THE REPRODUCTIVE BIOLOGY AND CONSERVATION OF TWO RARE *BANKSIA* SPECIES

by

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ABSTRACT

Two rare *Banksia* species, *B. chamaephyton* A.S. George and *B. elegans* Meissner, were the subject of this study. *B. chamaephyton* is gazetted as rare under the Wildlife Conservation Act of Western Australia and *B. elegans* has been recorded by various authors as restricted in range and habitat.

Data were collected on the distribution, habitat, reproduction and fire responses of each species. Both were found to occur predominantly in the Irwin Botanical District. *B. chamaephyton* is found in low heath on sand over laterite and *B. elegans* in scrub or thickets on deep, yellow sands. Data on species co-occurring with *B. chamaephyton* were gathered for the purpose of identifying habitats with actual or potential populations of the rare species. Several species appeared to be reliable indicators.

Both species are represented in areas set aside for conservation although some populations are vulnerable and their loss would considerably reduce the range of each species. Of particular concern are the southernmost populations of *B. chamaephyton* and the northernmost populations of *B. elegans*. The latter appears to represent a size variant within the species. Although neither species is currently endangered, it is recommended that *B. chamaephyton* remain a gazetted rare species and that consideration be given to the gazettal of *B. elegans*.

Both species are xenogamous and probably bird-pollinated although pollination by small mammals is a possibility. Both also have very low fruit and seed set. In *B. chamaephyton*, this is probably

related to resource availability but *B. elegans* possesses a malformed stigma which may prevent the normal reproductive process from taking place. Most populations of *B. elegans* are sterile. Further research into the sexual reproduction and propagation of *B. elegans* is recommended.

Fire is important to both species. In *B. chamaephyton*, fire, together with subsequent wet/dry cycles, is necessary for seed release from the follicles. Seedling recruitment is negligible in *B. elegans*. Mature individuals of both species survive fire and in *B. elegans* fire stimulates root suckering. Autumn burns appear to be most suitable for recruitment in both species, preferably at a minimum interval of ten years.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Rarity - a definition

The term 'rare' has been adopted by various authors as a category for the assessment of the conservation status of a species (see Leigh *et al.*, 1984) or to signify a species with a special legal status (Rye and Hopper, 1981). Harper (1981) and Main (1982) recognized the need for a succinct definition of 'rare', as it relates specifically to plant species. Reveal (1981) considers rare species to be "...restricted either in number or area to a level that is demonstrably less than the majority of other organisms of comparable taxonomic entities". The definition proposed by Reveal (1981) is accepted here and the subsequent use of 'rare' is in that context.

1.2 Rare species in south-western Australia

South-western Australia has an angiosperm flora of approximately 3600 named species, many of which are endemic (Hopper, 1979). Beard (1969) found the flora of the South-West Botanical Province to be 68% endemic and this could increase to 80% as knowledge of the flora improves (Hopper, 1979). Linked with the species richness and endemism is the high number of species which are geographically restricted, rare and endangered or even close to extinction.

Several assessments have been made of the rare flora of south-western Australia. Marchant and Keighery (1979) found 305 species have geographical ranges of less than 100 km with 124 of those "known only from a small geographical area or from small populations in a specific, rare habitat". A further 626 species were regarded as poorly known on the basis of having only five or less herbarium collections. Leigh et al. (1981) classified 40 species as "presumed extinct", 196 species as "endangered" or "vulnerable" and 359 species as "rare...but not currently considered endangered or vulnerable". A further 259 species were regarded as "poorly known" and "suspected...of belonging to any of the above categories". Rye and Hopper (1981) considered 100 species qualified to receive legislative protection as rare flora and this was subsequently increased to 132 species (Patrick and Hopper, 1982). Rye (1982) found 527 species occurring south of the 26th parallel to have geographical ranges less than 100 km.

Numerous species, therefore, appear to warrant further research and many of these will require special management to ensure their survival.

1.3 Causes of rarity

Hopper (1979) suggested that certain geohistorical circumstances have led to the species richness and high endemism evident in south-western Australia today. These circumstances include habitat continuity over a long geographic period due to the persistence of some early Tertiary landscapes; the existence of marine, edaphic or climatic barriers to migration to or from the south-west; the formation of nutrient-deficient sands and gravels favouring a sclerophyllous heathland flora; and the existence of a mosaic of landforms due to dynamic erosional processes and recurrent climatic stresses. The present flora is likely to include species which are relicts adapted to and found in remnants of former ecosystems (Main, 1982). Conversely, the flora may also contain taxa which are relatively recent in origin (Hopper and Burgman, 1983) and have comparatively narrow distributions.

To avoid extinction in times of environmental change, populations must be able to generate new genetic combinations or migrate and successfully establish in a new territory (Solbrig, 1980). Populations of rare species may be disadvantaged by having low levels of heterozygosity (Stebbins, 1967). These species are likely to be depleted in respect to their former range. Genetic uniformity may be the major cause of rarity (Stebbins, in Main, 1982).

Some species may be adapted to a particular habitat which is uncommon. Habitable sites for the species may be small, or large but few in number, and dispersal to alternative habitable sites may not be possible (Harper, 1981). An example of such a species is the rare Eucalyptus caesia which is restricted to granite outcrops isolated from one another by undulating plateau country (Moran and Hopper, 1983). Main (1982) suggested that most rare species are not incipient or senescent but have only a few ecotypes. These species may be reproducing and competing well at the few sites where they do grow (Reveal, 1981).

Other causes of rarity may be predators, parasites or diseases (Main, 1982). There appear to be few case studies of species which are endangered primarily as a result of these causes.

However, the root fungus Phytophthora cinnamomi has caused local extinctions of some species in infected jarrah (Eucalyptus marginata) forests (Podger, 1972). The effects of the fungus on many species is not known and research may be required on species which are restricted to areas of known or potential infestations. At least one Banksia species is seriously threatened by the fungus (S. Hopper, pers. comm.).

The rarity of a species is often primarily attributable, directly or indirectly, to human activities. Leigh et al. (1984) reported that only 30% of Australian natural vegetation has remained unmodified since the arrival of European man. They list agriculture, grazing (domestic and feral), roadworks and competition from introduced plants as major present and future threats to the flora. Clearly, the impact of agriculture and grazing are considerable when over 65% of Australia (500 million ha) is alienated for these purposes (Leigh et al., 1984). Changes in fire frequency and season which have occurred over the last 150 years could also be responsible for some species becoming endangered (McMahon, 1984a; Cowling and Lamont, 1985).

Finally, extinctions are seldom attributable to a single factor (Simpson, 1969). Individual species are more likely to be affected by a combination of factors which act together to reduce their populations.

1.4 The conservation of rare species

McMichael (1982) suggested that "...the only possible approach to conservation (of rare species) is to maintain samples of their habitat in sufficient quantity and in as undisturbed a state as possible". Leigh *et al.* (1984) considered that the conservation of habitats is justifiable for "scientific and educational purposes, recreation, potential use to man, and for ethical reasons". Habitat conservation involves more than just the setting aside of land (Carter, 1982). Individual areas may require an active management programme to control the effects of fire, exotic plants and animals and detrimental human activities.

Retention of samples of the natural habitat of a rare species is far preferable to the maintenance of those species solely in botanic gardens (Reveal, 1981). Botanic gardens do, however, have a role to play in conservation. They provide the opportunity for research into the reproduction and propagation of selected species, the conservation of species in seed banks as well as adult specimens and the production of new individuals for re-establishment in natural habitats (Leigh *et al.*, 1984). Translocations into natural habitats lessen the risk of extinction from local catastrophes and helps generate diversity (B.H. Green, 1981).

Appropriate legislation can greatly assist in the conservation of rare species. In Western Australia, the Wildlife Conservation Act 1950-1979 gives special protection to species which have been gazetted as rare after meeting certain criteria (Rye and Hopper, 1981). Those criteria are that:

i) the taxon has been formally named under conventions proposed in the International Code of Botanical Nomenclature;

ii) a reasonably thorough search has been made to locate wild populations and count the number of plants present; and

iii) less than a few thousand reproductively mature plants are known to exist in the wild.

Once a species has been gazetted, no person may damage or destroy it from wild populations anywhere in Western Australia, whether on Crown land or private land, without the written permission of the appropriate government Minister.

Other State and Federal legislation helps control activities in national parks and nature reserves although in Western Australia mining legislation may override conservation legislation to permit mining in national parks (Leigh *et al.*, 1984).

Given that the causes of rarity are diverse it follows that each species should be understood separately and managed in a unique way (Main, 1984). Guidelines to research requirements suggested by various authors (see Synge, 1981; Morse and Henifin, 1981) are similar. The biological data required should include population size(s), life history characteristics and breeding system, reproductive success, responses to fire and the effects of predators, diseases and other pests. Often, however, such data may be difficult or undesirable to gather where plant numbers are low and normal methods of statistical analysis may be inappropriate or impossible (Main, 1982; Groves, 1982). Further, a knowledge of the biology of a species alone will not be enough to ensure its conservation (Main, 1982). An assessment of human impacts, both present and future, is necessary for the eventual management plan to be effective.

1.5 Two rare Banksia species

Two species in the genus *Banksia* (Proteaceae), *B. chamaephyton* A.S. George and *B. elegans* Meissner, were the subject of this study. Both occur north of Perth in the northern sandplains region, or Irwin Botanical District (Beard, 1980; Beard and Sprenger, 1984). The area is poorly known botanically and in recent years has undergone considerable development for agriculture and sand mining. *B. chamaephyton* is gazetted as rare (Patrick and Hopper, 1982) while *B. elegans* is restricted in range and habitat (Leigh *et al.*, 1981; Marchant and Keighery, 1979; Rye, 1982). Full descriptions of each species are given in George (1981).

B. chamaephyton is the only member of the series Prostratae to occur north of Perth with the other seven taxa being found near the south coast of Western Australia. Its specific name "chamaephyton" means "low-growing plant" (George, 1981) and its common name is the "Fishbone Banksia" in reference to the deeply divided leaves. Its closest relative is *B. gardneri* var. *hiemalis* and it differs from that taxon mainly in the underground stems, larger leaves with longer lobes and larger follicles and seeds (George, 1981). Prior to this study it was known from only a few collections with several of those localities subsequently cleared for agriculture (George, 1981). It has been found so far in sand over laterite in low heath. Another member of the series, *B. goodii*, is also gazetted rare (Rye and Hopper, 1981).

B. elegans, though not yet gazetted as rare, has a restricted distribution and some unusual reproductive attributes which place its conservation at risk. These attributes, together with attractive flowers and foliage, have brought the species to the attention of botanists and amateurs alike. The specific name "elegans" is probably a reference to the long, narrow, dentate leaves (Holliday and Watton, 1975). Seed set is extremely low - in the few follicles produced there are rarely any viable seed (George, 1981). It does, however, reproduce by root suckering and is the only Western Australian Banksia species to have this ability (George, 1981). Although a member of the series Cyrtostylis, along with eleven other species, its taxonomic relationships are obscure (George, 1984). It has been found so far in deep yellow sands in low woodland or tall shrubland (George, 1981).

The ultimate aim of this study was to ensure each species can be adequately conserved. This was done by researching aspects of the biology of each species accompanied by an assessment of threats to population stability and culminating in recommendations for a suitable management programme.

CHAPTER TWO

DISTRIBUTION AND HABITATS

2.1 Introduction

George (1981) recorded *Banksia chamaephyton* and *B. elegans* as occurring north of Perth, mostly in the Irwin Botanical District (Beard, 1980) (Figure 2.1). The main physiographical units (and associated vegetation systems) in the lower Irwin Botanical District are distinct regions running parallel to the coast (Beard, 1976, 1979a) (Figure 2.2). Westernmost are two limestone belts (the Cliff Head and Illyarrie Systems) which give way to a flat, sandy plain (Eridoon System) and eventually to a slope reaching a maximum elevation of 300 m (Tathra and Le Sueur Systems) and featuring gentle undulations with small laterite scarps or breakaways. Further eastward is a gentle descent within a series of physiographical units running north-south and finally, the Darling Fault. The species ranges given by George (1981) suggest that *B. elegans* is found within the Eridoon System and *B. chamaephyton* in the Tathra and Le Sueur Systems.

