A PLAN FOR MANAGEMENT OF BANKSIA WOODLAND RESERVES ON THE NORTHERN SWAN COASTAL PLAIN

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PART I.

1. INTRODUCTION

Banksia woodland remnants under public control have a high conservation value. This is a result of the fact that a large proportion of the Swan Coastal Plain has been cleared for pine plantations, residential or industrial development and farming.

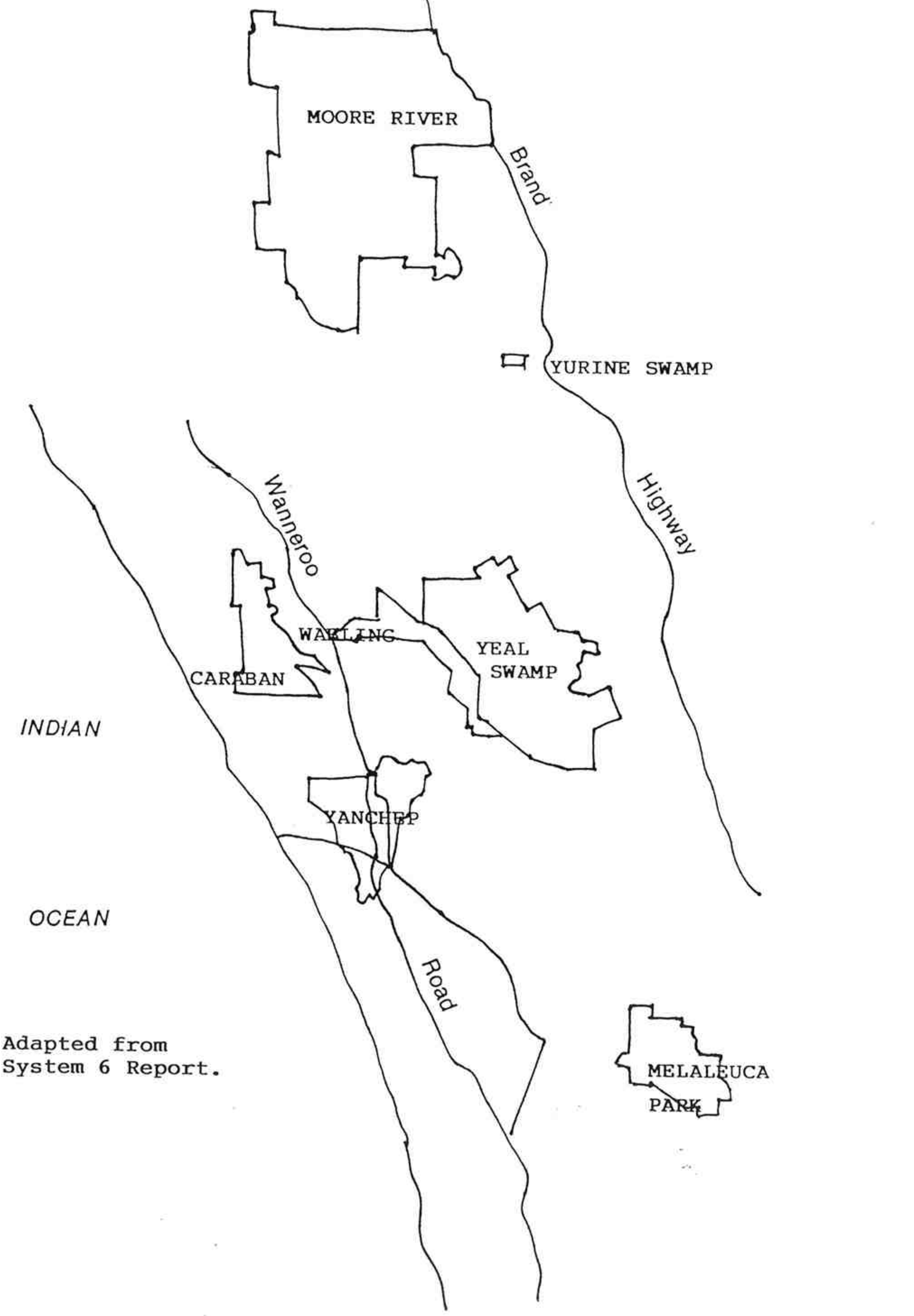
An environmental review and plan for management of Banksia woodlands under public control would aim to buffer the woodlands from the effects of these increasing human pressures so that the conservation status is maintained. This is particularly important for those conservation values which are most often at risk and most fragile, and which are often difficult and expensive to return to their natural levels. The plan would therefore be based on a knowledge of the biological and physical resources of the area, and the ecological processes that sustain those resources.

This report considers existing and proposed conservation areas containing Banksia woodlands north of the metropolitan area. Included are those areas subject to System 6 recommendations and the proposed additions to the CALM conservation estate (Fig. 1). These areas are considered to be of high conservation value and relatively undisturbed. Areas not considered in this report (although management recommendations would probably be applicable) are those where the integrity of the natural systems have been disturbed and their importance for conservation has been undermined. These areas are mostly outside reserves.

1.1 Location

Banksia woodland occurs along the length of the Swan Coastal Plain (Beard 1989), within the South-west Botanical Province of Diels (1906). The northernmost extreme is around Jurien, where it is replaced by kwongan in response to declining rainfall. In this area, the woodland is restricted to deeper sands.

Fig 1: Major reserves of Banksia Woodland (existing and proposed) on the Northern Swan Coastal Plain.



Adapted from
System 6 Report.

Heavier soils and increasing rainfall limit the Banksia woodland in the south. The last of the extensive stretches of woodland occurs on the Coastal Plain midway between Armadale and Pinjarra (or used to before clearing). Here the heavy soils at the foot of the escarpment and the increasing wetness are more conducive to taller eucalypt woodlands.

Banksias persist as an understorey or as a component of a tripartite woodland mosaic with paperbarks and eucalypts (Beard 1989). This situation extends in a disjointed fashion as far south as Busselton.

2. PHYSICAL ENVIRONMENT

2.1 Climate

The northern Swan Coastal Plain enjoys a temperate mediterranean climate, with a mild wet winter and a hot dry summer (Beard 1984). Most of the area's rainfall is received in winter months from May to September, when eva-potranspiration is low (Butcher 1986). The summer season from November to March receives only 9% of the annual average rainfall. Rainfall decreases further north, and increases eastwards until the Darling Scarp is encountered.

Winter daytime temperatures approximate 18°C at Gnangara, while summer temperatures for this area average between 30°C in December to 28°C in March, increasing further north (Butcher 1986).

Rainfall can have a major influence on the habit of species and vegetation structure. Banksia woodlands are generally contained within the 650-800mm rain isohyets. In the north, the transition from low woodland to scrub-heath occurs at around 625mm (Beard 1984). Further north towards Eneabba (500mm per year) B. attenuata and B. menziesii are components of the shrublands, attaining heights of approx. 1 m. This is in contrast to the south where these two species reach up to 8 m, forming the dominants in the wood-lands (Hopkins and Griffin 1984).

2.2 Geology, Geomorphology and Soils.

Banksia woodlands occupy part of a geological structural feature known as the Dandaragan Trough, the deepest subdivision of the Perth Basin. The coastal plain is one of the geomorphological features of the trough. It is low lying and gently undulating and ranges from 75-90m above sea level (Playford et al 1976). Quaternary deposits cover much of the surface of the Basin.

Soil and landform are the features generally found to correlate with vegetation. The deep, well drained sandy soils of the Bassendean and Spearwood dune systems of the coastal plain are the most common substrate of the Banksia woodlands. A third system, the Quindalup dunes, are of less importance to the woodlands.

The Bassendean and Spearwood dunes run longitudinally along the central part of the coastal plain. Bassendean dunes are generally of higher relief than the Spearwood dunes and are considered to be older (McArthur & Bettenay 1960). The parent material for the dunes is considered by McArthur & Bettenay (1960) to be highly calcareous beach sand, overlying a hard capping of secondary calcite. The sand covering the calcite capping increases in depth from west to east, indicating removal of material from the west by the prevailing westerly winds and redeposition in the east. The differences in soils are thought by McArthur and Bettenay (1960) to be attributable to the degree of leaching undergone by them. In contrast, Sememiuk & Glassford (1989) consider the parent material for the soils of the Bassendean and Spearwood dunes to be a relict Pleistocene yellow sand, not limestone. They believe (p 88) that classification should be made on the actual surficial soils, rather than on the basis of the stratigraphy underlying the dunes and interdunes.

