gnangara – 6B	1	126	3	2	131	149	281	47%	0.01	0.7	0.8	126	1%	148	53%
Gnangara – 6A	1	105	124	1	229	507	736	31%		153	153	445	34%	353	48%
Gnangara – 4	2	154	2	14	171	226	397	43%	18	20	37	183	20%	189	48%
Gnangara – 8	2	72		0	72	141	213	34%		22	22	113	20%	119	56%
Gnangara – 7	2	56	91		147	325	472	31%	7	81	82	273	30%	242	51%
Gnangara – 1	2	67	26	13	106	332	438	24%	10	31	32	251	13%	300	69%
Gnangara – 14	3	29	36		65	1006	1071	6%	60	139	161	840	19%	845	79%
Gnangara – 10	3		17	0	17	235	252	7%		34	34	210	16%	202	80%
Gnangara – 11	3	18	15	0	34	885	919	4%		113	113	304	37%	772	84%
Gnangara – 13	3	8	18		26	1262	1288	2%	2	9	11	35	32%	1251	97%
Gnangara – 12	3	2	11	0	12	703	716	2%	9	184	186	617	30%	517	72%
Gnangara – 15	3	0	0		0	111	111	0%		10	10	30	34%	100	91%
West Gnangara - 5A	1	709	47		756	75	832	91%	12	38	38	53	73%	37	4%
West Gnangara - 5D	1	136		23	158	145	303	52%		61	61	130	47%	84	28%
West Gnangara - 5B	1	110	68	2	181	218	399	45%	46	198	198	201	98%	21	5%

West Gnangara - 5C	2	43	18	1	61	151	212	29%	14	109	110	139	79%	41	19%
West Gnangara - 17	3	5	6	1	12	179	191	6%		31	31	170	18%	148	78%
West Gnangara - 18	3	4	17		21	383	405	5%	6	299	299	358	84%	84	21%
West Gnangara - 19	3	31	16	3	50	986	1036	5%	48	751	754	883	85%	232	22%
West Gnangara - 16	3	0	17		18	703	721	2%	6	182	187	606	31%	517	72%
West Gnangara - 20	3	14	6		20	257	277	7%	44	24	59	231	26%	197	71%
West Gnangara - 21	1	176		0	176	61	238	74%	28	23	34	48	71%	28	12%
West Gnangara - 22	3	19			19	531	550	3%	103	262	269	478	56%	262	48%
West Gnangara - 23	1	338	44	0	382	216	599	64%	39	65	68	104	65%	148	25%
East Yanchep – 1	3					552	552	0%						552	100%
East Yanchep – 2	1	52		0	52	1409	1461	4%						1409	96%
East Yanchep – 3	3		5	1	6	185	192	3%						185	97%
East Yanchep – 4	1	680		2	682	1324	2006	34%						1324	66%
East Yanchep – 5	3	4			4	2352	2356	0%						2352	100%
East Yanchep – 6	1	102		1	102	1335	1437	7%						1335	93%
East Yanchep – 7	3	50	16	6	73	3572	3644	2%						3572	98%
East Yanchep – 8	1	673	0	1	675	1482	2157	31%						1482	69%
East Yanchep – 9	3	3		0	3	1154	1157	0%						1154	100%
East Yanchep – 10	1	540		4	545	751	1296	42%						751	58%
East Yanchep – 11	1	343		5	348	919	1267	27%						919	73%
Grand Total		**4680**	**765**	**80**	**5525**	**25410**	**30935**	**18%**	**452**	**3043**	**3152**	**7364**	**43%**	**22258**	**72%**