The Eridoon System features a bleached sand turning yellow with depth and has numerous small lakes and swamps in depressions (Beard, 1976). The sandplain vegetation within this system consists of scattered small trees, an open layer of tall shrubs and a closed layer of smaller shrubs. *B. elegans* is associated with deep yellow sands (George, 1981), and Beard (1976) suggests that it may be confined to this community near water channels.

The Tathra and Le Sueur Systems are similar to each other. The

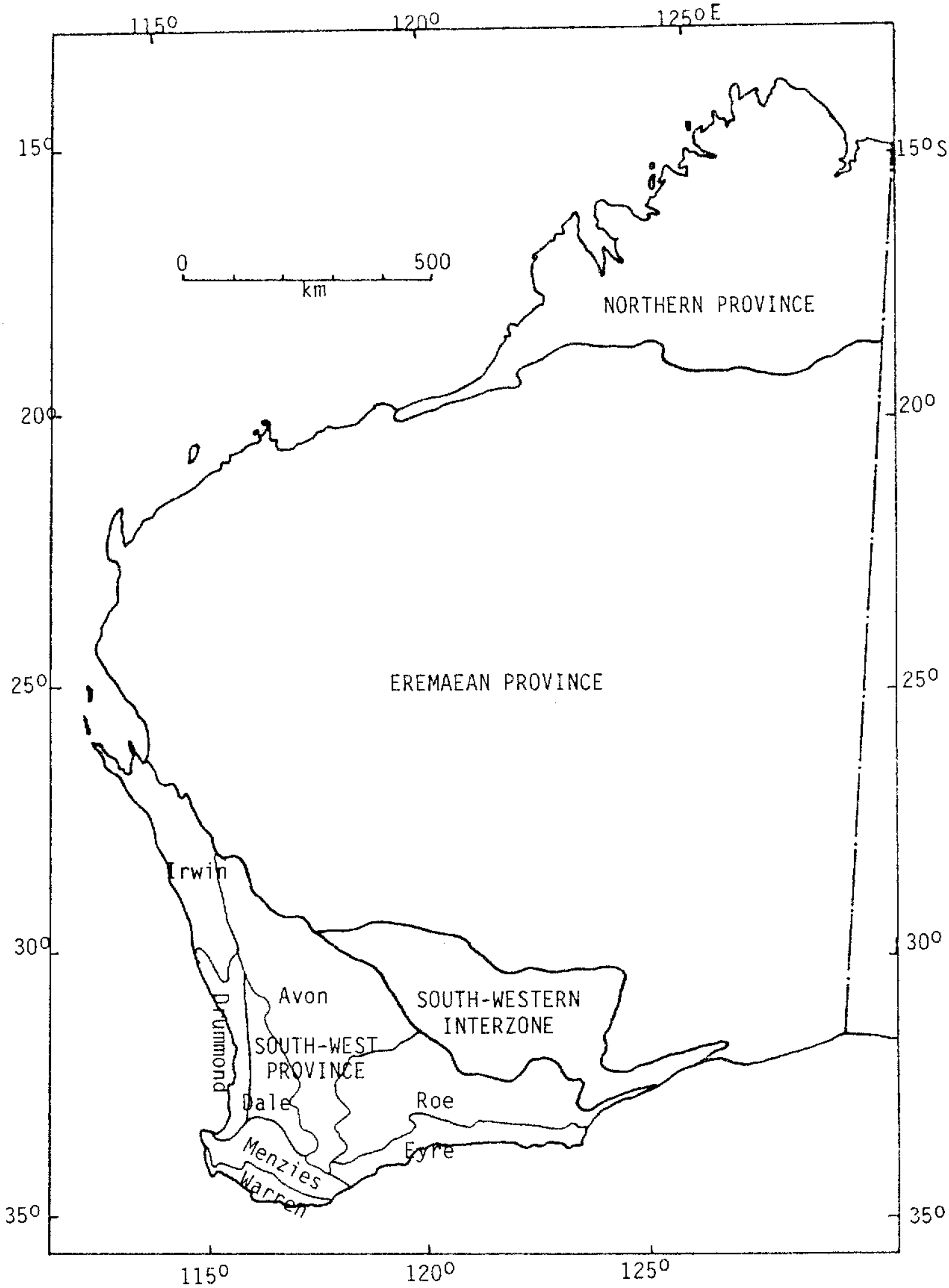


Figure 2.1: Map of Western Australia showing botanical districts of the South-West Province (from Beard, 1980).

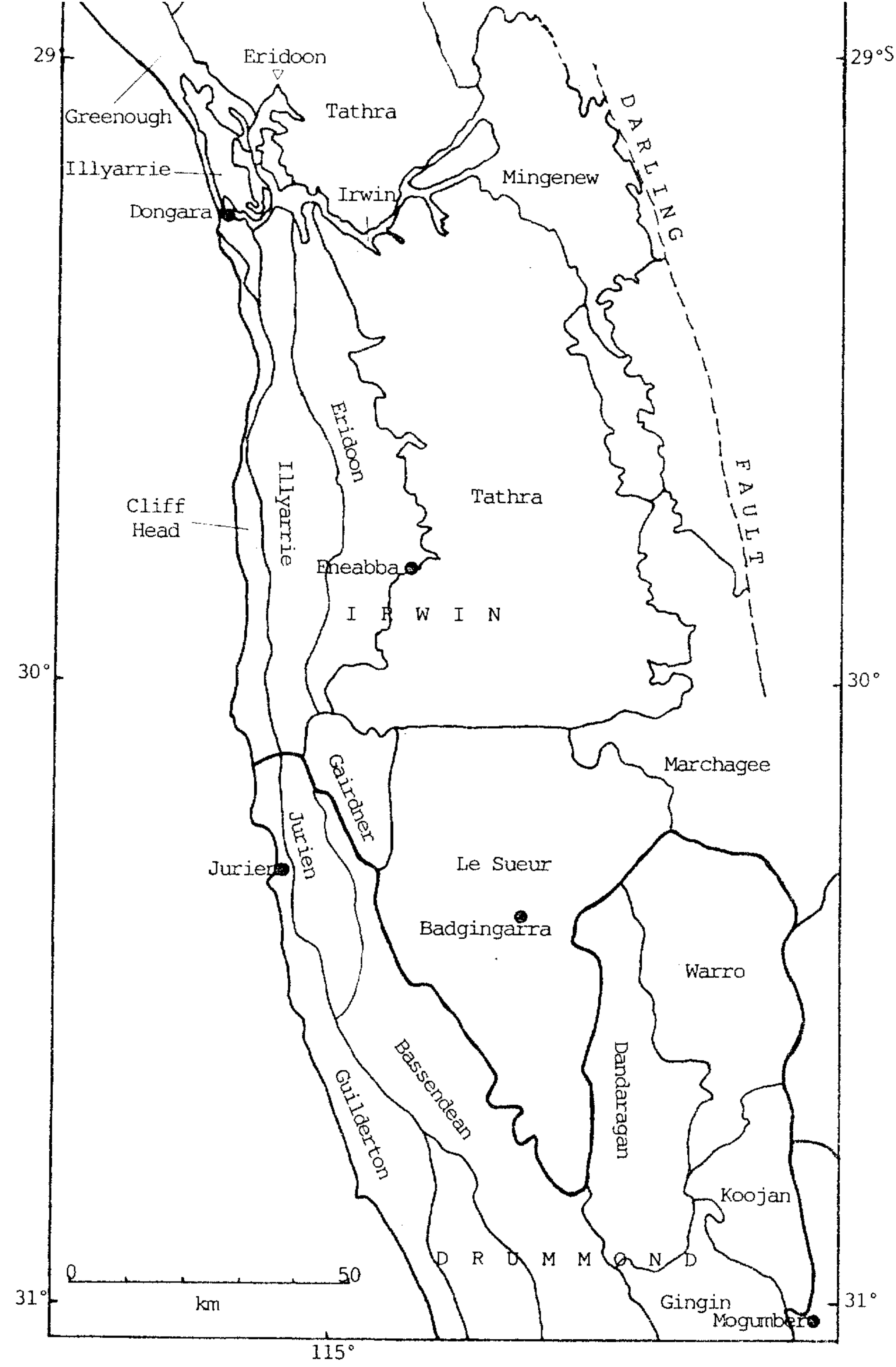


Figure 2.2: Map of southern portion of Irwin Botanical District and northern portion of Drummond Botanical District showing vegetation systems (from Beard, 1976, 1979a, 1979b, Beard and Burns, 1976).

boundary separating them is indistinct and the flora has numerous species in common (Beard, 1979a). Within these systems the heath communities occurring in sand over laterite are species-rich, particularly in members of the Proteaceae and Myrtaceae (Lamont, 1976; Hopkins and Hnatiuk, 1981). George (1981) described B. chamaephyton as occurring in open heath in sand over laterite. It appears to occur in both systems with at least one population to the south in the Gingin System of the Drummond Botanical District (see Figure 2.2), again in heath on laterite (George, 1981; Beard, 1979b).

Fifty eight percent (23 069 km^2) of the vegetation of the Irwin Botanical District was heath or scrub-heath prior to clearing (Beard and Sprenger, 1984). Although the Aboriginal population altered much of the vegetation of south-western Australia before the arrival of European man (Hallam, 1975), since 1829 the region has been considerably affected by land clearing for agriculture, roads and other urban and rural developments. Fifty nine percent of the Irwin Botanical District has been cleared, although to 1984 no clearing had occurred north of the Murchison River (Beard and Sprenger, 1984). Limited land clearing is continuing within the Tathra and Eridoon Systems (Beard, 1976; pers. obs.). In the Eneabba area, some land has been alienated for mineral sands mining. There is also a petroleum exploration permit and a number of coal mining leases throughout the area (Hopkins and Hnatiuk, 1981).

Neither species appears to be significantly affected by commercial harvesting for the wildflower trade. Rye et al. (1980) reported B. elegans as commercially exploited although no quantitative data were available. A subsequent publication (Burgman and Hopper, 1982), however, showed neither species as having been collected in 1980-81, at least by licensed wildflower pickers. Some seed of B. elegans has been collected by persons interested in establishing garden plants (R. Aitken, G. Oxman, B. Vaughan, pers. comm.) and seed harvesting for this purpose has sometimes been indiscriminate (Anon, 1980). Seed of B. chamaephyton has been harvested for inclusion in mine rehabilitation programmes (M. Ryall, D. Brooks, pers. comm.) although this practice has ceased since its gazettal as a rare species (Rye and Hopper, 1981).

The high species richness and uniform life forms of the heath communities in the northern sandplains make the detection of associations between species difficult. Hnatiuk and Hopkins (1981) found a suite of species in the Eneabba area which occurred predominantly in sand over laterite as well as numerous other species which were less site-specific. No species was dominant. In such a habitat it may be of benefit to examine the co-occurrences of B. chamaephyton and other species of the heath communities. Those species which closely reflect the ecological preferences of B. chamaephyton may be used as indicators which could help detect further populations of the rare species or identify alternative habitable sites in national parks or nature reserves to which translocations could be made.

In any project which aims to conserve a rare species it is essential to first know where existing populations occur and the extent and condition of the populations. It is also important to collect data on the habitat of the species to enable the environmental variables which control distribution to be identified. The purpose of this part of the study was to compile concise population, distribution and habitat data for each species and assess factors, such as land clearing or wildflower harvesting, which would affect the stability of these populations. Additional data on species relationships in heath communities containing B. chamaephyton were gathered.

2.2 Materials and Methods

2.2.1 General site data

Location data from herbarium collections at the Western Australian Herbarium (WAH), Kings Park Harbarium (KPH) and the University of Western Australia Herbarium (UWA) were recorded together with sites known or recorded in literature by botanists or other interested persons. Additional sites with comparable habitats were searched. Distribution maps for each species were prepared.

The vegetation at each location was classified according to the system developed by Muir (1977) (Table 2.1). Natural topographic features and prominent plant species were noted. Soil profiles were dug to 1 m (where possible) and soil colour, texture and pH noted. Soil colour was recorded using a Munsell Soil Colour Chart. Soil texture was obtained using a geological field guide (Seismic Supply International Pty. Ltd.) and a 10X hand lens. Particle sizes for the various textures are given in Table 2.2. Soil pH was determined following the method given by Bascomb (1974) after drying the soils for 24h at 105°C. Climatic data for the range of each species were compiled from meteorological records (Bureau of Meteorology, 1975, 1977).