2.3 Hydrogeology

Major groundwater resources of the Swan Coastal Plain are the unconfined groundwater in the surface formations, and the confined water in the older, underlying sedimentary rocks. The surface formations are saturated with water to a depth dependent on the annual rainfall, regional relief, vegetation and

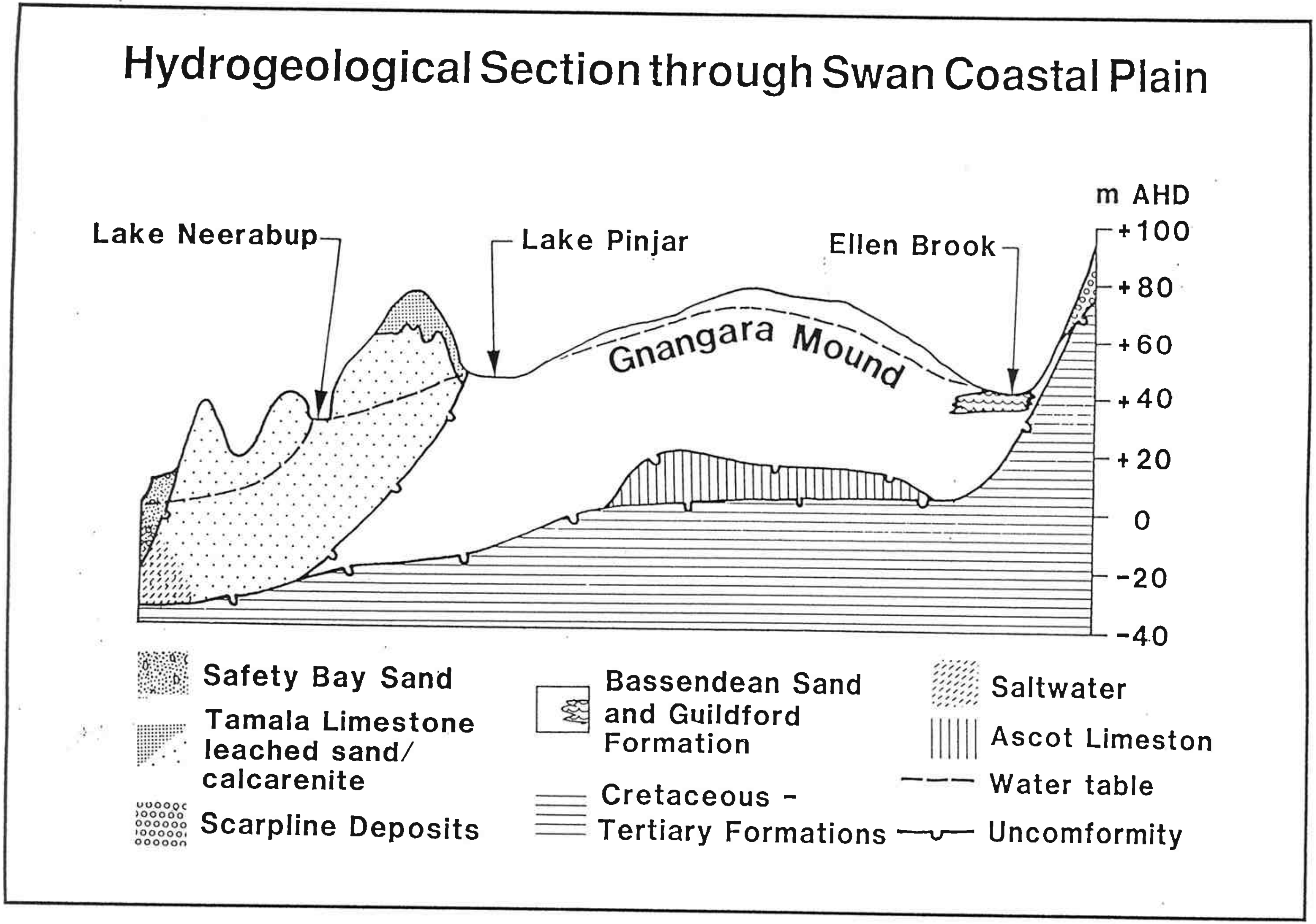


Fig. 2 (Webster 1989)

hydraulic characteristics of the sands (Butcher 1979). The top of the saturation zone forms a water table which extends beneath all of the coastal plain. Wetlands occur where the water table is at or near the surface as the water table is generally related to the topography (Fig. 2).

Groundwater in the superficial formations forms a broad mound to the north of Perth referred to as the Gnangara Mound . This mound tends towards a north-south ridge, bordered in the south by the Swan River, and extending northwards past the Gingin Brook. An area of 2,200 km^2 is covered, with approximately 70% of the area having a saturated water depth exceeding 40m (Water Authority 1986). In the mound area the water table reaches an elevation of about 70m above sea level beneath the Bassendean Dunes in the northern-central part of the coastal plain (Allen 1981).

The groundwater originates from rainfall which has infiltrated through the surface horizons and superficial formations and been discharged at hydraulic boundaries (Allen 1976). Recharge is directly from rainfall. Infiltration occurs over most of the coastal plain, however net recharge is affected by vegetation (Allen 1981). An estimated 70-90% of average annual rainfall is returned to the atmosphere by evapotranspiration. Where the water table is deep, 30% of the rainfall may reach and remain as groundwater; in areas where the water table is shallow most of the rainfall which reaches the water table may be used by the vegetation (Caldwell 1981).

Depletion may also occur through infiltration into underlying formations as a result of human activities, drainage or extraction. The rate of groundwater movement is controlled by the gradient of the water table, toward the sea or major rivers and by the size and degree of interconnection of void spaces in the water bearing formation. Depending on the groundwater gradient and the hydraulic conductivity, the rate of groundwater movement is about 30 m/y beneath the Bassendean dunes from north to south and about 90 m/y east to west beneath the coastal strip (Allen 1981).

3. BIOLOGICAL ENVIRONMENT

3.1 Vegetation - Structure and Floristics

The tree layer of Banksia woodland comprises Banksia attenuata, B. menziesii, and less commonly B. ilicifolia, Eucalyptus todtiana and Nuytsia floribunda. Allocasuarina fraseriana becomes apparent around Yanchep and further south. B. littoralis is favoured by damp swamps. The understorey is generally well developed sclerophyll scrub.

Edaphic features of the northern coastal plain determine the local vegetation associations. Factors such as location within dune type or interdune, depth to water table, organic soil development, kaolin content, colour, thickness of bleached soil, and subsurface stratigraphic or pedogenic features are all environmental conditions which cause variations in habitats and affect understorey assemblages in Banksia woodlands.

Some studies have identified vegetation habitats in terms of these edaphic features. Speck (1952) classified the vegetation of the Swan Coastal Plain, according to its structural and floristic composition. He recognised two formations, forest and scrub. The scrub formation was divided into tall and low subformations, each of which was divided into dry and moist phases.

Havel (1968) delineated site-vegetation types that were determined according to the degree of leaching and the soil moisture. His studies were restricted to the Bassendean and Spearwood Dunes, and were based on the conception of the vegetation as a continuum. Eleven different understorey communities and site types were determined. Cresswell and Bridgewater (1985) reasoned that the sharply changing nature of the soil systems and a highly seasonal climate favour sharp, rather than diffuse boundaries in vegetation. This classification allows allocation of vegetation of a particular bushland to a plant community. A broad approach was adopted by Heddle et al (1980), based on the identification of structural formations and detailed analysis of the vegetation in site-vegetation types. The relationship to landform, soils and climatic conditions was examined, and vegetation complexes were used to delineate plant communities. Twenty-nine vegetation complexes were identified, 13 of which related to Banksia woodlands. Low-lying swamp areas and regional north-south variations lead to differences between the complexes.

Floristically, the Banksia woodlands are considered by Dodd and Griffin (1989) to be representative of the state's south-western flora, since their dominant families and genera are also the dominant taxa throughout the southwest. The dominant families of the Banksia woodlands include the Proteaceae, Myrtaceae, Leguminosae and Epacridaceae. The total number of plant species in the woodlands is relatively great and approaches that of kwongan, but is substantially less than the jarrah forest. With the exception of B. laricina, no understorey or canopy species is peculiar to Banksia woodlands - all can be found in other vegetation types (Dodd and Griffin 1989).

Species considered rare and contained in the Banksia woodlands on the coastal plain include B. laricina, the King Spider Orchid Caladenia huegelii and two hammer orchids Drakaea jeanensis and D. micrantha (Hopper and Burbidge 1989). B. laricina has a very limited occurrence in sandy depressions about 16km south of Regan's Ford on the Moore River.

3.2 Fauna

The Banksia woodlands contains many species of birds and mammals which depend on the banksias and scrub species for nectar and cover. In general, the fauna do not rely on ready access to water or are wide ranging enough to obtain water from local wetlands.

The fauna of the Banksia woodlands has undergone major changes since European settlement, most obviously within the vertebrates. The mammals of the Northern Swan Coastal Plain originally numbered 33. Only 15 of these native species are now believed to be extant (Kitchener et al 1978). However none of these vertebrate species is unique to Banksia woodlands (How & Dell 1989).