Appendix 2

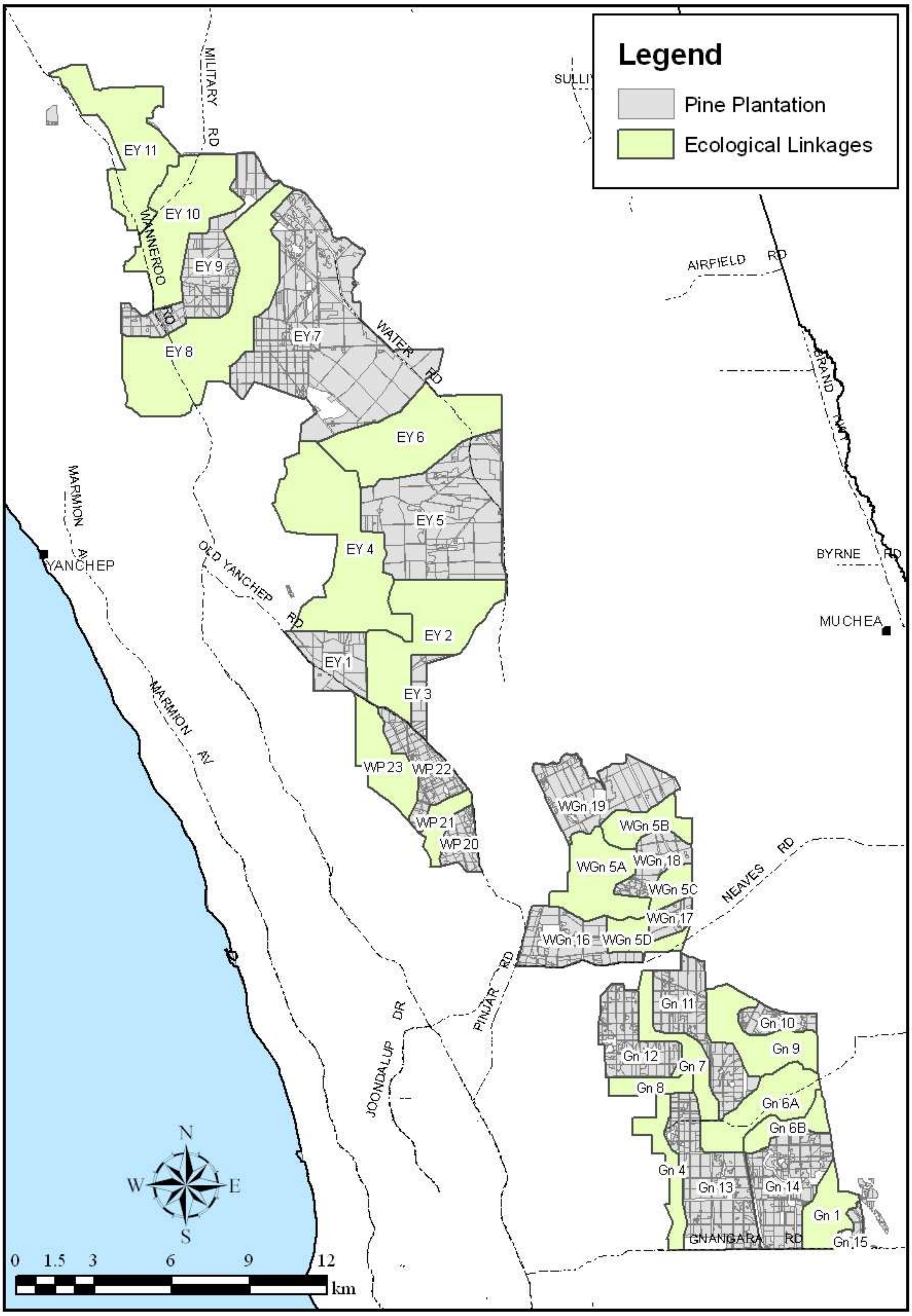

Figure 1: Linkage ID for all areas assessed with ecological linkages shown in green.

Appendix 3

Table 1: Strengths and weaknesses of each proposed ecological linkage through the ex-pine plantation lands on the Gnangara Groundwater System.

Ecological Linkage	**Linkage Strengths**	**Linkage Weaknesses**
Gnangara 1	Links to remnant vegetation on south (Whiteman Park) and north in Melaleuca Park across ex-pine plantation.	Major east-west barrier at Gnangara Road (proposed four lane road) and sealed road through centre (Gaskell Ave). A number of other unsealed roads. [Total 6.6km of roads]
	Contains ex-sand mined and rehabilitated area	Contains BRM Priority Area (with large block already mined)
	Forms a bushland break between Ellenbrook townsite and the large expanse of the ex-Gnangara plantation	Area contains Water Corporation production bores
	Contains two Bush Forever sites	
Gnangara 4	Aligned with or adjacent to proposed ecological linkage for most of corridor	Approx ½ is Basic Raw Materials (BRM) Priority Area with mining tenements
	Links several large blocks of rem veg along the western edge of State forest, including Gnangara Lake, and to the south (Whiteman Park)	Significant areas of pine plantation already felled with little native vegetation and adversely impacted by weeds
	Links two Bush Forever sites	A proposed major transport corridor is proposed on the State forest boundary but alignment not yet determined. A number of unsealed roads through linkage (approx 8.4 km)
		Contains 1 production bore (not operating)
Gnangara 6B	Approx ½ is Bush Forever Site in very good condition	Almost entirely BRM Priority Area with a large section of the remaining upland bushland planned for removal during sandmining process.