At each location an actual or minimum number of plants was obtained. Banksia chamaephyton foliage occurred in clumps connected by rhizomes. Clumps occurring less than 50 cm apart were regarded as one individual. The number of individuals in each population was counted. Counting continued until no further plants were found after a reasonable length of time or a physical

Table 2.1: The system developed for classification of vegetation consisting of small trees and shrubs (from Muir, 1977).

Life Form	Canopy Cover			
	Dense (70-100%)	Mid-dense (30-70%)	Sparse (10-30%)	Very Sparse (2-10%)
Trees < 5 m	Dense Low Forest B	Low Forest B	Low Woodland B	Open Low Woodland B
Shrubs > 2 m	Dense Thicket	Thicket	Scrub	Open Scrub
Shrubs 1.5-2.0 m	Dense Heath A	Heath A	Low Scrub A	Open Low Scrub A
Shrubs 1.0-1.5 m	Dense Heath B	Heath B	Low Scrub B	Open Low Scrub B
Shrubs 0.5-1.0 m	Dense Low Heath C	Low Heath C	Dwarf Scrub C	Open Dwarf Scrub C
Shrubs 0.0-0.5 m	Dense Low Heath D	Low Heath D	Dwarf Scrub D	Open Dwarf Scrub D

Table 2.2: Particle size ranges for various soil textures given by Seismic Supply International geological field guide.

Texture	Particle Size (mm)
Very coarse sand	1.0 - 2.0
Coarse sand	0.5 - 1.0
Medium sand	0.25 - 0.5
Fine sand	0.125 - 0.25
Very fine sand	0.063 - 0.125
Silt	< 0.063

or ecological barrier was reached. Individuals of B. elegans were even more difficult to distinguish. As populations often had numerous suckers from the lateral roots of larger plants, only stems at least 1.0 m tall were regarded as individuals. Because of the potential inaccuracy of this method, the number of stems at least 1.0 m tall in each B. elegans population was estimated, except where the population was very small. Searches for both species were limited to locations accessible by two wheel drive vehicles or within reasonable walking distance of roads or tracks.

Each location was classified as private land, vacant Crown land or reserve (road, flora and fauna, national park or other) from maps available from the Lands and Surveys Department of Western Australia. Evidences of disturbances such as clearing, burning, invasion by weeds or predators, flower or foliage harvesting, or fertiliser drift from agricultural lands were recorded.

2.2.2 Floristic analysis of heath communities with Banksia chamaephyton

Four sites with populations of 50 or more Banksia chamaephyton plants were sampled for floristic analysis. At each site, a 40 m x 60 m plot was established. The plots were situated around a point subjectively selected as the centre of the B. chamaephyton population. The number of B. chamaephyton plants occurring in each plot was counted and their density calculated. Within each plot thirty 4 m x 4 m quadrats were randomly selected for sampling. A quadrat of this size should contain most species at a site (George et al., 1979) and has been used in a previous analysis of heath vegetation in the Irwin Botanical District

(Hopkins and Hnatiuk, 1981).

The presence or absence of species within each quadrat was recorded. When field identification was not possible, specimens were collected, dried and mounted for subsequent identification at WAH. Following their identification the specimens were housed in the herbarium at the School of Biology, WAIT.

The floristic composition of each quadrat provided 120 sets of binary data. The ubiquity (number of occurrences) of each species for all quadrats was calculated. The similarity in occurrences of each species with that of _B. chamaephyton_ was calculated using the absolute dissimilarity measure ($S_B + S_Y - 2S_{BY}$) where:

S_B = no. of occurrences of _B. chamaephyton_
S_Y = no. of occurrences of Species Y
S_{BY} = no. of co-occurrences of both species

The absolute measure disregards conjoint absences and is considered more sensitive than alternative measures (Lamont and Grant, 1979).

Some data reduction was necessary prior to further analysis. All species with a ubiquity less than 10 out of 120 were omitted as they were unlikely to show any clear relationships with other species. All species with a ubiquity of 60 or greater were included. The remaining species were included or excluded on the basis of an inclusion value (after Stephenson and Cook, 1980). The mean absolute dissimilarity value for each species was calculated and subtracted from each individual value, and the sign reversed, to give the inclusion value. All species with negative inclusion values were then excluded.

The remaining data were analysed using detrended correspondence analysis (DECORANA) (Hill, 1979) to show relationships between species. Correspondence analysis is synonymous with reciprocal averaging (RA). In ecological contexts, RA has been shown to be more satisfactory than other, more frequently used, methods such as principal components analysis (Hill, 1973; Gauch et al., 1977). DECORANA differs chiefly from RA by the removal of any correlation between the first and subsequent axes and is thus superior to that method (Hill, 1979).

The program was run with no transformation of data, no downweighting of rare species and default values for rescaling of axes, the number of segments and the rescaling threshold. The first two axes only were plotted. Inferred relationships between B. chamaephyton and other species were tested using chi-square analyses.

2.3 Results

2.3.1 General site data

Details of herbarium specimens are given in Appendix One. All three herbaria contained a total of 10 collections of Banksia chamaephyton and Griffin (1981) recorded a further four collections not housed in herbaria. The first collection (Grigson 9435) was made in 1949. The herbaria contained 17 collections of B. elegans with an additional two noted by Griffin (1981). The earliest collection was by F. von Mueller in 1877.

Appendix Two gives the precise locations of sites examined during this study and they are plotted in Figure 2.3. The source of locality data for each site is given in Appendix Three. Any further known or possible locations of populations were not personally examined and are excluded from Figure 2.3.

Most sites were located through the locality descriptions given on herbarium specimens. However, some locality descriptions were imprecise and it was not possible to link with certainty some collections with locations examined by the author. Furthermore, some collections could not be located again due to an inadequate locality description. For B. chamaephyton, some collections were made at locations which may not (George 11190, Dixon S4803, George 2345A) or were definitely not (Cranfield 107) located again during this study. Two other known sites, near Rose Road via Eneabba (Griffin, 1981) and on the Allied Eneabba Pty. Ltd. mining leases (M. Ryall, pers. comm.), could not be located again. A small number of plants also occurs near Mt. Lesueur (E. Griffin, pers. comm.) and east of Clarke Road in Alexander

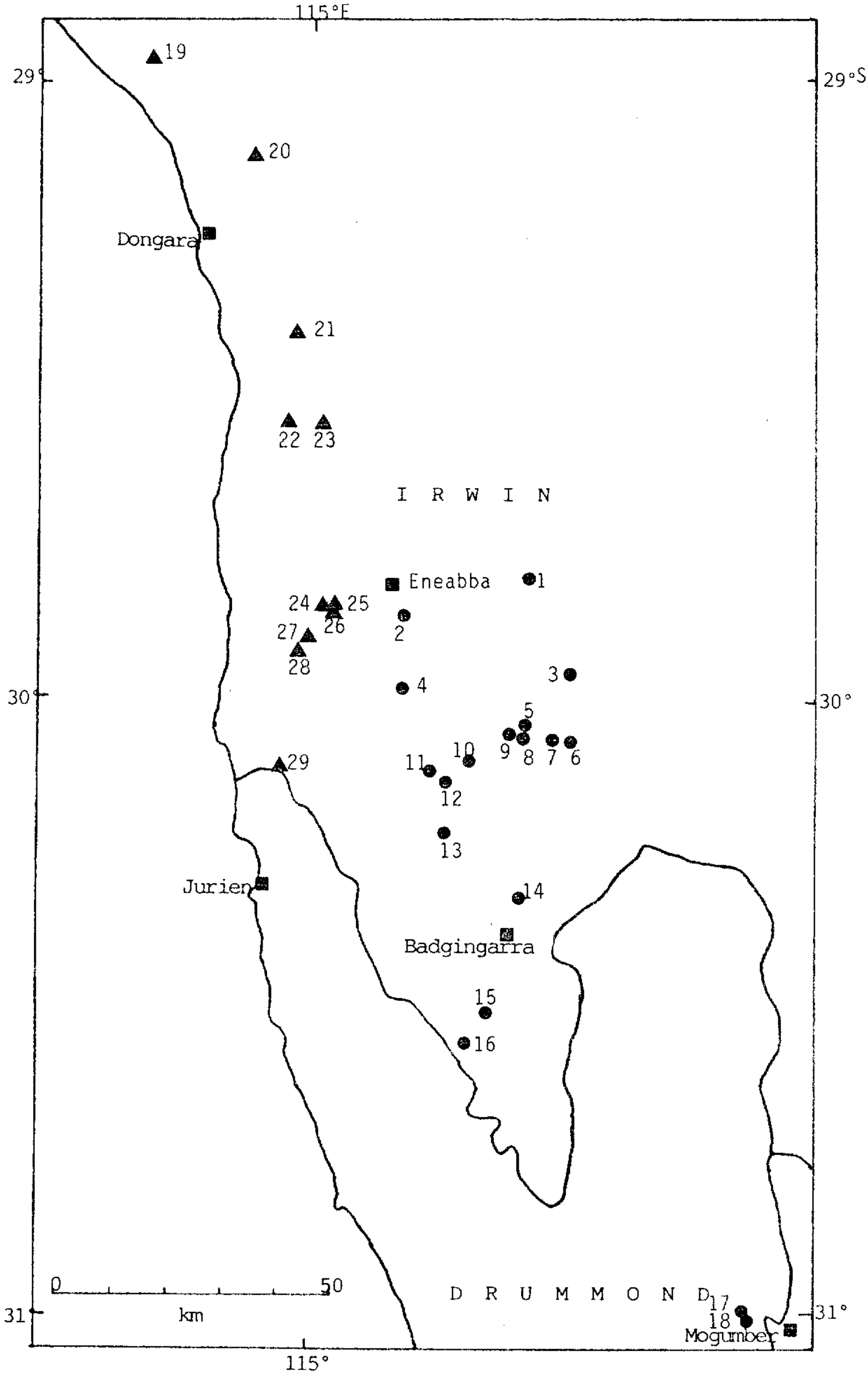


Figure 2.3: Distribution of Banksia chamaephyton (site ref. no.s 1-18) and B. elegans (19-29). Key to symbols: ■ = townsite; ● = B. chamaephyton; ▲ = B. elegans.

Morrison National Park (R. Rickman, pers. comm.).

Similarly, some collections of B. elegans (von Mueller, Gardner 12075, Gardner 8486, Gardner 9385) were possibly not located again. One collection of B. elegans (Mrs ?Theak S382) gave a concise locality description but could not be located again. Some observations recorded by Griffin (1981) to the north of Lake Indoon were not located. The Mt. Adams area contains more B. elegans plants than those observed by the author (location 21) and scattered patches of this species appear to be relatively common in that area (B. Lamont, pers. comm.).

B. chamaephyton extends from a location adjacent to Tathra National Park (location 1) in the north to Mogumber (17, 18) in the south giving the species a geographic range of 140 km. Most locations (1-16) occur in the Tathra and Le Sueur Systems of the Irwin Botanical District. The remaining two populations (17, 18) are found in the Gingin System of the Drummond Botanical District, approximately 70 km from the nearest population to the north.

B. elegans was found to have a geographical range of 130 km. Most localities (20-28) occur within the Eridoon System near its boundary with the Illyarrie System to the west. The northernmost population, near Walkaway (19), occurs in the Greenough System near its boundary with the Tathra System. The Diamond of the Desert Springs population (29) is the most southern. It occurs at the southern tip of the Illyarrie System.

The vegetation, topography and soils of each population are given in Appendix Four. All populations of B. chamaephyton occurred in Low Heath C or Low Heath D. Lambertia multiflora and Xanthorrhoea reflexa were often prominent members of the heath communities. Most populations occurred on slight undulations, near but not at the crest of a rise, and with no particular aspect evident. Most soil profiles consisted of a stratum of light grey or light brownish grey medium sand, pH 4.5, over a stratum of light grey or white medium sand, pH 4.7, underlain by laterite. Depths of laterite ranged from very shallow and sometimes outcropping, at a Brand Highway population (11) and at the Badgingarra Agricultural Research Station (14), to greater than 1.0 m at Willis Road (5).