Forest birds which relied on thickets and trees for shelter and nesting sites have declined in numbers in response to clearing of woodland vegetation (Storr et al 1978a). Birds such as the Scarlet Robin, Yellow Robin, Crested Shrike-tit, Rufous Tree Creeper, Yellow-plumed Honeyeater, White-naped Honeyeater, Dusky Wood-swallow and Grey Currawong are either no longer found in the region or are rare. The Brown Falcon became scarce due to the use of DDT in the south-west. In general birds have not declined in numbers to such an extent as mammals. A total of 223 birds occur on the Swan Coastal Plain (Water Authority 1986). The Banksia woodlands do not constitute a major part of the breeding habitat of any declared endangered bird species (Saunders et al 1987).

Of the herpetofauna, 42 genera and 70 species occur on the northern Swan Coastal Plain (Storr et al 1978b). The composition of the reptile assemblage reflects different substrates on the Banksia woodlands. Habitat fragmentation has resulted in the goannas Varanus gouldii, V. resenbergi and V. tristis becoming less numerous. The agamids Pogona minor and Tympanocryptis adelaidensis are present over the extent of the Banksia woodlands (Storr et al 1978b).

The species Morelia spilota (carpet python) and Vermicella calonotus (black-striped snake) are declared endangered reptiles that occur on the Banksia woodlands. Lerista lineata (lined skink) is not declared endangered but is of limited occurence, found only on the coastal plain from Perth to Yalgorup (Hopper and Burbidge 1989).

The invertebrate community of the Banksia woodlands is different from that of adjoining plant formations due to the poor nutrient status of the Bassendean and Spearwood sands. Majer (1989) considers that the overall invertebrate fauna of these woodlands is distinctive, although some species would be shared with adjacent plant formations.

3.3 Forestry

State Forest No. 65 occupies a significant part of the northern Swan Coastal Plain. This forest is in three blocks and lies north of Perth and extends along the Moore River to approximately 5 miles inland of Ledge Point (Havel 1968). The vegetation of the forest was primarily Banksia woodland, however of the total area of 50,000ha, 40% has now been cleared and planted with pine (Water Authority 1986).

This State forest is managed for multiple uses, including water production, timber production and conservation. The priority land use is water production over much of the forest south of Gingin Brook, although some areas have been designated for conservation.

industry over much of the area. Phosphate fertiliser application began around the start of the First World War. The introduction of the myxomatosis program, a dramatic increase in wool prices, trace element application and increased mechanisation resulted in a dramatic increase in productivity after the Second World War. These factors led to further rapid changes in the environment. (Students N319).

4.2 Current Population and Land Use

The broad zoning categories applying within areas of Banksia woodland include urban, urban deferred, industrial, rural, special rural, parks and recreation, State forest and vacant crown land (Water Authority 1986).

Local government authorities administering these areas include the Shires of Wanneroo, Chittering, Gingin, Swan, Dandaragan and Coorow. Land use varies from predominantly market gardening, horticulture and hobby farming in Wanneroo to stock grazing and cropping further north.

The growth of the North-West corridor on the coastal strip will progressively open up areas that are presently zoned urban deferred. Most of the corridor is undeveloped, although this is changing rapidly. This growth, coupled with increasing land values, will result in many of the large agricultural activities moving outside the metropolitan area. Joondalup is designated as a sub-regional centre on the North-West corridor plan and is located on undeveloped bushland, significantly Banksia woodland. The market garden areas of Wanneroo have been recommended to be retained for intensive agriculture (Yeates 1988) and have the potential to expand northward into the Shire of Gingin.

Of all the current land uses, those with the most potential to impact on the continuation of Banksia woodlands are likely to be the most intensive. The generally infertile sands with low water-holding capacity means that although the soils can be used for irrigated horticulture, they require extensive soil amendments and frequent irrigation. The extensive agricultural practices further north are unlikely to impact as severely on nearby bushland.

PART II

The Banksia woodlands represent a diminishing vegetation type and are susceptible to pressure from human activities. Such pressures include;

- water table variation
- plant diseases
- exotic species
- increases in soil fertility
- fire (naturally occurring, controlled burning) and arson
- degradation due to rubbish dumping and vandalism.

All of these activities have also diminished the range and availability of faunal habitats. Further degradation will occur as urbanisation spreads.

The following sections consider in turn the pressures facing the continuation of the Banksia woodlands as a recognisable entity, and the management issues dealing with them.

5.0 Water Table Variation

5.1 Groundwater Developments

Land surrounding conservation reserves and parks of Banksia woodland will be subjected to the effects of current and proposed groundwater extraction schemes (Water Authority 1986). Increasing pressure as a result of continued urban growth along the Northern Corridor and the expansion and relocation of horticultural industries has led to an increase in demand for water. Irrigation water is a key requirement for agricultural and horticultural production. Water supply is likely to be one of the main limiting factors to future growth in this region (Fig. 3).

It is vitally important that the quality and quantity of the groundwater resources are protected from excessive extraction by irrigation and the adverse effects of pollution from such sources as leaching of fertilisers, recharge by contaminated runoff, waste disposal sites, industrial discharges, leaking fuel storage tanks, septic tank leachates and road transport spills.

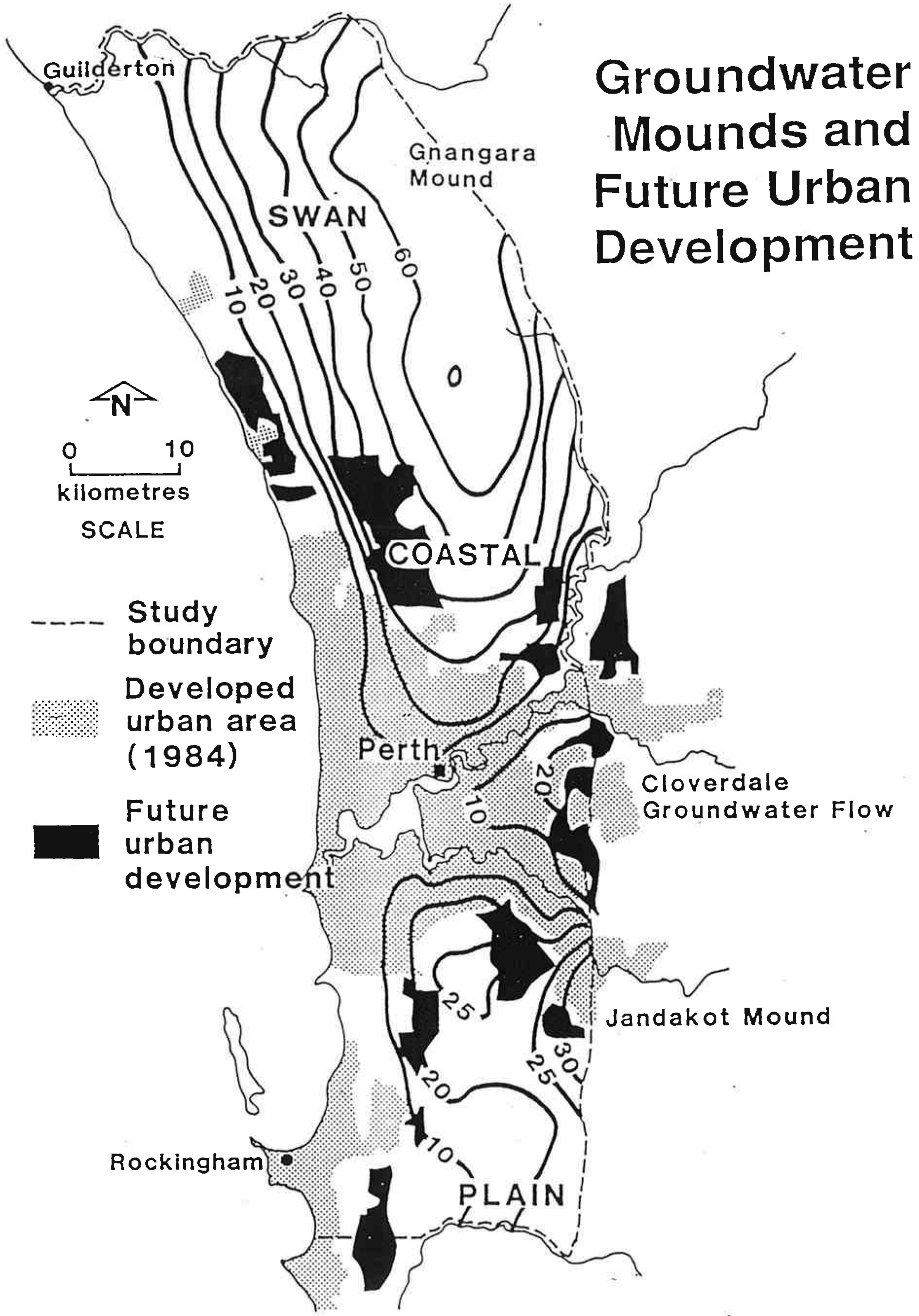


Fig. 3

From; Webster 1989

5.1.1 Natural Factors Affecting Groundwater Levels

Recharge of the groundwater in the Gnangara Mound is directly by rainfall. Because of this, seasonal fluctuations in annual rainfall will have marked effects on groundwater level. Other factors such as vegetative canopy cover, transpiration by vegetation, soil type and depth to water table will also directly affect groundwater recharge. Plants can affect recharge indirectly by removing water from the soil profile, and directly by accessing groundwater by means of deep tap roots.