	Adjoins large block of proposed ecological linkage (Gnangara 6A and 9). Links into the Melaleuca Park ‘core’ area to the east.	A number of sealed and unsealed roads (approx 3 km)
		Contains 700m of powerlines
		Banksia woodland in this general area has been broadly infected by Phytophthora dieback.
Gnangara 6A	This linkage has numerous small blocks of bushland and wetland forming a basis for linkage	Small area is BRM Priority Area
	Adjoins large block of proposed ecological linkage (Gnangara 6B, 7 and 9. Links into the Melaleuca Park ‘core’ area to east.	Contains 1.4km of powerlines
	Contains small portion of Bush Forever site	A number of sealed and unsealed roads (approx 10.6 km) including Warbrook Road through the middle of the linkage.
		Contains a production bore (not currently operating)
		Banksia woodland in this general area has been broadly infected by Phytophthora dieback.
Gnangara 9	No BRM Priority areas	A number of sealed and unsealed roads (approx 9km)
	Bordered by extensive ‘core’ bushland areas to the north and by Melaleuca Park and State forest. Adjoins Gnangara linkage 6A.	Contains almost 3.5km of powerlines
	This linkage has numerous small blocks of bushland and wetland forming a basis for linkage	Banksia woodland in this general area has been broadly infected by Phytophthora dieback.
Gnangara 7	Contains a Bush Forever site	A number of sealed and unsealed roads (approx 5.3 km)
	No BRM Priority areas	Land to the west is likely to be excised from state forest
	This linkage has numerous small blocks of bushland and wetland forming a basis for linkage. Is a north-south linkage.	Contains 3 production bores (not operating)
Gnangara 8	Almost ½ is Bush Forever	A proposed major transport corridor is proposed on the State forest boundary but alignment not yet determined. A number of sealed and

		unsealed roads (approx 2.3 km)
	Proposed ecological linkages to the western border of State forest close to Lake Jandabup Nature Reserve.	Land to the north is likely to be excised from state forest
	Contains small portion of Pinjar complex which is largely restricted to the GSS and poorly reserved	Contains 2 production bores (not operating)
West Gnangara 5A	Almost entirely one large Bush Forever site with excellent bushland and wetland vegetation.	Contains approx 2.2 km of powerlines
	No BRM Priority areas	A number of sealed and unsealed roads (approx .35 km)
	Contains small portion of Pinjar complex which is largely restricted to the GSS and poorly reserved	Contains 4 production bores (not operating)
West Gnangara 5B	Almost ½ the linkage is a Bush Forever site	A number of sealed and unsealed roads (approx 900 m)
	Eastern border shared with UCL (RAAF) remnant vegetation that forms part of the 'core' arc of excellent condition bushland. Links west into bushland area (linkage West Gnangara 5A)	
	No BRM Priority areas	
West Gnangara 5C	Contains 3 Bush Forever sites, and portions of another 2 (almost 1/3 of the linkage)	Contains 1 production bore (not operating)
	No BRM Priority areas	Contains approx 1.6 km of powerlines
	Eastern border shared with Melaleuca Park and links west into large area of bushland (linkage West Gnangara 5A)	
West Gnangara 5D	Approximately ½ is Bush Forever	Contains approx. 300m of powerlines
	Eastern border shared with Melaleuca Park and links west into large area of bushland (linkage West Gnangara 5A).	A number of sealed and unsealed roads (approx 1.6 km)
	No BRM Priority areas	Contains 2 production bores (not operating)

		Land to the west is likely to be excised from state forest and become industrial
West Pinjar 21	Over half the linkage is a Bush Forever site with excellent vegetation cover	Adjacent to BRM priority area for limestone including a number of existing limestone mines (to west of linkage)
	Borders remnant vegetation to the south-west	Contains approx 3.1 km of major powerlines and a gas pipeline along its eastern boundary.
	Adjoins the major Bush Forever site over Lake Pinjar	Sealed roads through northern portion of linkage (Wesco Road), along its western boundary (Old Yanchep Road and along its southern boundary (Road). Total road network is approximately 6km.
	Whole linkage covers Spearwood Dune vegetation complexes (Karrakatta and Cottesloe Central and South complexes) that are poorly represented in the conservation reserve system.	Barbagallos Raceway to the SE and the Pinjar Off Road Vehicle Area over most of the linkage
	No Water Corporation commercial bores in or adjacent to this linkage.	
West Pinjar 23	Contains a Bush Forever site, and the majority of another larger remnant of high ranking (approx. ¾ of linkage of excellent condition)	A sealed road on its eastern boundary (Old Yanchep Road) with a total length of sealed & unsealed roads (approx 4 km)
	Includes a major wetland (Camel Swamp) and the populations of the Limestone Ridges TEC.	Contains approx 2 km of powerlines
	Whole linkage covers Spearwood Dune vegetation complexes (Karrakatta and Cottesloe Central and South complexes) that are poorly represented in the conservation reserve system.	Half linkage a BRM priority area for limestone including a number of existing limestone mines
	Links remnant vegetation to the west and north-east.	
East Yanchep 2	Only remaining patch of remnant veg is part of a Bush Forever site	Small portion of linkage in BRM Priority area for limestone
	Borders remnant vegetation to the east (state forest and proposed 5(1)(h) reserve which are Bush Forever sites) and linkage through West Pinjar linkage 23.	A number of sealed and unsealed roads (approx 12.5 km) including sealed Old Yanchep Road on the southern boundary