B. elegans usually occurred in Scrub or Thicket vegetation often with B. attenuata, B. menziesii and B. prionotes. Most large populations occurred on gentle slopes near winter-wet depressions or lakes. No particular aspect was evident. Soil profiles usually consisted of an upper stratum of grey, pale brown or yellowish brown medium to coarse sand, pH 4.7, over a stratum of yellow or reddish yellow medium to coarse sand with a pH of 5.0.

Meteorological data for seven weather stations in the region are given in Table 2.3 and mean annual rainfall isohyets are shown in Figure 2.4. Mean daily maximum temperatures tend to increase away from the coast and at stations further north. The temperature range is less near the coast. However, mean temperatures overall vary by only a few degrees throughout the region whereas rainfall appears to be more variable. The approximate mean annual rainfall

Table 2.3 : Mean annual rainfall and mean daily maximum and minimum temperatures for seven weather stations (from Bureau of Meteorology, 1975, 1977). (n.d. = no data).

Weather Station	Lat. S	Long. E	Elevation (m)	Mean Annual Rainfall (mm)	Mean Daily Maximum Temp.(°C)	Mean Daily Minimum Temp.(°C)
Mingenew	29°11'	115°26'	33	421	27.6	12.6
Dongara	29°15'	114°55'	9	469	n.d.	n.d.
Eneabba	29°48'	115°21'	229	590	26.6	11.6
Carnamah	29°41'	115°53'	268	397	26.6	12.3
Jurien	30°18'	115°02'	2	519	24.3	12.6
Badgingarra	30°20'	115°33'	258	633	25.6	11.4
Moora	30°38'	116°00'	203	466	25.1	11.4

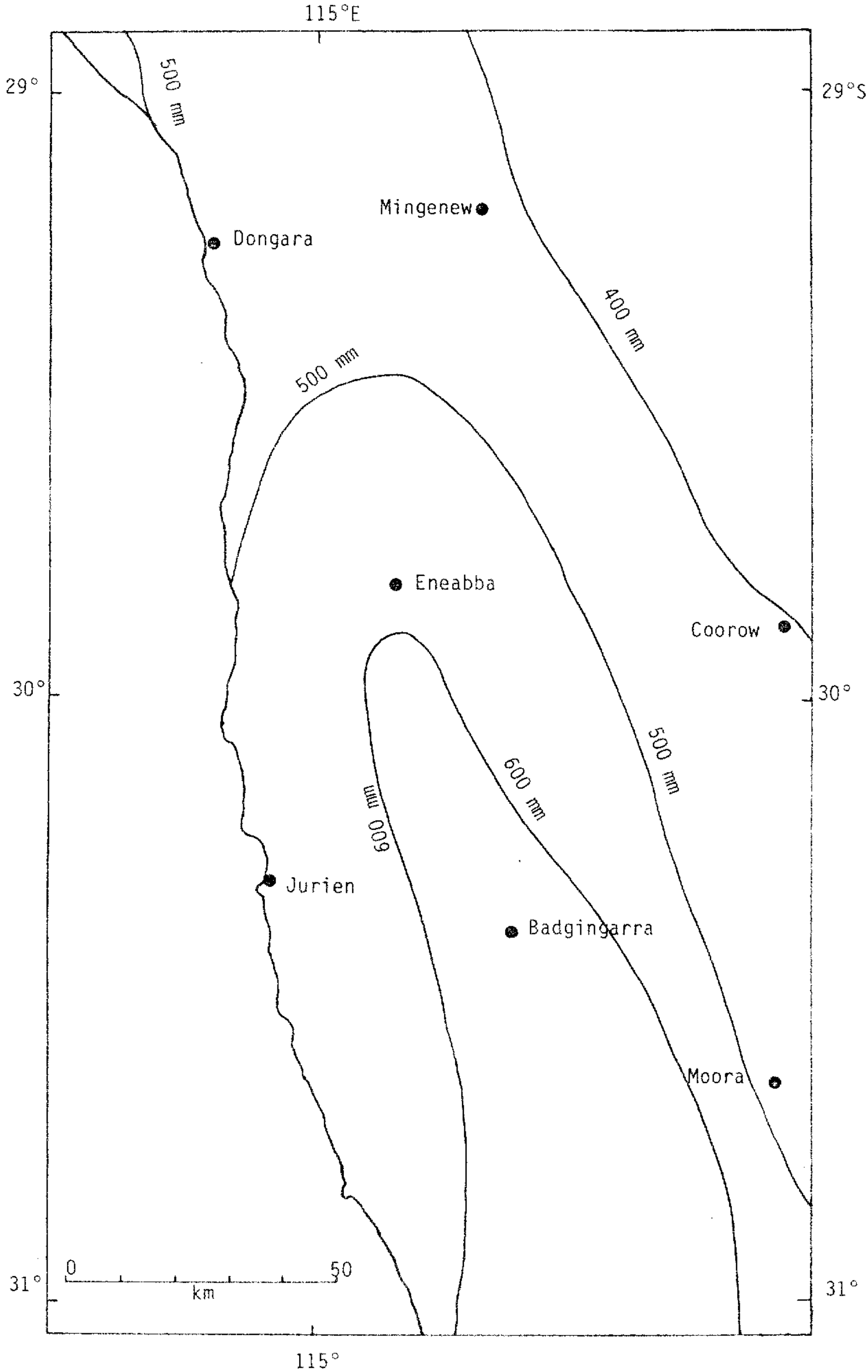


Figure 2.4: Approximate mean annual rainfall isohyets over the range of Banksia chamaephyton and B. elegans (from Bureau of Meteorology, 1975, 1977).

near the coast is 500 mm and it increases to in excess of 600 mm along areas of higher relief such as Badgingarra. Further inland annual rainfall decreases to about 400 mm.

The number of plants found in each population of B. chamaephyton and the status of the land are given in Table 2.4. Most populations were small (< 100) but the largest had over 300 plants. A total of 1,428 plants were counted by the author. Many occurred on non-private, vested Crown land, particularly road reserves (679 plants), and the reserves and the number of plants in each are given in Table 2.5. The population occurring on land under lease for sand mining at Associated Minerals Consolidated (2) was recorded as on private land.

B. elegans populations contained an estimated 2,465 plants greater than 1.0 m tall with most occurring on private or vacant Crown land (Table 2.6). One small, geographically isolated population, on Mt. Horner West Road (20), contained only 15 plants. All other populations had at least 50 and up to 1000 plants at Beharra Spring (23). Reserves with populations of B. elegans are given in Table 2.7.

Observations of disturbances at each population of B. chamaephyton and B. elegans are shown in Tables 2.8 and 2.9 respectively. Most populations of B. chamaephyton showed few signs of disturbance. Road verge populations were sometimes susceptible to invasion by weeds or soil disturbance from roadworks. Some seed collection had occurred but there was no evidence of flower or foliage harvesting by wildflower pickers.

Table 2.4: The number of plants and the status of the land for each population of *Banksia chamaephyton*.

Site Ref. No.	Number of plants: Reserves: National Park	Conservation of Flora and Fauna	Road	Aboriginal Purposes	Other	Vacant Crown Land	Private Land	Total
1			17					17
2							61	61
3			15	76				91
4		30				14		44
5			56					56
6	128		30					158
7	24							24
8			34					34
9	30		278					308
10							22	22
11			152				52	204
12			36					36
13			40			19		59
14					127			127
15	91							91
16			16					16
17				54				54
18			5				21	26
						Total all locations		1428

Table 2.5: The number of *Banksia chamaephyton* plants occurring on reserves.

Reserve type and no.	No. of plants	
Reserves for conservation:		
National Park:		
29800 (Alexander Morrison)	30	
29803 (Alexander Morrison)	152	
31809 (Badgingarra)	91	
Conservation of Flora and Fauna:		
31030	30	303
Other reserves:		
Aboriginal Purposes:		
16833	54	
28606	76	
Research Station Agriculture:		
25143 (Badgingarra)	127	
Road reserves:	679	936
Total plants on reserves		1239

Table 2.6: The number of plants and the status of the land for each population of *Banksia elegans*.

Site Ref. No.	Number of plants							
	Reserves							
	National Park	Conservation of Flora and Fauna	Road	Aboriginal Purposes	Other	Vacant Crown Land	Private Land	Total
19							50	50
20			4				11	15
21		100						100
22							500	500
23						1000		1000
24		50						50
25					50			50
26					500			500
27					100			100
28	50							50
29			50					50
						Total all locations		2465

Table 2.7: The number of *Banksia elegans* plants occurring on reserves.

Reserve type and no.	No. of plants	
Reserves for conservation:		
National Park:		
36419 (Stockyard Gully)	50	
Conservation of Flora and Fauna:		
29073	50	
36203	100	200
Other reserves:		
Public Recreation:		
29072	550	
Stock Route:		
19219	100	
Road reserves:	54	704
Total plants on reserves		904

Table 2.8: The level of disturbance in each population of *Banksia chamaephyton*.

Site Ref.No.	Level of disturbance	Comments
1	Mostly undisturbed.	Road reserve adjoins cleared agricultural land with national park opposite. Some disturbance from roadworks.
2	Mostly undisturbed.	Minor effects from activities associated with mining operations. Some seed collection.
3	Undisturbed.	
4	Disturbed.	Most plants occurring at edges of fire breaks, tracks, truck bay and roadside.
5	Disturbed.	Population on road reserve by cleared agricultural land. Some incursion of exotic plants and a small gravel pit has been dug.
6-10	Undisturbed.	
11	Disturbed.	Some plants on road reserve affected by roadworks with some incursion of exotic plants and litter. Road reserve adjoins mostly cleared private land.
12	Disturbed.	Road reserves bordered by cleared agricultural land and disturbed by roadworks.
13	Mostly undisturbed.	Some disturbance from roadworks.
14-16	Undisturbed.	
17	Disturbed.	By roadside bordered by cleared agricultural land. Considerable incursion of exotic plants and some litter.
18	Mostly undisturbed.	In islands of uncleared land surrounded by cleared land for agriculture.

Table 2.9: The level of disturbance in each population of *Banksia elegans*.

Site Ref.No.	Level of disturbance	Comments
19	Lost.	Population completely cleared for agricultural purposes during course of study.
20	Disturbed.	Narrow road reserve and small island of uncleared vegetation surrounded by land cleared for agriculture.
21	Undisturbed.	
22	Mostly undisturbed.	Regenerating after fire in 1984. Near lake formerly used for watering stock.
23	Mostly undisturbed.	Regenerating after fire in 1984. Near winter-wet depression formerly used for watering stock. Some evidence of seed collection.
24	Undisturbed.	
25	Mostly undisturbed.	Some tracks and small clearings amongst vegetation.
26	Disturbed.	Regenerating after fire in 1982. Some exotic plant incursion and litter. Slightly affected by roadworks and susceptible to trampling from human usage. Possibly some seed collection.
27-28	Disturbed.	On fenceline and fire break adjoining cleared agricultural land.
29	Mostly undisturbed.	Some clearings have occurred due to trampling by stock.

One population of B. elegans, near Walkaway (19), was cleared during the course of the study. The population was on private land. The nearest population, on Mt. Horner West Road (20), was also considerably affected by clearing. Most other populations were relatively undisturbed although several were recovering after fire. The extent of seed collection was difficult to assess as some apparently fertile sites had been burnt although two locations with unburnt seed stores, near Lake Logue (24) and north of Lake Indoon (25), had not been affected. No flower or foliage harvesting was evident.

2.3.2 Floristic analysis of heath communities with Banksia chamaephyton

The locations selected were Associated Minerals Consolidated (2), Green Head Road east of Willis Road (9), on the Brand Highway (11) and at the Badgingarra Agricultural Research Station (14). Some characteristics of each site are given in Table 2.10. The density (plants/ha) of B. chamaephyton ranged from 112.5 at the Green Head Road location to 145.8 on the Brand Highway. Species richness was greatest on the Green Head Road (51.6 species per 4 m quadrat).

Two hundred and seventeen species were recorded in all four plots. They are listed in Appendix Five together with their ubiquity, absolute dissimilarity value and inclusion value. The families Proteaceae and Myrtaceae were strongly represented with 47 and 40 species respectively. On the basis of ubiquity or inclusion value 77 species were retained for analysis with DECORANA. Among those species excluded from further analysis were Adenanthos cygnorum, Banksia attenuata, Eucalyptus todtiana and

Table 2.10: Characteristics of four plots with low heath containing *Banksia chamaephyton*. The species richness value is the mean of thirty quadrats.