As mentioned in Section 2.3, water use by Banksia woodlands and other native vegetation is estimated to return 70-90% of average annual rainfall to the atmosphere (Caldwell 1981). Net recharge is greatest at upland sites where the water table is many metres below ground surface, and inaccessible to even the deepest plant tap root systems (Dodd & Heddle 1989).

In recent years there has been a reduction in soil moisture content and a lowering of the water table on a regional scale throughout the coastal plain. This has been mainly attributed to a reduction in annual rainfall, although land use changes and groundwater extraction have also had an impact (Heddle 1980).

Forestry also contributes to groundwater usage in the Gnangara Mound. Pine plantations cover 20,000ha in State Forest No. 65 (see Section 3.3). This timber species grows taller and denser than the native vegetation it replaced. It can consume 20% more of the rainfall, eliminating recharge to groundwater in some circumstances (Bartle 1989). Generally the limiting factor for pine growth in this area is water supply. A program of thinning the plantations is being undertaken to reduce water use (Butcher pers. comm.).

5.1.2 Artificial Factors Affecting Groundwater Levels

Groundwater extraction for both public and private use has enormous potential to impact on the water balance of the Gnangara Mound. These not only include direct extraction of the groundwater, but indirect impacts such as the construction of water and sewer mains.

The water consumption of the Perth region approximates 400 million m³, half of which is supplied by the Water Authority and the other half is extracted by private users (Webster 1989). This water is used for a number of purposes -

private domestic irrigation, local government parks and gardens, Water Authority public supplies, agricultural irrigation, and industrial and commercial purposes.

5.1.3 Effect of Groundwater Developments on Banksia Woodlands

The Water Authority (1986) considers that the environmental impact of groundwater abstraction on surrounding vegetation is acceptable. However the need to maintain groundwater levels within limits necessary to support environmental requirements required the Water Authority to review its use of groundwater as a drought protection strategy. Because of the proximity of groundwater to the urban centres, the need arises for management of not only the water resources but of the land uses in the surrounding area.

Many native plants are adapted anatomically and physiologically to fluctuations in water availability. Dodd et al (1984), in an investigation of the root systems of a variety of plants on the Bassendean Dunes demonstrated a diverstiy of rooting types and a range of rooting depths. A range of native woody species of Banksia woodlands were excavated, and classified into shallow, medium and deep-rooted species. Thirteen of 43 examined were found to have tap roots potentially capable of reaching groundwater. These included B. attenuata, B. menziesii and B. ilicifolia. Essentially the deep-rooting species were recognised as being more likely to be dependent on the water table and the adjacent moist layer. Shallow-rooted species were thought to be more likely to be highly responsive to large seasonal fluctuations in soil water content and hence unaffected by groundwater changes. Consequently the deeper-rooted species are more likely to be affected by water table drawdown than the shallow-rooted species. This appears to be the case in studies done so far. Heddle (1980) noticed a reduction in height and percentage foliage cover through the older and larger trees being replaced by smaller and younger saplings in the northern Swan Coastal Plain in areas where water tables have declined.

The consequences of a lowering of the water table for the Banksia woodlands is being monitored; Dodd and Heddle (1989) have documented some changes in vegetation. They considered that many of the vegetational changes likely to be associated with a lower water table would be comparable to those already observed as responses to long-term regional drought.

Changes in vegetation observed by Dodd and Heddle (1989 p 92) in response to a reduction in soil moisture content include;

> reductions in some tree and understorey species which tolerate wetter soils, e.g. E. marginata, B. littoralis and Hypocalymma angustifolium,
>
> many species which tolerate drier soils or which are not site-specific in occurence have maintained or increased their abundance, e.g. B. attenuata, B. menziesii and Gompholobium tomentosum,
>
> certain short-lived understorey species have declined, probably because of the lack of suitable conditions for germination and establishment.

The location of wellfields, regional drawdown, depth to water table and the topographical position of the native vegetation are important when considering the likely impact of groundwater extraction on native vegetation. Conservation parks and reserves were grouped by Heddle (1986) according to the likely impact. Those relevant to Banksia woodlands include;

High potential impact - Melaleuca Park Management Priority Area, Yeal Nature Reserve, Wabling Management Priority Area.
Moderate potential impact - Yanchep National Park.
Low potential impact - Caraban Management Priority Area, Two Rocks open space and Ridges Management Priority Area.

The survival of plants depends on their ability to adjust to changes in soil conditions and on their capacity to tolerate periods of water stress. In general, most of the native species studied appeared to be able to tolerate some decline of the water table on a regional basis, with some loss of older trees and shrubs (Heddle 1986). Plants unable to adapt to the current water stress could serve as indicators of changes in soil moisture, so that the influence of the withdrawal of underground water on the native vegetation can be predicted and prevented.

6. Plant Diseases

Two plant diseases are of concern to managers of Banksia woodlands. Dieback disease caused by the fungus Phytophthora cinnamomi is of particular importance because of the susceptibility of this vegetation type to the fungus. P. cinnamomi is widely distributed in Banksia woodlands of the coastal plain (Shearer and Hill 1989). Other Phytophthora species have also been isolated from dying vegetation (Hill in press). Compared to P. cinnamomi, little is known about the factors affecting reproduction and survival of other Phytophthora species, however evidence to date indicates that they are also highly pathogenic. Of equal importance is the plant pathogen Armillaria luteobubalina, a fungal disease which, like dieback, spreads in the soil and by root to root contact. Spread of the disease is slower than for dieback disease. However devastation to infected vegetation can be just as great.

6.1 Ecological Impact of P. cinnamomi in Banksia Woodlands.

First observed in the 1920's, dieback disease has spread throughout the south-west of Western Australia. Thought to have been introduced, this disease is now a major threat to the ecology and conservation of susceptible plant communities, particularly those of the Banksia woodlands. Dominant families such as the Proteaceae, Epacridaceae, Dilleniaceae and Myrtaceae contain a large number of susceptible species (Shearer and Tippett 1989).

P. cinnamomi infection has the potential to cause major changes in the floristic structure and diversity in the woodlands, and have a deleterious effect on the conservation values of these areas. For Banksia woodlands on the Bassendean Dune System the banksia overstorey is killed and often none remains in infected areas. Understorey is also affected, with species rich areas being replaced by resistant species, predominantly grasses and sedges (Shearer 1990). The Moore River National Park is the most northerly known occurrence of P. cinnamomi on the coastal plain. Geographically restricted and susceptible B. laricina is being killed in affected areas in this park (Shearer and Hill 1989).

The incidence of P. cinnamomi on the Spearwood dunes is much less than on the Bassendean dunes, even though plant species are susceptible and disturbance from human activity is high (Podger 1972).

Of 330 species examined by Wills (1990) in the Stirling Range National Park (in similar vegetation community types to Banksia woodlands), one third were recorded as being affected by the disease. Most monocotyledonous species were recorded as resistant to the disease, while 42% of the dicotyledonous species showed some degree of susceptibility to the fungus. Significant differences could be seen in species richness and projective foliage cover between healthy sites and high impact sites. The loss of susceptible species resulted in changes in patterns of diversity and abundance.

Changes in community structure following infection are as a result of the differential susceptibility of woody and herbaceous perennials. Plants unaffected by the disease may be affected indirectly. Alteration of community structure often leads to a more open stand, devoid of canopy structure and therefore protection for some shade loving species (Wills 1990).

Introduced annuals have been shown to increase in abundance following the removal of canopy of native plant communities (Hobbs & Atkins 1989). As a number of non-native species are resistant to the disease, infected areas are potentially more susceptible to weed invasion than adjacent healthy sites.

Changes in the structure of plant communites can also affect the composition of associated animal communities. Many susceptible Banksia species are important food sources and habitats for nectarivorous and other animals. Many key susceptible plant species of the Banksia woodlands such as B. menziesii and Adenanthos cygnorum have obligate vertebrate and invertebrate associations (Lamont 1989).

Decline in projective foliage cover following P. cinnamomi infection can lead to a rise in the water table as a result of decreased interception and reduced transpiration. Shearer and Hill (1989) recovered the fungus from groundwater at 3 and 5 metres below the soil surface in affected Banksia woodland.

In addition to losses of conservation values, P. cinnamomi also has the potential to impact on the tourism and wildflower industries. Many important wildflower genera of the Banksia woodlands are susceptible to the disease. Such genera include Banksia, Darwinia, Grevillea and Verticordia.