	Large portion covers Spearwood Dune vegetation complexes (Karrakatta and Cottesloe Central and South complexes and Karrakatta North) that are poorly represented in the conservation reserve system.	Almost 8 km of powerlines servicing the Pinjar gas fired power station to the east of linkage. Major gas pipeline.
East Yanchep 4	Seven Bush Forever sites with vegetation in excellent condition, and parts of two others, comprising almost ½ of linkage	A number of unsealed roads (approx 11.2 km)
	Borders proposed extension (Ridges) to Yanchep National Park to the west.	Under pine native vegetation cover not yet surveyed.
	No BRM Priority areas, production bores or powerlines	
	Whole linkage covers Spearwood Dune vegetation complexes (Karrakatta and Cottesloe Central and South complexes and Cottesloe North) that are poorly represented in the conservation reserve system.	
East Yanchep 6	Borders remnant vegetation to the north-east (state forest and proposed addition to Yeal Nature reserve) and to East Yanchep 4 linkage	A number of unsealed roads (approx 11 km)
	No BRM Priority areas, production bores or powerlines	Under pine native vegetation cover not yet surveyed.
	Contains 3 Bush Forever sites and part of another	
East Yanchep 8	No BRM Priority areas or production bores	Contains approx 6.2 km of powerlines
	Bordered to the south by State Forest and Yanchep National Park and to the NE by Yeal Nature reserve and its proposed additions	A number of sealed and unsealed roads (approx 11 km) including a major sealed road (Wanneroo Road) which cuts through the western side of the linkage
	Contains 2 Bush Forever sites, and part of another 2 BF Sites	Under pine native vegetation cover not yet surveyed.
East Yanchep 10	Bordered to north-east by remnant vegetation (Yeal NR proposed addition) and to the west by proposed Wilbinga Conservation Park.	Almost entirely BRM Priority area
	No production bores present	Contains approx 3.7 km of powerlines
		A number of sealed and unsealed roads (approx 10.8 km) including

		Wanneroo road which cuts through the western side of the linkage and Military road, which cuts through the northern portion of the linkage
East Yanchep 11	Small portion of Bush Forever site to the west	Over half is BRM Priority area
	Remnant veg on three sides (west, north and east) in excellent condition.	Contains approx 3.8 km of powerlines
	Contains proposed addition to Yeal Nature reserve which provides a strong east-west linkage between Yeal Nature reserve and the proposed Wilbinga reserves.	A number of sealed and unsealed roads (approx 6.3 km) including a major sealed road, Wanneroo rd, which cuts through the western side of the linkage

Appendix 4

Management Actions

1. Prepare policy on managing remnants and wildlife corridors (*Phytophthora cinnamomi*, no burning, pine removal in bush and within buffer, remove or relocate tracks).
2. All residual pine trees and wildings over 1m high in an ecological linkage (and perhaps buffer) either be pushed over with a machine or cut by chainsaw (pending Phytophthora dieback status). Undertake in partnership with Water Corporation and FPC. Make a decision about burning the crowns where they fall or preferably to remove the whole tree from good quality bushland using a tractor with forks.
3. No prescribed burning or clearing burns through remnant bushland in the plantation.
4. Most remnants have not been burnt for a long time, are in good condition and retain significant faunal diversity. However, this flora and fauna diversity plus mature tree health can be lost with one excessively hot burn at the time of pine clear felling. Thus it is essential to protect remnants at the time of the clearing burn by a previous low intensity prescribed burn beforehand and pushing back the pine debris away from the edge of the remnant. Active fire protection may be warranted during the clearing burn.
5. In addition, isolated sapling or mature native trees in the plantation need to be protected during harvesting and the subsequent clearing burn. Minimize pine debris from around the base of such trees. Active fire protection may be warranted during the clearing burn.
6. Remove all rubbish from within and adjoining the ecological linkage.
7. Contract survey and mapping for *Phytophthora* dieback in all Very Good to Excellent condition bushland
8. No soil heaps on edge or inside of any patch of bushland (remove or flatten with bobcat, given excessive damage is not done to bushland and the risk of *Phytophthora* spread is appropriately managed). Similarly, remove the mound of soils along the edge of any graded tracks through the bushland.

9. Review all current vehicle access through each linkage, particularly through bushland remnants with the view to closing non-essential tracks (except where a decision is made to break the patch up for fire control or a major road already exists).
10. Establish an appropriate boundary track around the linkage.
11. Undertake more detailed vegetation condition, flora and fauna surveys using tertiary students.