Site Ref. No.	Density of Banksia chamaephyton (plants/ha)	Species richness (species/4m2)
2	120.8	36.6
9	112.5	51.6
11	145.8	42.2
14	141.7	45.1

Hakea obliqua all of which have a wide distribution and may be locally dominant.

DECORANA gave eigenvalues for four axes. The first two axes had the highest eigenvalues (0.205 and 0.176) with subsequent axes having eigenvalues of 0.081 and 0.051. Figure 2.5 shows the first two axes plotted with axis 1 horizontal and axis 2 vertical. Species occurring at extreme points in Figure 2.5 are mostly or completely restricted to one location with species occurring at two or more locations being more centrally located on the ordination.

The ordination shows a central cluster of species in which B. chamaephyton (species 1) occurs. Other species in the central cluster are Lambertia multiflora(2), Conothamnus trinervis(110), Xanthorrhoea reflexa(24), Macropidia fuliginosa(106), Mesomelaena tetragona(46), Hibbertia crassifolia(21), Banksia incana(22), Hakea conchifolia(75), Allocasuarina humilis(66) and Persoonia rudis(70) and Calothamnus sanguineus(25). These species were represented at all or most locations and usually had ubiquity values higher than most other species. While their inclusion values were not necessarily high, their positions on the axes suggest they have similar ecological preferences to B. chamaephyton.

Of the species selected for analysis by the ordination, 19 were found to have a statistically significant number of co-occurrences with B. chamaephyton. These species are listed in Table 2.11. They tended to have high inclusion values but not

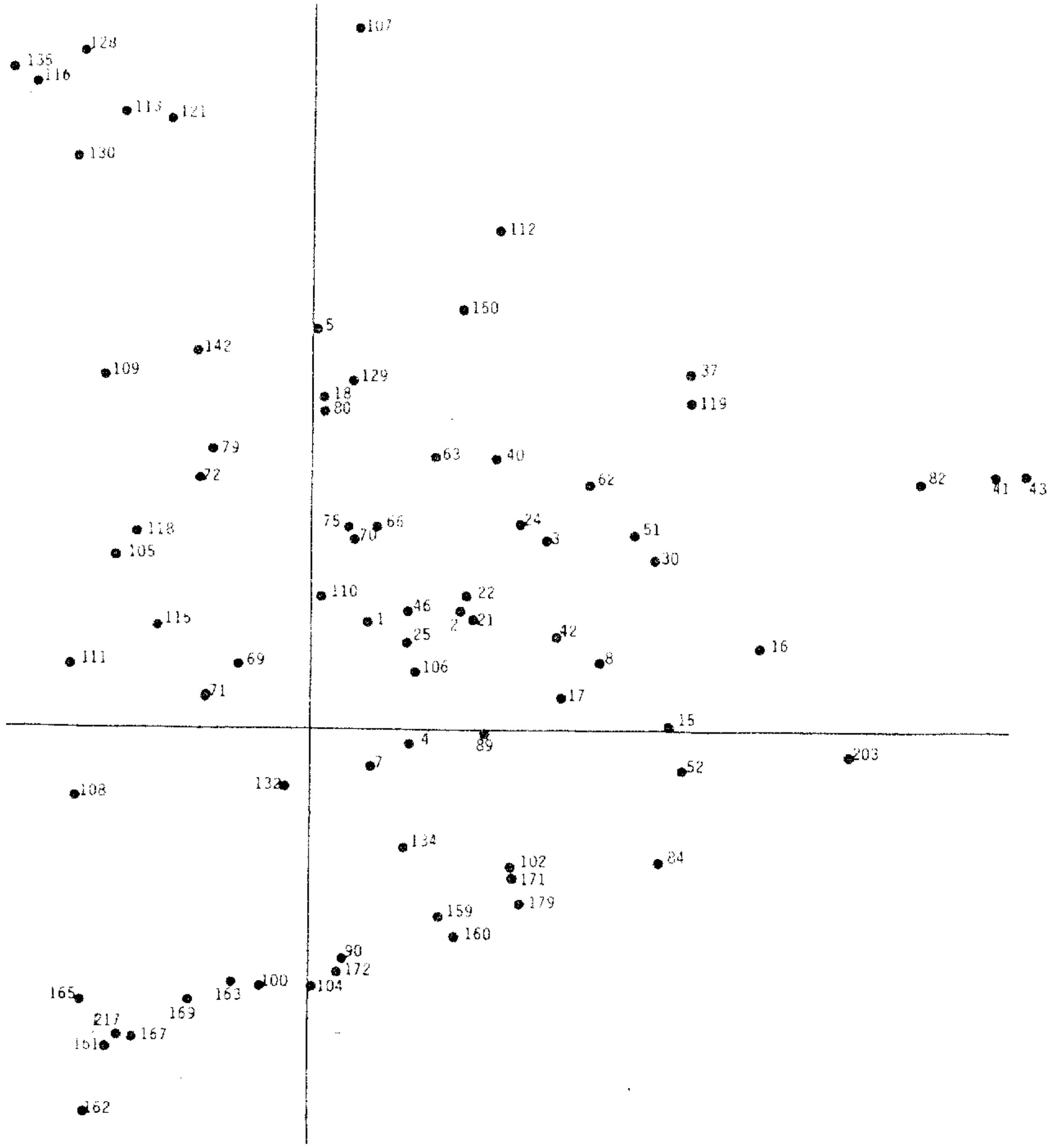


Figure 2.5: DECORANA analysis of 77 species in four plots containing Banksia chamaephyton. B. chamaephyton is species 1.

Table 2.11 : Species having significant co-occurrences with *Banksia chamaephyton* based on chi-square tests. (* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$).

Species Ref. No.	Species
69	*Leucopogon striatus* *
71	*Astroloma stomarrhena* *
72	*Hypocalymma xanthopetalum* ***
75	*Hakea conchifolia* *
79	*Haemodorum paniculatum* **
89	*Loxocarya fasciculata* *
105	*Calothamnus torulosus* ***
108	*Hibbertia mylnei* *
109	*Grevillea synapheae* ***
110	*Conothamnus trinervis* *
111	*Gastrolobium bidens* *
115	*Calectasia cyanea* *
116	*Drosera barbigera* *
118	*Petrophile shuttleworthiana* *
130	*Astroloma microdonta* *
132	*Dryandra nana* *
135	*Leucopogon strictus* *
161	*Comesperma acerosum* **
217	*Stylidium adpressum* **

necessarily high ubiquity values. Two of the species, *Conothamnus trinervis* and *Hakea conchifolia*, occur in the central cluster of species shown in Figure 2.5.

2.4 Discussion

2.4.1 General site data

Banksia chamaephyton is restricted to white or grey sand over laterite in species-rich heath. It occurs predominantly in the Tathra and Le Sueur Systems but it is also found in the Gingin System where the extent of heath vegetation is limited and woodlands are far more common (Beard, 1979b). It has been poorly collected (the first collection was less than 40 years ago) and this may be indicative of our knowledge of many other species occurring in the region. A study conducted in 1977 in the Eneabba area (Hopkins and Hnatiuk, 1981) resulted in the collection of 429 species, 14% of which were regarded as rare or poorly known.

As a result of this study, 18 populations of B. chamaephyton were located and described and a total of 1,428 plants were recorded. The approximate locations of some additional plants are known but these were not examined in this study. In some instances, vague locality descriptions on herbarium collections hindered the search for populations.

B. chamaephyton was found at several locations in Alexander Morrison National Park. There are few published data on the flora of Alexander Morrison National Park and further surveys could possibly find the species to be relatively common especially considering the incidence of plants on road verges nearby and the fact that the landform and flora appear fairly uniform (R. Rickman, pers. comm.). The species also occurs in Badgingarra National Park and plants were found on a flora and fauna reserve.

B. elegans is found in yellow sand in thicket, scrub or heath. It often occurs near lakes or winter-wet depressions and is largely restricted to the Eridoon System with one population to the north and one to the south in adjoining systems. Eleven populations were recorded in this study with an estimated total of 2,465 plants. B. elegans is not well represented in national parks but two populations occur in relatively large flora and fauna reserves. These populations in particular are probably more extensive than recorded here.

Both species, therefore, are represented in areas set aside for conservation. However, many of the populations observed in this study were less secure. A large proportion of the B. chamaephyton observed occurred on road verges. Though road verges are unlikely to suffer significant physical disturbance from roadworks they are, however, susceptible to weed invasion and fertiliser drift from agricultural lands and may have a limited life (Beard, 1976). Road verges in some areas of south-western Australia represent the last vestige of native vegetation (Scott, 1981) but their conservation value largely depends on the status of the land upon which it borders. Fertiliser drift from farms will exacerbate weed invasion (Specht, 1963) and cause the early death of native species (Heddle and Specht, 1975). Weed invasion was evident in some populations observed in this study although there were no recognisable signs of fertiliser toxicity. To date, B. chamaephyton has been relatively unaffected by mining operations (M. Ryall, D. Brooks, pers. comm.).

B. chamaephyton and B. elegans both have small, geographically isolated populations at the extremes of their ranges. Drury

(1974) considered that small populations may retain considerable heterogeneity and the number of sub-populations of a species may be more important than the total population size. Moran and Hopper (1983) found significant genetic variation between geographically isolated populations of Eucalyptus caesia and they suggested that the optimal conservation strategy was to retain as many populations as possible. B. chamaephyton had two populations in the south of its range which are 70 km from the next known population. Both southern populations are on land substantially alienated for agriculture. Although the species is morphologically "fairly uniform" (George, 1981) there is a strong case for the conservation of some plants from this isolated area. The loss of these populations would decrease the range of the species by fifty per cent to only 70 km.

Similarly, B. elegans had two northern populations which are either lost or threatened through clearing for agriculture. The northernmost population, near Walkaway (19), appears to have been completely cleared and had been recorded by George (1981) as having larger inflorescences than all other populations. However, the other northern population, on Mt. Horner West Road (20), also possesses the larger inflorescence size (Barrett, unpub.) and a few plants of this population remain. Although it is often difficult to distinguish between genetic and environmentally-induced variation (Gould and Johnston, 1972), there are no apparently unusual environmental factors affecting these populations. An attempt should be made to conserve plants with the larger inflorescence size.

There was no evidence of flower or foliage harvesting of B. chamaephyton for the wildflower trade. While the flowers are not spectacular, the leaves, however, are unusual and attractive (George, 1984) and may receive some attention from the industry in the future. No harvesting of B. elegans flowers or foliage was apparent although interest in seed collection continues.

2.4.2 Floristic analysis of heath communities with Banksia chamaephyton

This study compared the occurrence of B. chamaephyton with that of other species occurring in species-rich heath. Occurrences of other species ranged from some which were present with high frequencies at all four locations to those which occurred only once in 30 quadrats at a single site. From these data, two broad categories of species were identified which could help detect actual or potential sites where B. chamaephyton may occur.

The first category has a suite of species which were found at all or most sites and could be regarded as primary indicators of the ecosystem in which B. chamaephyton may be found. Some of these species, however, are not restricted to the vegetation and soil type in which B. chamaephyton occurs. This vegetation and soil type is analogous to Group 3 as described by Hnatiuk and Hopkins (1981). They found Lambertia multiflora, Mesomelaena tetragona, Xanthorrhoea reflexa and Hakea conchifolia to occur predominantly in Group 3 but extending into other groups. L. multiflora, for example, is also found in deep sands (Hnatiuk and Hopkins, 1981; Lamont, 1976) as are Hibbertia crassifolia, Macropidia fuliginosa and Hakea conchifolia (Lamont, 1976).

The second category contains species whose occurrence was statistically related to that of B. chamaephyton. These species generally are more restricted in their occurrence but may also reflect the ecological preferences of B. chamaephyton. Grevillea synapheae, for example, is characteristic of lateritic sites (Hopkins and Hnatiuk, 1981). However, some of these species only occurred at one or two sites limiting their usefulness as indicators. Further, some species may have broader ecological ranges than this study suggested. For instance, Hypocalymma xanthopetalum was found predominantly in Group 3 by Hnatiuk and Hopkins (1981) but also occurred in other groups.