Dieback is spread either by the movement of infected soil or plant material, or in flowing water (Shearer 1990). The pattern of disease development at Gnangara reflects the ability of P. cinnamomi to exploit various mechanisms of spread. Disturbance associated with market gardening, roads and off-road driving have resulted in the dispersal of P. cinnamomi in infected soil, and is responsible for the widespread distribution of the pathogen throughout the coastal plain (Hill pers. comm.). The impact of the disease is dependent on temperature, moisture, floristic composition, antagonistic microflora, drainage characteristics and soil type. Control measures focus on prevention of the introduction of the disease. There is no treatment of infected sites to date - management is aimed at restriction of spread.

6.2 A. luteobubalina in Banksia Woodlands

A. luteobubalina is a pathogenic fungus capable of infecting Banksia species and members of the understorey. The fungus persists in colonized roots or debris in the soil. Trees in the next generation are infected by rhizomorphs or by root contact with infected wood (Blenis and Mugala 1989). Deep, sandy soils are associated with high disease incidence, whereas poorly drained soils are indicative of sites with a lower risk of disease (Blenis and Mugala 1989). The deep, sandy soils of the Bassendean and Spearwood dunes present high hazard sites for the fungus. The disease is difficult to remove from an area once infected. Spread is slower than the spread of P. cinnamomi although the impact can be just as devastating.

7. Increases in Soil Fertility and Salinity

The coastal plain south of the metropolitan area is increasingly being threatened not only by eutrophification of estuaries caused by phosphorus fertilization but also by salinization, unsympathetic land use and pesticide pollution. In this regard, forestry is a more suitable land use than clearing of native vegetation for agriculture as these problems would not be incurred. With the increasing likelihood that the northern coastal plain will be subject to greater intensive horticulture and agriculture these problems must be addressed before they arise.

7.1 The Use of Phosphorus and Nitrogen

The soils of the Bassendean and Spearwood Dune systems that support Banksia woodlands generally have very low inherent fertility and water holding capacity. These soils are easily leached, do not accumulate salts and have a poor ability to hold nutrients. Heavy fertilizer applications are required to support plant growth, particularly under irrigation (Wells and Bettenay 1987). Due to this low ability to hold water and nutrients, any quantities in excess of those which can be used by the crop will move through the soil to the groundwater. Horticultural crops traditionally receive frequent heavy applications of water and nutrients.

Application rates of water on the Swan coastal plain need to be about 25% more than the crops' requirement (Luke 1987). High rates of irrigation are needed to keep the water content of the soil above the level at which reduced soil hydraulic conductivity may limit water uptake, and hence production. Extra water is also applied to prevent sand blasting of seedlings, to wash in fertilisers, to cool crops on hot days and for frost control. Sprinkler irrigation is applied several times a day, with the surplus draining through the soil.

Recommended rates of fertilizer application vary enormously. Vegetable crops on the coastal plain may receive frequent applications of fowl manure and inorganic fertilizer. Fowl manure contributes significant quantities of phosphorus and nitrogen to the system (Luke 1987). As fertilizer and water only contribute about 10% of the total cost of production, there is little incentive for growers to restrict their use. The consequences of under-fertilizing and under-watering are more serious than over-fertilizing and over-watering.

Phosphate leaching from the soils of the coastal plain has been investigated in detail in recent years because of the contamination and consequent algae problems in the Peel-Harvey estuary. A large contributor to nitrogen losses in the area are thought to be from biologically fixed N leached from legume pastures throughout the catchment of the river systems. Nitrogen fertilizer application is not likely to be a major source of leached N (Yeates 1988).

Luke (1989) presented data to show that one hectare of vegetables on leaching sands could contribute more than 500kg of P and 2,000kg of N per year to the groundwater. It was concluded that an additional 50ha of irrigated horticulture could double the phosphate load into the system, under current practices.

Increased urbanisation would also lead to an increase in the number of septic tanks in an area. Nutrients leach from the tanks into the surrounding ground and through to the groundwater. The Water Authority (cited in CALM 1988) estimates that 18 kg of nitrogen seeps into the groundwater from one septic tank per year. Increased fertilizer application to lawns and gardens would also increase the phosphorus and nitrogen load to the system.

Because of their nature, wetlands on the northern coastal plain would be the first to be impacted by an increase in soil fertility. The increase in nutrient levels and pollutants from intensified agriculture and horticulture would contribute to destabilisation of these ecosystems and lower their conservation values.

However the impact of these factors on the Banksia woodlands is less well documented and likely to be much more subtle. Little research has been done on the tolerance levels of woodland species to increases in nitrogen and phosphorus concentrations in the groundwater and soil. It is probable that species will react differently, with those species most affected being those with direct access to the groundwater. A massive collapse of the agricultural ecosystem through abuse of chemicals and fertilizers that so poison soils and pastures that they become unusable is a very remote possibility, according to Newman (1988). This scenario is probably equally remote for the vegetation communities of the Banksia woodlands, however there is an increased likelihood, considering the very low tolerance of may of these species to excessive nutrients.

7.2 Soil Salinity

The high rainfall experienced by the Swan Coastal Plain has led to expectations that soil salinity would not be problematic. The widespread land-use changes have proven this not to be the case and extensive and expanding areas of saline land are now evident. Both dryland and irrigation induced salinity occur (George 1988).

Land clearing has resulted in the slow release into streams and wetlands of salts previously stored in the soils. The Moore River is saline throughout its length (Students N319 1989). Increased seepage activity and lake salinity have also been observed in the Gingin shire.

Saltland is caused by shallow, saline watertables, with the sea ultimately being the source of the salt (Hingston and Gailitis 1976). The severity of soil salinity is a function of the groundwater salininty. Saltland is most obviously manifested by bare, scalded areas although poor pasture production and quality are also symptoms. Waterlogging in winter and after irrigation are compounding factors. A recent survey on the coastal plain in the Harvey/Waroona area concluded that 35% of irrigation areas were affected by salinity (George 1988).

In irrigated areas salt may be introduced through the use of saline irrigation water, though the prime cause of soil salinity in all areas is thought to be poor drainage and shallow watertables (George 1988). These factors then combine to further exacerbate the problem. By far the biggest risk to the quality of groundwater in the Perth region of the coastal plain is the intrusion of the salt water wedge in coastal areas due to overpumping (McPharlin and Stynes 1989).

With the projected increase in clearing and the replacement of deep rooted vegetation with shallow rooted crops and pastures and accompanying irrigation, the potential for further salt encroachment and stream salination is high in areas surrounding remnant Banksia woodlands. The toxicity of a saline watertable poses as great if not a greater threat to these areas than does an increase in soil fertility.

8.0 Exotic Species

The integrity of conservation areas of Banksia woodland are seriously threatened by exotic flora and fauna species.

8.1 Exotic Fauna

The principal reasons for the decline of the native vertebrates of the Banksia woodlands are thought to be the introduction and successful establishment of eutherian animals early in the twentieth century, altered habitat by land clearing and changed fire frequency (Kitchener et al 1978). Replacement of native shrub vegetation by suites of alien grasses and forbs may also be instrumental in the decline of native species. Introduced animals include species such as the mouse *(Mus domesticus)*, the fox *(Vulpes vulpes)*, the rabbit *(Oryctolagus cuniculus)* and the cat *(Felis cattus)*. The fox and the rabbit are declared pest species. These animals have thrived in the modified environment created by man and have displaced native species either by direct predation or by competition for food and shelter resources.

8.2 Exotic Flora

Weeds are generally vigorous growers, and compete strongly with natives for nutrients and moisture. They have induced drastic floral conversions of native Western Australian communities, most often attributed to aggressive hemicryptophytes (Bell 1984). Severe summer bushfires damage the tree canopy and as a result more light penetrates, encouraging strong weed regeneration (Wycherley 1984).

Little information is available on the effects of introduced plants on the Banksia woodlands - no comprehensive survey has been undertaken (Keighery 1989). Many exotics are weed species which are adapted to spread following disturbance and are frequently encouraged by fire. The major avenue of introduction of weeds is dumping of rubbish and garden refuse, and soil transportation. Other disturbance factors are present and past grazing, clearance and tree felling.

From a survey of naturalised flora of Banksia woodlands between Moore River and Mandurah, Keighery (1989) concluded that major weeds of Banksia woodlands include Ehrharta calycina, Avena barbata, Gladiolus caryophyllaceus, Pelargonium capitatum and Homeria flaccida. Weed species abundant throughout Banksia woodland remnants were Avena barbata, Ehrharta calycina, Ehrharta longiflora, Romulea rosea, Gladiolus caryophyllaceus, Pelargonium capitatum and Homeria flaccida. A total of 120 species were recorded, with the majority being annual or bulbous herbs (Fig. 4).

Ehrharta calycina (veldt grass) is particularly aggressive in a fire situation. This species is an invader on sandy soils and is encouraged by frequent fires. Fuel characteristics of a community are also changed by the establishment of this species, increasing fire susceptiblity and further favouring the veldt grass (Christensen and Abbott 1987). The responses of individual native species to veldt grass competition vary. However overall, native species are adversely affected (Wycherley 1984).

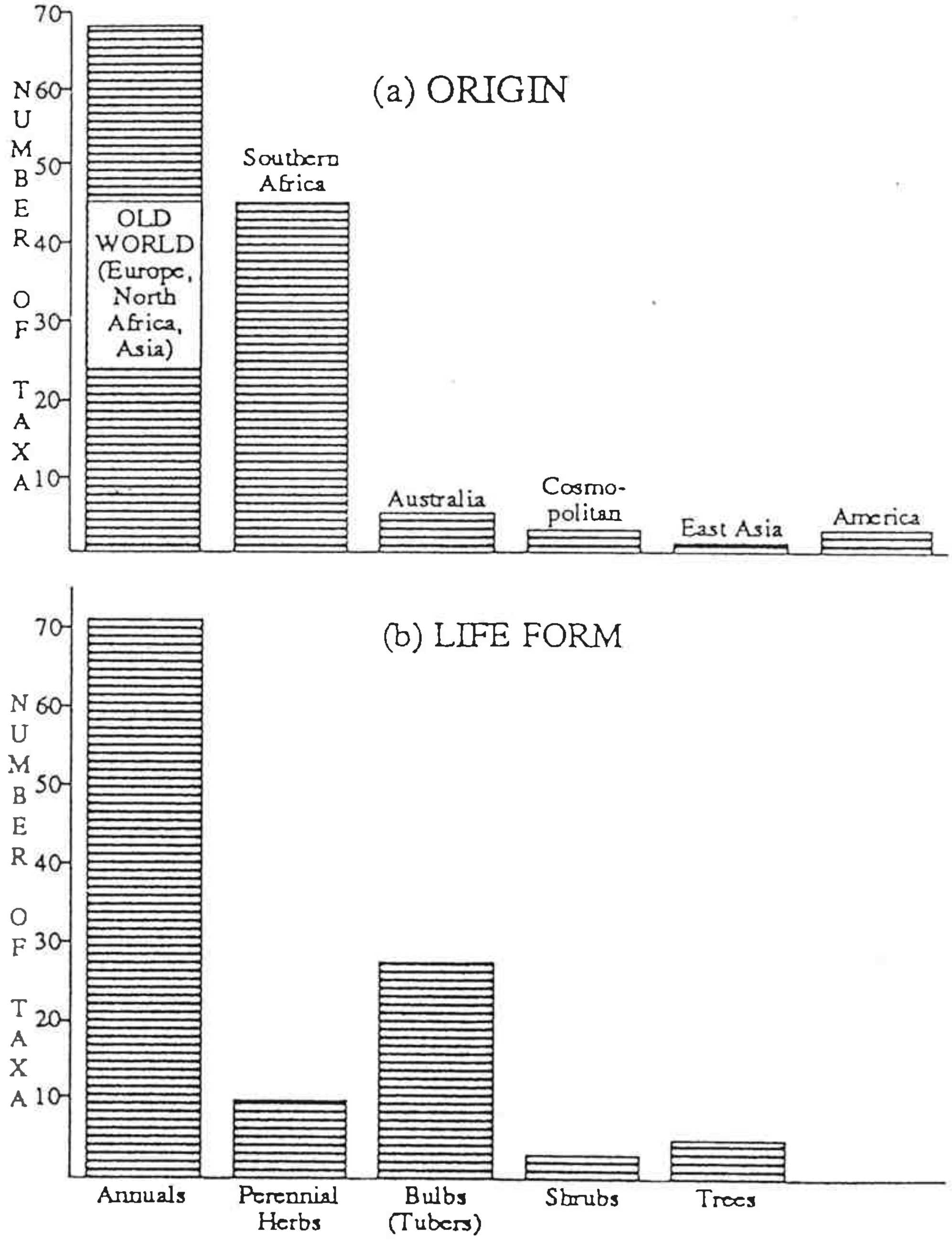


Figure4 Area of origin and life form of *Banksia* woodland weeds.

Keighery (1989).

9. Fire and Arson

The aims of a fire management program are to protect life and property from uncontrolled wildfires, and to manage natural ecosystems to maintain the greatest species richness and diversity. The Banksia woodlands are a vegetation type that is prone to accumulation of flammable vegetation, and the region has experienced large, intense wildfires (Burrows and McCaw 1990). The proximity to the metropolitan area make some reserves of Banksia woodland prone to arson, with burning of stolen cars becoming an increasingly obvious ignition source. Other causes of accidental fire in the Yanchep National Park include escapes from prescribed burns and lightning (CALM 1988).

Fuel accumulation in Banksia woodlands is rapid. Burrows and McCaw (1990) estimated that the amount of fuel accumulated after four years was sufficient to sustain an intense and fast moving fire under extreme fire weather conditions. However fuel accumulation declined after this period, and was about 80% of that which would be expected after 20 years (see Section 14 on fire management).

Considering the high risk of wildfires, particularly from incendiaries, reserves of Banksia woodlands need fire management. The "do nothing" option should also be a consideration, given that fire is an integral part of the landscape and has the capacity to promote conservation values and well as degrade them.

PART III.

Environmental Management

This section describes programs for management of the identified impacts. Management of reserves should reflect their conservation status. The fact that an area has been classified as a reserve is indicative of its value for conservation, and a cautious and conservative approach should be taken when all management decisions are considered.

Size and location of a reserve is an important management consideration. However as the reserves under consideration are of very different sizes, reserves are not considered individually and recommendations given are aimed at all reserves. Area management plans cover a specific area or set of areas, often of common purpose, such as national parks, nature reserves, State forest etc. A plan such as this would be prepared when management details specific to an area cannot be covered adequately by a regional plan.

Categorisation of Banksia woodland reserves currently vested in controlling bodies and managed by CALM include;

State forest
national parks
nature reserves

Controlling bodies are the Lands and Forests Commission and the National Parks and Nature Conservation Authority.

10. Water Table Variation

The primary objective of any plan to manage or utilise groundwater resources in the vicinity of remnant Banksia woodland must be compatible with the conservation of the reserves. However as the value of the groundwater is considerable, an overall management proposal of the groundwater resources should consider:

- land management practices that minimise groundwater utilisation and degradation
- methods of recovering the costs of groundwater management
- water conservation policies and targets

- a provision for improved information and understanding of the quality and quantity of the resource and so reduce the risk of over-extraction
- the determination of beneficial uses
- criteria that relate to beneficial uses

Legislation in place to protect the sustainability of groundwater resources and to ensure its quality remains unaffected is primarily the Environmental Protection Act (1986). Sections of this Act that relate to water supply and quality include Pollution Control, Environmental Impact Assessment and The Environmental Protection Policy (Murray 1989). The Water Authority Act (1984) also provides for control of polluting activities over water supply catchments.

The expansion of the intensive horticultural industry, groundwater developments, agriculture and continued urban growth in the north-west corridor will dramatically increase demand for water. By the year 2000 it is estimated that the total water consumption in the Perth metropolitan region could be close to 550 x 10^6 m^3/annum of which 350 x 10^6 m^3/annum could come from groundwater (Webster 1989). However this demand must not be allowed to compromise the integrity of remaining woodlands.

The majority of native species can tolerate fluctuations in the soil moisture regime (Heddle et al 1980). There are species however that are intolerant of such changes. Havel (1979) predicted a vegetation shift to the xeric end of the vegetation continuum if water tables were lowered. In the management strategies for the Gnanagara Mound extraction proposal (1986 p 137 Appendices), the only reference made to the protection of conservation areas is "in the northern part of the area, particularly Yeal Swamp". Although the Water Authority currently monitors over 900 points using the existing network, the current level of information is scarce and is considered insufficient when considering conservation reserves in the area.

Recommendations for groundwater management include;
- continue current monitoring system, plus
- expansion of monitoring points, particularly on the Bassendean Dunes,
- establishment of control monitoring points outside the predicted drawdown area
- recognition of the value remnant woodland cover affords groundwater protection
- provisions for detailed vegetation mapping of reserves in the area of influence
- further clearing of land in proximity to reserves to be restricted

- development of allocation strategies for private users
- a community awareness or education program aimed at encouraging water efficient activities.

11. Plant Diseases

The disease of primary importance to species in the Banksia woodlands is P. cinnamomi (see Section 6.1). This root pathogen has the potential to change the structure and floristic composition of the woodlands and alter the conservation value of these areas. Loss of rare species and threats to food sources and habitats of fauna, as well as adverse effects on aesthetics occur. Dieback infected sites still retain some conservation value however, as not all species are susceptible to the disease. For example, the geophytes are known to be unaffected.

Areas of greatest concern are tracks on which the disease has been confirmed and/or have a high risk of infection and spread and/or pass through vegetation with a high proportion of susceptible species. Disease is less likely to be spread from well constructed roads with good drainage. Active and passive dispersal of zoospores in free water contributes to spread within an area and results in the contamination of swampy areas.

Once the disease is present, eradication is virtually impossible. Because of this, management objectives need to consider the prevention of introduction and spread of this disease, and of A. luteobubalina.