Fox (1985) adopted another approach in the determination of indicator species. Using the binary data gathered in this study he formulated a model based on the probability of finding B. chamaephyton at a site given the presence (or absence) of other species. The model found four species (in order of importance - Calothamnus torulosus, Stylidium adpressum, Melaleuca acerosa and Loxocarya fasciculata) to have a positive predictive ability of the occurrence of B. chamaephyton. Of these species, all except M. acerosa recorded a significant chi-square relationship with B. chamaephyton but none were highlighted by the ordination as closely related to B. chamaephyton.

In summary, a number of species appear to have ecological preferences similar to those of B. chamaephyton. I propose that two types of indicator species be used to identify sites where B. chamaephyton does, or could, occur. The first is a primary indicator which is widespread and characteristic of, but not restricted to, the habitat of B. chamaephyton. The second type is a species which occurs less frequently but may be useful as an indicator in particular geographic areas. Table 2.12 lists species of each type selected from the available data as the most suitable for use as indicators.

Table 2.12: Primary and secondary indicators of the likely occurrence of *Banksia chamaephyton*.

Primary indicator	Secondary indicator
Lambertia multiflora	*Calothamnus torulosus*
Hakea conchifolia	*Grevillea synapheae*
Xanthorrhoea reflexa	*Stylidium adpressum*
Conothamnus trinervis	*Loxocarya fasciculata*
Hypocalymma xanthopetalum	*Haemodorum paniculatum*

CHAPTER THREE

SEXUAL REPRODUCTION

3.1 Introduction

The flower head of Banksia is referred to as a conflorescence (Johnson and Briggs, 1975) or, more commonly, an inflorescence (George, 1981). It consists of a central woody axis along which tightly-packed unit inflorescences are borne, each containing two sessile florets. Nectaries are present at the base of each floret. Anthesis along the entire axis may take from a few days to several weeks to complete (George, 1981). As maturation of the cone occurs the axis thickens and woody follicles, which may contain one or two seeds, are formed.

Most Banksia species are not autogamous and require a pollen vector to effect seed set. Scott (1980) found B. attenuata and B. menziesii to be almost completely xenogamous and Keighery (1982) recorded seven species as obligate outbreeders although some other species were highly self-fertile.

The genus is regarded as essentially bird pollinated (Keighery 1980, 1982) either as a result of direct observation (eg. Ford and Paton, 1979; Whelan and Burbidge, 1980; Hopper and Burbidge, 1982) or by inference from the floral structure. There is, however, evidence of pollination by small mammals in some species (Carpenter, 1978; Wiens et al., 1979; Hopper, 1980; Turner, 1982). Carpenter (1978) and Holm (1978) described a set of attributes of some Banksia species which they suggested were adaptations specifically for mammal pollination but subsequent empirical data (Ford and Paton, 1979; Hopper, 1980) failed to support these hypotheses. Mammal pollination in the Proteaceae appears to be less well developed in south-western Australia than in South Africa (Lamont et al., 1985) where rodent pollination is an active syndrome (Wiens and Rourke, 1978). In south-west Australia, pollen loads on birds have been found to be considerably higher than on mammals (Hopper, 1980; Hopper and Burbidge, 1982). Birds are more mobile than mammals and do not preen themselves of pollen or intentionally ingest it (Paton, 1981). For these reasons birds are probably responsible for greater pollen transfer between plants and more outcrossing than other vertebrates although the relative importance of different pollinators will vary between species and even populations. Invertebrates are probably unimportant as pollinators of Banksia although insects may play a role in the pollination of some species (Whelan and Burbidge, 1980; B. Lamont, unpub.).

Percentage seed set in Banksia is very low. An inflorescence carries many more florets than ever set seed (Whelan and Burbidge, 1980; Abbott, 1985) although the surplus of florets may allow the plant to have some control over the quality of offspring (Stephenson, 1981). The maximum potential seed set in Banksia varies between species depending on follicle size, infructescence size and floret numbers. Only a proportion of this potential is achieved in nature where seed set is limited by numerous factors such as breeding system, the availability of resources (moisture and nutrients) (Pyke, 1982; Stephenson, 1981) and the predation of florets or seed (Scott, 1982). Resource limitation is likely to be a factor in those species which routinely form only one seed where two ovules are available

(Blake, 1971).

Most Banksia seed will germinate without pretreatment, although the optimal temperature requirements for germination are related to geographical distribution (Sonia and Heslehurst, 1978; George, 1981). The seeds of some members of the Proteaceae contain cyanogenetic glycosides which, when broken down by enzyme action, make them toxic to predators (Aplin, 1975). The presence of such a substance may afford the seed some protection from predation. Cyanogenetic glycosides may be detected by a simple chemical test and the results give an indication as to the possible fate of seed while retained in the follicle and following its release.

Rare plants usually do not reproduce freely. They may have a limited overall reproductive potential or suffer a breakdown at some point in their life cycle. B. chamaephyton and B. elegans both have a low seed production (George, 1981) and little is known of their breeding system or pollination requirements. This chapter examines aspects of the sexual reproduction of both species including breeding system, pollination (pollen vectors, pollen viability, stigmatic receptivity, nectar production), fruit formation (seed set, abortion, predation and cyanide content) and seed viability and germination.

3.2 Materials and Methods

3.2.1 Breeding system

The breeding system of each species was estimated using pollen/ovule ratios (Cruden, 1977) as a conservative indicator. They have been found to accurately reflect the breeding systems of other Western Australian Proteaceae (Briffa and Lamont, unpub.). Ranges of pollen/ovule ratios with the inferred breeding system is given in Table 3.1. Unopen florets were collected and opened using a fine needle to separate the anthers. Pollen was carefully removed from the pollen-presenters and anthers and placed on a microscope slide. A drop of aniline blue in lactophenol was added and the pollen grains mixed thoroughly within the drop. A coverslip was added and five fields of view were observed under a light microscope at 100X. The number of pollen grains in each field of view was counted and from this data the number of pollen grains per floret was estimated. The pollen/ovule ratio was obtained by dividing this number by two (the number of ovules).

3.2.2 Pollination

Pollen viability was assessed using the stain described by Alexander (1980). The stain colours callose tissue (pollen walls) green and cytoplasm purple. Pollen grains which stained green only or mostly green only, or which were abnormally shaped, were considered non-viable. Pollen from mature but unopened florets was used. This stain was selected because it gives a clear result, is easy to use and may be stored. Similar alternative methods such as MTT (Werner and Chang, 1981) and aniline blue in lactophenol (Hauser and Morrison, 1964) did not

Table 3.1: Pollen/ovule ratios and breeding systems of 96 species of flowering plant (from Cruden, 1977).

Pollen/ovule ratio	n	Breeding system
5 ± 1	6	Cleistogamy
28 ± 3	7	Obligate autogamy
169 ± 22	20	Facultative autogamy
797 ± 88	38	Facultative xenogamy
5859 ± 937	25	Xenogamy

give as clear a result when tested. Other more complex methods based on the capacity of pollen for oxidative metabolism (NBT - Hauser and Morrison, 1964) or the integrity of the plasmalemma (fluorescein diacetate - Heslop-Harrison and Heslop-Harrison, 1970) were not found to be correlated with pollen germinability (Werner and Chang, 1981; Widrlechner et al., 1982).

Stigmas of each species were examined with a scanning electron microscope to observe changes occurring during anthesis. Stigmas were regarded as receptive if the stigmatic cleft was open. Three categories of floret were recognised:

i) unopened;

ii) newly opened;

and iii) open for 24 h.

For B. chamaephyton, four stigmas in each category were examined. In B. elegans, eight stigmas in each category were examined.

The pollen-presenter of B. elegans was also examined as George (1981) found it to be often shrivelled at anthesis.

Florets were collected and fixed in FAA. They were dehydrated in graded ethanol solutions and brought through an amyl acetate series. After critical point drying from CO_2, specimens were mounted and coated with gold to a thickness of 300 A°. They were examined with a Jeol JSM-35C scanning electron microscope operated at an accelerating voltage of 25 kv.

A Green Head Road population (9) of Banksia chamaephyton and a population of B. elegans north of Lake Indoon (25) were selected for pollination studies. The studies were conducted from the 22nd to 28th November, 1984, and 25th October to 1st November, 1984, respectively. Descriptions of vegetation, topography and soils at each site are given in Appendix Four. Species in flower at each site were noted and their frequency estimated.

Vertebrates were either mistnetted (birds) or trapped in pit traps or Elliot traps (mammals) and examined for pollen loads. Mist nets measuring 10 m x 3 m were used. Netting was conducted during the first two hours after sunrise and the last two hours before sunset. Inverted "witches hats" were utilised as pit traps. The traps were placed at approximately 3 m intervals along a 40 m x 30 cm aluminium wire drift fence. Elliot traps were baited with a honey/peanut butter/rolled oats mixture. They were placed at approximately 3 m intervals. Invertebrates were collected from flowers and placed in killing jars with ethyl acetate for subsequent identification and examination for pollen.

The catch effort of mistnetting and trapping is given in Table 3.2. Pit traps, although more suitable than Elliot traps for the capture of some native mammals (Hopper, 1980), were not used at the Green Head Road location due to the lateritic terrain.

Permanent records of the pollen loads of all animals were made using the procedure described by Wooller et al. (1983). An increase in gelatine content of the glycerine jelly (to 10g) was necessary for the substance to maintain a usable consistency in the field. The jelly was used to collect all pollen on the head and beak of birds and on the head and snout of mammals. Species of pollen were identified by taking samples direct from flowers

Table 3.2: Catch efforts for vertebrates at Green Head Road (9) and north of Lake Indoon (25).

Site Ref. No.	Mist net mornings/ afternoons	Pit trap nights	Elliot trap nights
9	14	0	130
25	8	64	60

using the same method.

Where the total number of pollen grains per species per individual was less than 10, the data were excluded. It was sometimes difficult to identify species from one or a few grains and it was considered that the information contributed little to the overall analysis of pollen loads. In addition to the pollen load data, faecal samples from captive animals were obtained, where possible, by placing the animal inside a paper bag until a sample was produced. The faeces inside the bag was then checked for the presence and identity of pollen.

Opportunistic observations of bird and invertebrate visitation were made. A captive mammal north of Lake Indoon was offered inflorescences of B. elegans (nectar and pollen available, no odour), and B. attenuata (nectar and pollen available, strong odour), and its response noted.

Stigma to nectary distances were recorded to support visitation and pollen load data. A comparison was made with bill and snout lengths taken from captive animals. Measurements were made from the top to the tip of the bill and from eye level to the tip of the snout. All measurements were made to the nearest 0.1 mm using Mitutoyo calipers.

Nectar production was assessed over a 24 h period. All nectar was removed from inflorescences and they were enclosed in perspex boxes sealed at the stem with stocking and tape. The stocking and small holes in the perspex boxes allowed for the passage of air while preventing any harvesting of nectar. All nectar was removed at 4-hourly intervals and measured using 100 ul microcaps and a micropipette. Where sufficient nectar was available, the concentration of sugar was measured using a sugar refractometer. Any odour from the inflorescences was noted.

3.2.3 Fruit and seed set

At each site, the number of follicles per infructescence on a representative number of plants was counted. The number of florets per inflorescence was obtained by sampling plants at a Green Head Road population (9) of B. chamaephyton and north of Lake Indoon (25) for B. elegans and counting the number of florets on representative inflorescences. From these data, the seed set for each location, expressed as follicles per 100 florets, was calculated. Infructescences with no follicles were included.

The percentage viable seed for each species was determined by collecting a number of infructescences from the Associated Minerals Consolidated lease population (2) of B. chamaephyton and the B. elegans population north of Lake Indoon (25) to assess seed predation, abortion and germinability. Follicles were opened by lightly burning them with an oxyacetylene torch and the seed removed. The number of seed which was predated (seed damaged, frass present) or aborted (very little or no embryo formation) was recorded.

Intact seeds were placed in petri dishes on moistened filter paper over vermiculite. The petri dishes were kept in an incubator at 15 ± 1°C in darkness. This temperature was found to be suitable for germination of other species from the same geographical area (Davies <u>et al.</u>, 1983; Cowling and Lamont, 1984). The dishes were checked daily for germinants (1 mm or more of emergent radicle) which were removed and a log was maintained until it was apparent that no further germination would occur. The final germination percentage served as an approximation of seed viability. Viable seed was defined as apparently intact seed able to germinate under optimal conditions.

Seeds of <u>B. chamaephyton</u> were assayed for cyanogenetic glycosides to ascertain whether they had any chemical protection from predation. No <u>B. elegans</u> seed was available for this purpose. Portions (approximately 50 mg) of six single seeds (seed coat and embryo) were macerated separately and each placed in a 9 ml vial. Three seeds were moistened with deionised water and three with emulsin (β- glucosidase). The addition of emulsin gives a more rapid result (Aplin, 1975). A 6 cm long, 5 mm wide strip of Feigl-Anger paper was placed over the lip of each vial carefully avoiding wetting any strips with the contents of the vials. The vials were then sealed and checked after 2 and 24 hours. If cyanogenetic glycosides were present the colourless strips would turn light blue or dark blue depending on the concentration of the substance. The procedure was repeated using <u>Grevillea pteridifolia</u> (Proteaceae) seed as a control. <u>G. pteridifolia</u> has significant quantities of cyanogenetic glycosides in the seed coat and embryo (Majer and Lamont, 1985).

3.3 Results

3.3.1 Breeding system

The pollen/ovule ratios for *Banksia chamaephyton* and *B. elegans* were 2811 ± 598 (s.d.) (range 1918-3949) and 2152 ± 662 (1127-3850) respectively. This places each species between the categories of facultative xenogamy and xenogamy (Table 3.1).

3.3.2 Pollination

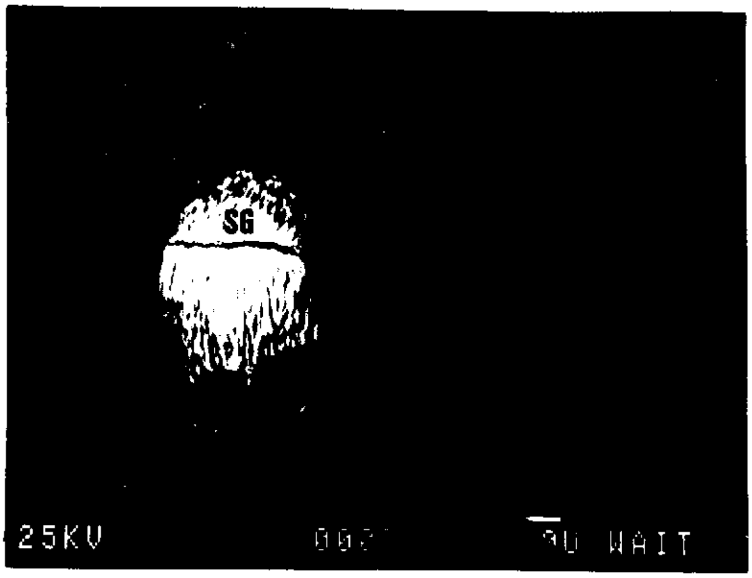
The pollen viability of *B. chamaephyton* and *B. elegans* was 94.6% (n = 2500) and 69.9% (n = 3000) respectively.

In each *B. chamaephyton* floret examined, the stigmatic clefts were closed prior to anthesis and 24 h after anthesis. In all newly opened florets the stigmatic cleft was also open. Stigmas of *B. chamaephyton* are represented in Plate 3.1.

Plate 3.2 shows the stigma of *B. elegans*. Some stigmas (two of eight examined) had opened prior to anthesis. Soon after anthesis half (four of eight) were open and after 24 h all were open. The stigmatic groove in each case was irregularly shaped and usually split or torn (Plate 3.2c). After 24 h, the surface of the stigma had degenerated and did not appear to be viable although one groove contained a pollen grain (Plate 3.2d).

The pollen-presenter of *B. elegans* is shown in Plate 3.3. It consists of a series of rows of gland-like structures some of which appear to have a terminal secretory pore. In the field, pollen was observed to adhere around these structures in aggregates held together by a viscous substance. In contrast, the

(a)



(b)

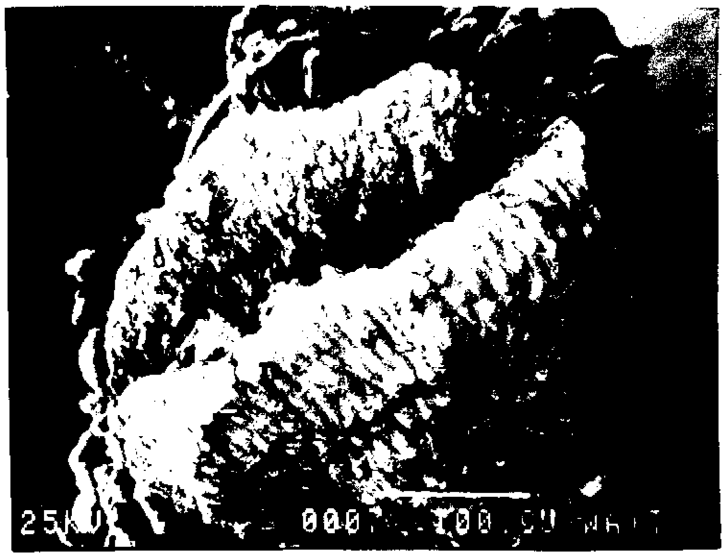
(c)

Plate 3.1: Pollen-presenter and stigma of <u>Banksia chamaephyton.</u>
(a) floret prior to anthesis; (b) newly opened floret; (c) floret 24 h after opening. (SG=stigmatic groove).

(a)

(b)

(c)



(d)

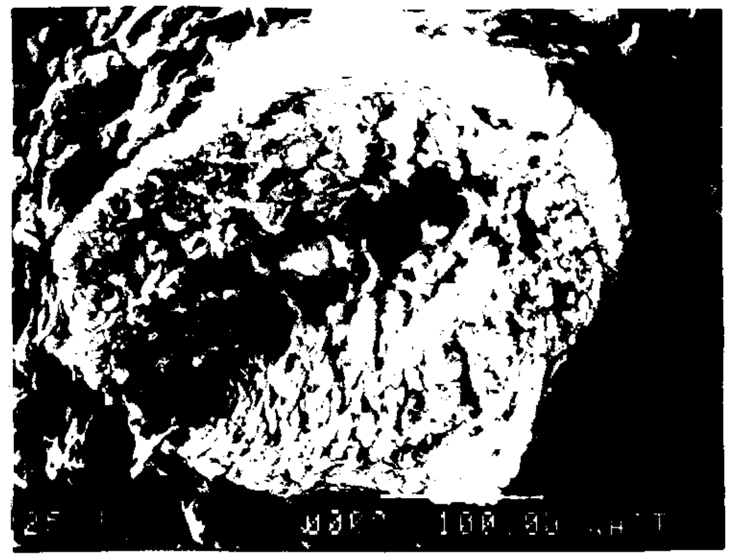
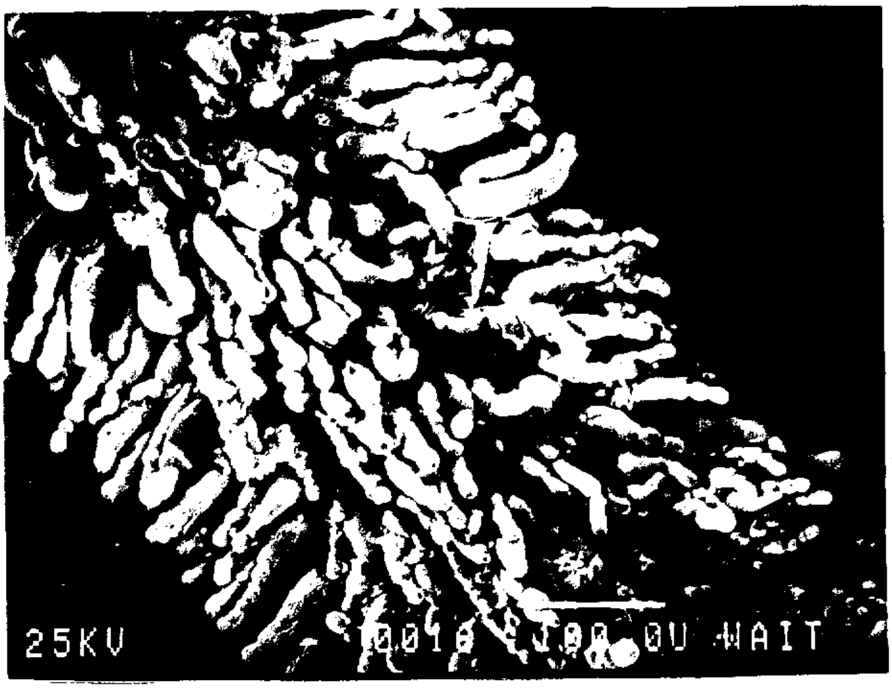


Plate 3.2: Stigma of Banksia elegans. (a) floret prior to anthesis; (b) newly opened floret; (c) and (d) floret 24 h after opening. (SG=stigmatic groove,PG=pollen grain,T=tear, or split).

(a)



(b)

Plate 3.3: Pollen-presenter of Banksia elegans. (a) gland-like structures covering pollen-presenter (b) greater magnification of (a) showing pores on gland-like structures. (P=pore).

pollen-presenter of B. chamaephyton has a series of corrugations and no gland-like structures are present (Plate 3.1).

The species flowering at each site at the time of the study are given in Table 3.3. B. chamaephyton and B. elegans were both in full flower and moderately common at their respective sites. B. chamaephyton usually had one to three inflorescences per plant at peak flowering. Some plants produced no inflorescences. Although inflorescences of B. chamaephyton always contained nectar, other species in flower at the Green Head Road location appeared upon inspection to be producing little nectar. Mature (>1.5 m) B. elegans had five to ten open inflorescences at peak flowering. The only other major source of nectar evident north of Lake Indoon was from early B. attenuata inflorescences.

The size and shape of all pollen grains encountered during the study are given in Figure 3.1. Most species were readily distinguished by size or shape. Pollen of B. chamaephyton and B. attenuata was similar but the former was slightly longer and flatter. Pollen of Species B and C were the same size and shape but were found at different locations. These, and pollen of Species A, were not identified although pollen from all plant species observed to be in flower was collected. Their pollen, however, was found on some of the animals captured.

Only two birds and one rodent were captured at the Green Head Road location. Their pollen loads are given in Table 3.4. The low number of vertebrates trapped was probably due to a low density of animals and poor weather conditions during the fieldwork.

Table 3.3: Species in flower at Green Head Road (Banksia chamaephyton) and north of Lake Indoon (B. elegans). Flowering stages are given as YF (some flowering, most in bud), FF (full flower) or OF (some flowering, most fruiting or dehiscent). Frequencies are given as + (only a few plants), ++ (moderately common) or +++ (dominant or very common).

Site Ref. No.	Plant Species in Flower
9	Banksia chamaephyton (++, FF) B. micrantha (++, FF) Lambertia multiflora (+++, OF) Macropidia fuliginosa (+, OF) Verticordia grandis (+, OF)
25	Banksia attenuata (+++, YF) B. elegans (++, FF) Calothamnus quadrifidus (+, FF) Dryandra sessilis (+, OF) Melaleuca hamulosa (+, YF)

Table 3.4: Pollen loads of animals netted or trapped at Green Head Road. + indicates the presence of pollen in faecal samples. Species A and B are unidentified.