Recommendations for management of dieback and other diseases:
- establish a comprehensive survey of the northern Banksia woodlands in an attempt to identify protectable dieback-free areas
- inform park or reserve users about dieback and the need to stay on constructed roads
- practice dieback hygiene for every operation involving soil movement
- isolate known dieback sites and close infected tracks
- consider temporary closure of tracks when risk of spread of disease is high (e.g. after summer rain)
- erect alternative walkways through known infected sites
- determine susceptibility of rare and keystone species
- establish a hazard rating system so future operations can be assessed.

12. Non-indigenous species

12.1 Weeds

Weeds are generally aggressive opportunists able to thrive in a natural situation to the detriment of the native species. Unaggressive weed species do not establish unless there is an unoccupied niche in the environment, or unless other circumstances suit their establishment.

Areas of Banksia woodland within close proximity to the metropolitan area are becoming increasingly susceptible to the invasion and establishment of weeds, due to the increased traffic of walkers and vehicles, and the surrounding farming areas.

Weeds frequently establish in areas of disturbance such as fire breaks, on edges of native communites, or in litter under trees (Keighery 1989).
Control of weeds is intensive and time-consuming, and impractical in large areas. The best management is therefore to prevent establishment of weed species. Control methods can take 3 forms, i) chemical, ii) mechanical and iii) biological. Chemical methods can be used in areas where drift is not a problem and large areas need to be treated. Mechanically removing weeds is labour-intensive but does not harm other species. However the soil disturbance can encourage further weed growth. Biological methods are generally not used as they have the potential to harm indigenous species.

Management should aim to lower disturbance and prevent further introductions. The effect of weed control should therefore be weighed against the effects of no control. Rehabilitation of an area with indigenous species after weed control should be considered as an important adjunct to weed control.

Recommendations for weed control;
- establish survey of naturalised non-indigenous flora of northern Banksia woodlands
- determine effects of fire regimes on aggressive weed species
- conduct control programs in areas of high weed infestation/high conservation value
- rehabilitate areas in which weeds have been controlled
- determine practicality of slashing in areas of weed infestation
- inform park/reserves users of weed control programs.

13. Management of Soil Fertility and Salinity

Demand for vegetables is expected to rise by 10% per annum because of increased population and a change in eating habits. This will mean that the water and land requirements of the vegetable industry will increase by at least 50% in the next 5 years (Sumich 1989). Increased horticulture and agriculture will increase the pressure on groundwater and surface water quality. Land management practices that reduce the risk of groundwater pollution, and improved fertilizer management to reduce nutrient input into these waters are requirements of a more efficient industry.

Changes in agricultural land use in the Peel/Harvey catchment area in an attempt to alleviate increased soil fertility include changes in fertiliser use and changes in intensive agricultural activites (Halse 1989). While the damage has already been done in this area, there are valuable lessons to be learnt on the northern coastal plain.

Recommendations for management of soil fertility include;

- preservation of the better quality soils for vegetable production would restrict overuse of fertiliser. Soils of the Spearwood dunes have a greater ability to fix added nutrients than do soils of the Bassendean Dunes (Wells and Bettenay 1988) and are also neutral rather than acid and thus better for plant growth.
- red mud ammendment of highly P leaching soils to reduce loss. Red mud is high in Fe and Al oxides and hydroxides and would increase the P absorption capacity of these soils.
- clearing and drainage controls to slow nutrient losses.
- conversion of annual crops to perennial on high P-leaching soils wherever practical.
- more environmentally appropriate fertiliser regimes such as slow-release fertilisers and blends, more regular fertilizer applications in smaller quantities to more closely match nutrient supply to crop demand
- the use of soil and plant testing to monitor fertiliser programs
- introduce more suitable irrigation systems such a trickle irrigation.

Salinity management would be enhanced by more efficent use of groundwater. This would inhibit the development of saline areas. Current methods of control include intensifying surface drainage to reduce waterlogging, and to increase the perennial vegetation cover of the affected area with salt-tolerant species.

Recommendations for salinity control in addition to the above include;
- water monitoring to maintain low soil moisture deficits
- the use of irrigation systems whereby water application can be controlled i.e. not gravity-fed systems
- planting of salt-tolerant species
- fence off affected areas to reduce stock disturbance
- implement proper drainage.

14. Fire

Man is thought to have manipulated the environment by fire for thousands of years. Hallam (1979) proposed that presence of charcoal in stratigraphic sequences from various locations around Australia indicates that fire frequency increased dramatically about 40,000 years ago, coinciding with the arrival of the Aborigines. Her view is that firing by these people was largely part of a deliberate land management technique designed to create a mosaic burn pattern, the results of which were of varied benefit in their hunting and gathering.

Bell (1984) suggested a high frequency of occurrence of identical sets of morphological, phenological and functional characteristics found in taxonomically diverse sets of kwongan flora suggested a commonality in adaptive response to certain key environmental influences, including fire. Considering the close relationship of this vegetation type to Banksia woodlands, this could also be said of this ecosystem.

The aim of a fire management program would be to emulate the fire history of a region. The implementation of this aim is however open to interpretation. Industries such as apiculture, cut flower and tourism would prefer the woodlands remain unburnt for periods longer than those desired by managers of reserves.

The frequency and season of burn affects individual species in different ways. There is evidence that burning too often is a factor which is threatening some mammal species on the coastal plain. Pseudomys albocinereus and Tarsipes spencerae were only observed in isolated pockets of vegetation which had been unburnt for at least 6 years (Kitchener et al 1978). Bamford (1986) reported that burning in a woodland at Jandakot was too frequent for mammal recovery, even with the existence of a mosaic of different aged vegetation. He concluded that it may not be sufficient just to maintain a mosaic of burn ages; it may be necessary to have mature or even senescent areas to act as reservoirs from which recruitment can occur. Under fire regimes which advocate too frequent burning, mammal populations will be depleted and ultimately become extinct.

Christensen and Abbott (1987) state that fire intensity is the major factor influencing the impact of fire on bird populations in the jarrah and karri forests. Fire intensity influences vegetation structure and presumably the recovery of insect populations. Fewer birds were found in the ground vegetation, understorey and lower tree canopy levels in forest area unburnt for 40 years compared with burnt study areas.

Fire can also have an effect on recruitment of plant species of the Banksia woodlands. The high proportion of lignotuberous plants, and plants with underground regenerating organs and hard seed coats enables these elements of the flora to cope with a fire regime (Dodd et al 1984, Hopkins and Griffin 1989). Only 6 of 13 species identified by Hopkins and Griffin (1989) are in the most fire vulnerable category, being fire sensitive and having seed storage on the plant in bradyspores.

Fire has the potential to promote weed invasion, with the season of burning being important. Hobbs and Atkins (1989) suggested that autumn fires promoted increased invasion by non-native species, at the same time however autumn fires promoted seed germination of native species. They recommend the adoption of a spring burning regime, which encourages a more rapid vegetation recovery, resulting in a greater species diversity 2 years after the fire. However Cowling and Lamont (1987) recommend that in order to maintain populations of Banksia species, tracts of scrub-heath should be burnt in autumn, prior to the onset of winter rain.

Fire interval is an important factor when considering Banksia woodlands. In a survey (see Appendix I) done in spring this year, a site 6 years since burnt had a greater species diversity than either a 3 or >20 yrs since burnt. The >20 yr post-fire site was dominated by one understorey species, Beaufortia squarrosa. In the absence of disturbing agents, fire interval may be an important factor controlling weed invasion. Non-native species were present only in the most recently burned stand. This was also reported by Hobbs and Atkins (1989).

Conflicts between property preservation and conservation cannot be resolved without further information on fire effects. Burrows and McCaw (1989) in a study of structure and accumulation of understorey fuels suggest that buffers in

Banksia woodland need to be burnt every 3-4 years to remain effective. This would have pronounced effects on the vegetation and be unsuitable for large areas.

Recommendations for fire management;
- fuel reduction buffers around built-up areas, or areas of high conservation value
- implement a conservation-based fire rotation (i.e. longer intervals between fire) wherever possible
- implement further studies to determine most appropriate season to burn
- determine effect of burning on native fauna species of Banksia woodland.

15. CONCLUSIONS

The Banksia woodlands of the Swan Coastal Plain were a widespread and important vegetation type. Extensive clearing has severely reduced the range, and remnant vegetation is subjected to severe "people-pressure". These pressures include urbanisation, mining, industrialisation, recreation, horticulture, vandalism, arson, wood-cutting, and littering. These pressures place great emphasis on existing national parks, nature reserves and state forest, which are now highly valued for conservation.

It is now critical for effective management of the remaining Banksia woodlands be undertaken.

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APPENDIX II.

Effect of fire on floristic composition and stand structure in a Banksia woodland near Perth.

Introduction

The fire-related dynamics of a woodland community dominated by Banksia attenuata and B. menziesii, with an understorey of sclerophyllous shrubs were examined. Sites of three different ages since burnt were selected. The two most recently burnt sites had similar site characteristics and were of similar age and composition when burned. Time since last fire ranged from 3 to >20 years. Vegetation in the different stands was analysed to determine changes in floristic composition and stand structure with time since fire.

Methods

Sites were selected in Melaleuca Park, a Management Priority Area under the System Six Report. All study sites chosen were on Site Vegetation Type G (Havel 1968). This site type is characteristic of deep, dry pale grey sands which are are strongly leached throughout, and occur on lower slopes in the transition zone, and slopes and dune crests within the Bassendean Dune System. The vegetation was low woodland dominated by B. attenuata and B. menziesii with a diverse understorey.

All study sites were located within 1km. Stand ages since burning were 3, 6 and >20 years. The two most recently burnt sites had been burned in spring as part of CALM's fuel reduction program for the area (Underwood 1987). The older site was part of a trial being conducted by CSIRO into the effects of fire in the area.

Nested quadrats were established initially to determine a species area curve (Hopkins 1988). Ten 10 x 10m quadrats at each site were subsequently examined, with all species within the quadrats being recorded. Sites were examined in early spring 1990. Total cover and understorey height of the quadrats was estimated by eye.

Results

A quadrat size of 10 x 10m was selected from the species area curve as containing approximately 85% of species present (Fig.1).

Data obtained from the quadrats indicate that the majority of species are present 3 years after fire, with only a slight increase in species numbers 6 years after fire. After this period there is a decline in total species numbers (Fig. 2). The family Stylidiaceae, prominant on the 3 and 6 yrs since fire, was very rare on the >20 yrs since fire. Herbaceous species also declined in number on the older site. A total of 49 species were recorded during the study.

Total cover varied little between the 3 and 6 yrs since fire, with a slight increase in the 6 years. The >20 yrs since fire showed a dramatic increase in total cover, with the dominant species being the woody perennial Beaufortia squarrosa. Shrub height of this species increased with age and was up to 1.5m at the older site (Table 1).

Discussion

All sites were located on the same site type to eliminate differences in vegetation due to different substrates. In the absence of different site types, changes in vegetation were attributed to the differing fire treatments.

A trend of increasing species richness up to 6 years following fire was evident. In the older stand species numbers declined and many herbaceous species were no longer present. The family Stylidiaceae was noticable by its abscence, as were grasses. It also appeared that the abundance (this was not directly measured) of many species declined in the older stand, although there was very little difference in the two younger stands.

The height of the understorey showed a simple progression with stand age, with the shortest being 3 yrs since fire and the tallest >20 yrs since fire. This was due to the shrub B. squarrosa being considerably taller at the >20 yrs since fire than at either of the other sites. At these sites this species was of similar height to other woody perennials such as Eremaea pauciflora and Melaleuca scabra. With the exception of E. pauciflora, no other species showed a similar increase in height with age.

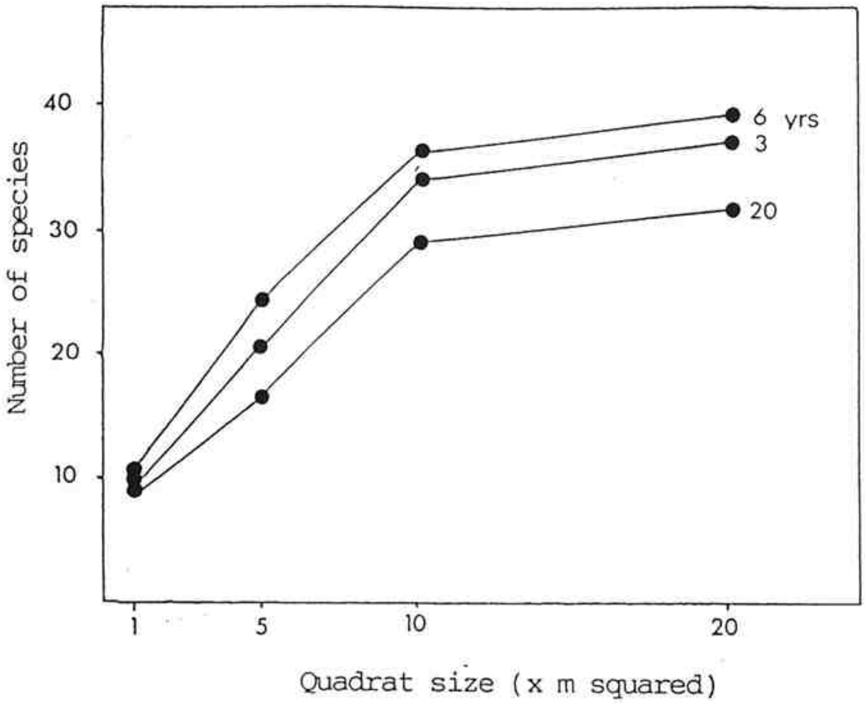

Fig. 1. Species area curve for Banksia woodland.

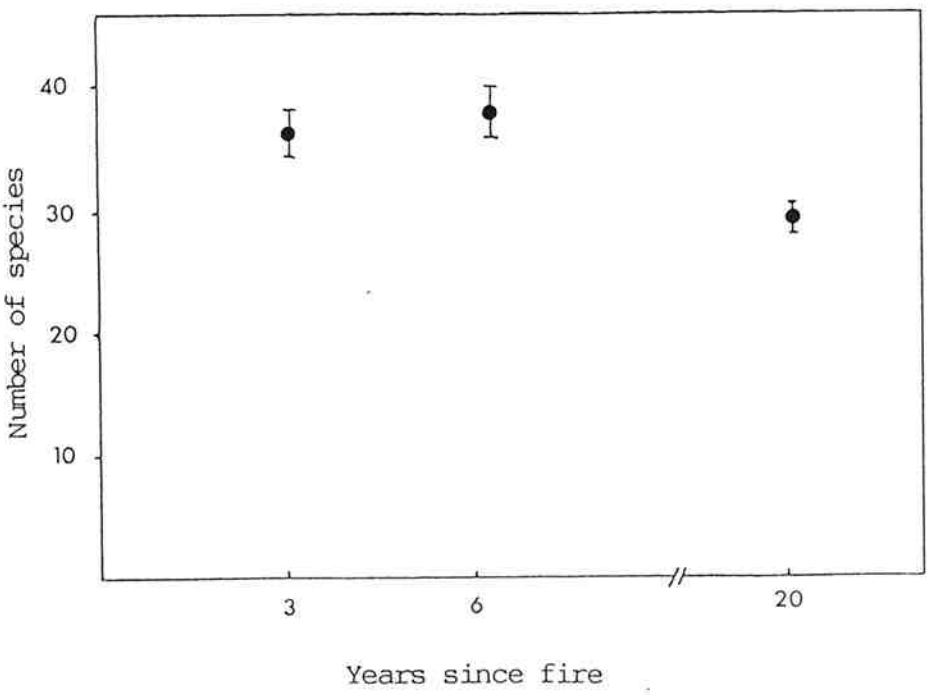

Fig. 2: Effect of years since fire on species number.

Table 1: Height and cover of understorey in <u>Banksia</u> woodland.

	% cover	height (m)
Yrs since burnt		
3	35-45	0.4-0.6
6	40-50	0.5-0.7
20	70-80	1.0-1.5

Similar trends in vegetative cover and species richness were observed by Hobbs and Atkins (1989) and Bamford (1983) in a Banksia woodland near Gingin. Hobbs and Atkins observed an increase in species richness for the first five years following fire, as more shrub species re-established. A decline in the abundance of many herbaceous and shrub species was also noticed in the older (>22 yrs since fire) stands. E. pauciflora became progressively more dominant with increasing stand age. Bamford (1983) observed that 3 yr post fire areas had a low dense understorey containing a wide range of species, while the > 20 yr post fire area had a very dense, much taller understorey, dominated by Melaleuca scabra.

Non-native species were rarely observed and then only in the 3 yr post fire site. Hobbs and Atkins (1989) had similar results, with non-native species only being observed in the recently burnt sites. They also observed that in autumn burn areas, weeds were more likely to establish than in a spring burn area. This is attributed to the possibility that non-native annuals were able to establish better there because they could take advantage of the short-term fertilising effect of the fire. An alternative hypothesis was that non-native annuals were less able to establish in the spring fire area because of the vigorous regrowth of the native species which was already well advanced by the time annual establishment commenced.

The value of this study is limited insofar as it relates to one specific location. Other studies however have produced similar trend to those observed, mainly that species richness is greatest after 5 yrs post fire, and declines after extended periods without fire. The invasion by non-natives is most evident in recently burned sites. In older sites (>20 yrs post fire), several studies have observed the increasing dominance of one of the local species - B. squarrosa in this study, M. scabra (Bamford 1983), E. pauciflora (Hobbs & Atkins 1989) and Heddle (1986).

These features indicate a fire rotation of >5-6 yrs is beneficial, possibly longer depending on the time taken for other species to reach fruiting maturity. Burning rotations longer than those required for fuel reduction purposes are necessary to maximise conservation values of the Banksia woodlands.

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