Animal	Pollen Loads			
	Banksia chamaephyton	Lambertia multiflora	Species A	Species B
Lichmera indistincta	-	440	60	-
L. indistincta	-	428+	-	14
Mus musculus	-	+	-	-

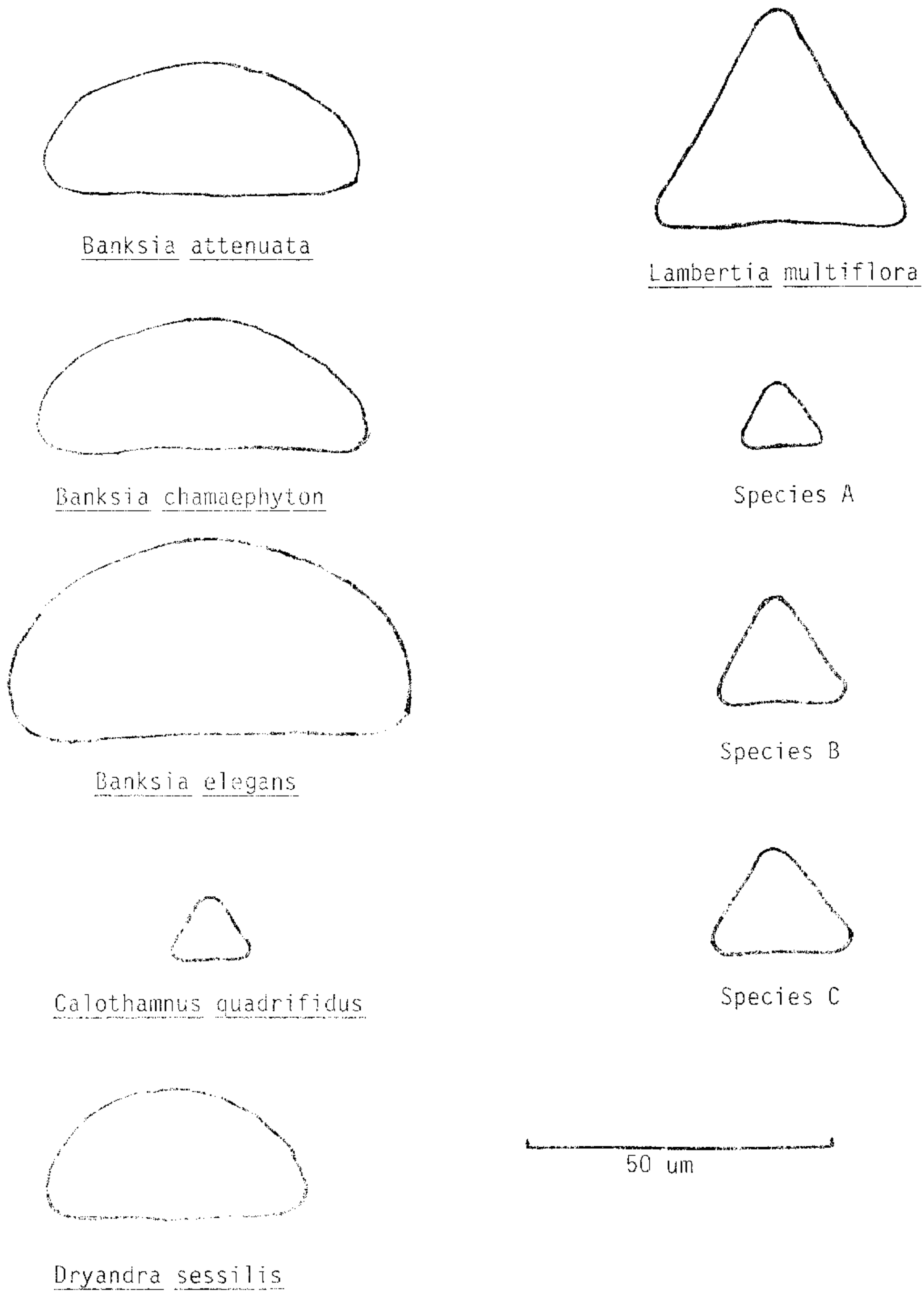


Figure 3.1: Shape and size of pollen grains occurring in pollen load records and faecal samples of captured animals. A minimum of ten pollen grains of each species were measured. Equatorial views throughout.

Furthermore, the low vegetation made the use of mist nets difficult and they were mostly ineffective. None of the animals carried pollen of B. chamaephyton. Lichmera indistincta (Brown Honeyeater) mostly carried pollen of Lambertia multiflora.

Nineteen birds and three mammals were captured north of Lake Indoon. Their pollen loads are given in Table 3.5. All bird species were found to carry pollen of B. elegans. The heaviest pollen loads of B. elegans were found on Phylidonyris nigra (White-cheeked Honeyeater) with much smaller loads on Lichenostoma virescens (Singing Honeyeater) and Lichmera indistincta. P. nigra and L. indistincta both carried large amounts of Calothamnus quadrifidus pollen. No B. elegans pollen was found on any of the mammals.

A small number of observations of birds directly feeding from inflorescences of B. elegans was made (Table 3.6). Most observations were of feeding bouts by P. nigra.

A captive Tarsipes rostratus (Honey Possum) fed at both B. elegans and B. attenuata inflorescences although it appeared to show a preference for the latter which had a much stronger odour. No observations of vertebrate visitation were made at the Green Head Road location as it was impossible to view the inflorescences (which rest on the ground) without disturbing the animals.

Both B. chamaephyton and B. elegans inflorescences frequently had Hymenopteran visitors. Three species of ant (two Iridomyrmex spp. and a Camponotus sp.) were observed in large numbers on B.

Table 3.5: Pollen loads of animals trapped or netted north of Lake Indoon. + indicates the presence of pollen in faecal samples.

Animal	Pollen Loads					
	Banksia elegans	*Banksia attenuata*	*Calothamnus quadrifidus*	*Dryandra sessilis*	*Lambertia multiflora*	Sp. C
Lichenostoma virescens	38	793				
L. virescens	198	201				
L. virescens	77+	23+				
L. virescens			18			
L. virescens			12			
Lichmera indistincta			164			
L. indistincta	25		29			
L. indistincta			659		10	
L. indistincta	19		1860	151		
L. indistincta	15+	14+	380			
Mus musculus						
M. musculus		86				
Phylidonyris nigra	24	383	607			
P. nigra	2620	166	528			
P. nigra	33		1810			
P. nigra	242+		6790			
P. nigra	158+		331			
P. nigra	25		2810		196	
P. nigra	269		352			
P. nigra	684+		895			
P. nigra	10	+	10250		233	
Tarsipes rostratus		+	199+			+

Table 3.6 : Bird species observed visiting *Banksia elegans* north of Lake Indoon.

Bird	No. of visits	No. of feeding probes
Anthochaera carunculata	1	2
Lichenostoma virescens	4	17
Phylidonyris nigra	6	25

chamaephyton inflorescences where they fed on nectar. Neither species, however, was found to carry any pollen. B. elegans inflorescences were visited in large numbers by Apis mellifera (Honey Bee) which usually gathered nectar exclusively but sometimes gathered pollen. Apart from their pollen sacs they carried no pollen on their bodies. B. elegans had two ant species (Iridomyrmex purpureus and I. sp.) often found on inflorescences. They fed on nectar but again neither species carried any pollen on their bodies. A tiphiid wasp was also observed feeding on nectar from a B. elegans inflorescence.

Stigma to nectary and bill and snout measurements are given in Table 3.7. B. elegans has a slightly larger stigma to nectary distance than B. chamaephyton. The bill length of Phylidonyris nigra was considerably larger than Lichenostoma virescens or Lichmera indistincta. The snout lengths of Mus musculus and Tarsipes rostratus were comparable but were much shorter than the bill lengths of birds.

Nectar production by B. chamaephyton and B. elegans is shown in Figure 3.2. B. chamaephyton produces most of its nectar early in the morning with production declining sharply during the rest of the day and evening. B. elegans had two peaks of production - in the early morning and early evening. For B. chamaephyton a mean nectar concentration of 56% was recorded for samples taken at 4 am and 8 am. B. elegans recorded a mean nectar concentration of 62% from seven readings taken during the times of greatest production. The early evening samples were the most concentrated. B. chamaephyton inflorescences had a slight odour

Table 3.7 : Stigma to nectary distances of *Banksia chamaephyton* and *B. elegans* and bill and snout lengths of birds and mammals. Bill and snout length data is supplemented with data from Barrett (unpub.) when annotated with an *.

Measurement	Distance in mm X ± s.d.
Stigma to nectary:	
Banksia chamaephyton	24.1 ± 0.8 (20)
B. elegans	27.6 ± 1.1 (20)
Bill:	
Lichenostoma virescens	15.3 ± 1.6 (5)
*Lichmera indistincta**	15.8 ± 1.4 (16)
*Phylidonyris nigra**	22.8 ± 1.5 (18)
Snout:	
*Mus musculus**	9.0 ± 1.0 (8)
*Tarsipes rostratus**	10.0 ± 1.4 (5)

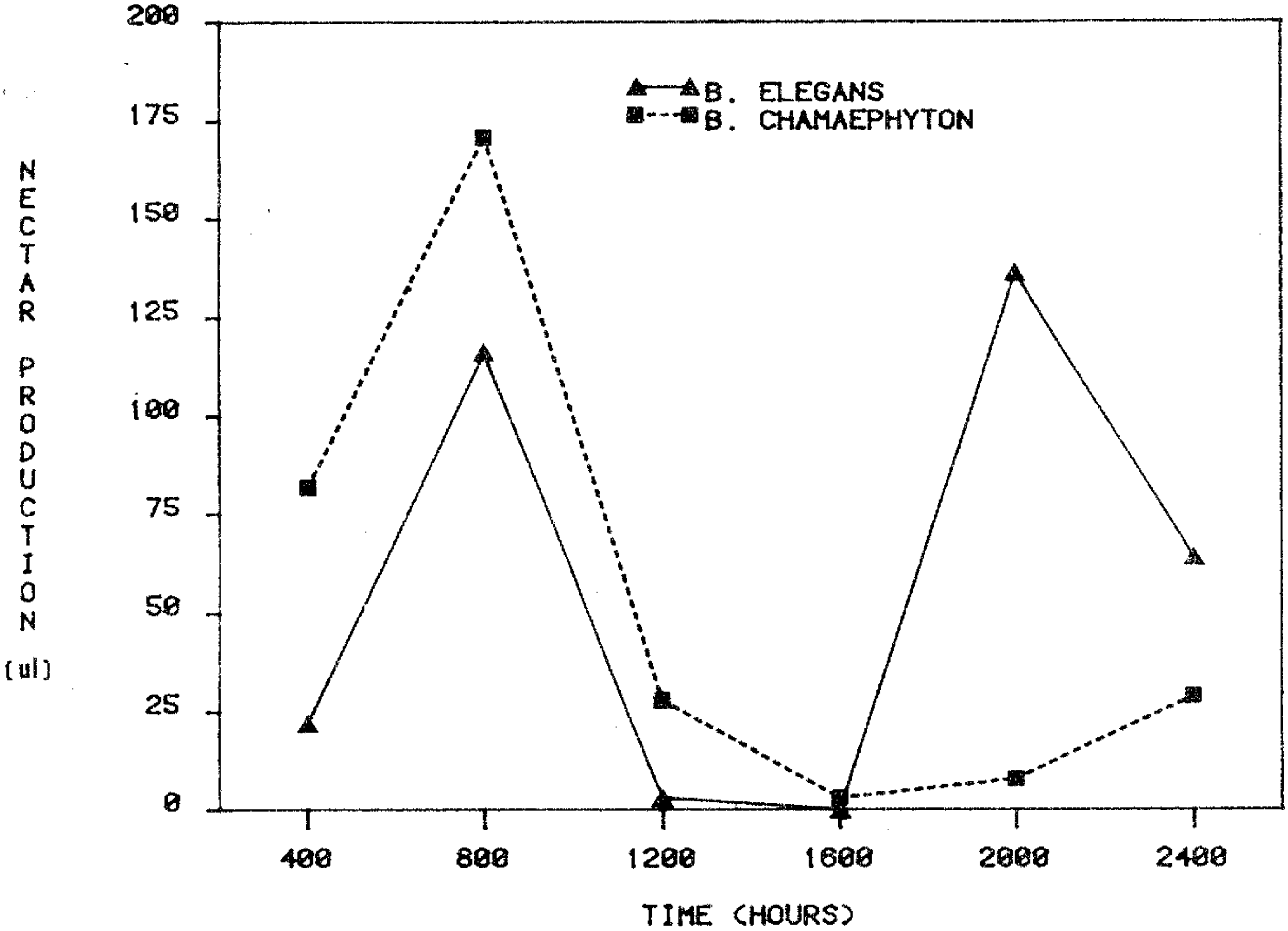


Figure 3.2: Mean nectar production per inflorescence in *Banksia chamaephyton* (n=3) and *B. elegans* (n=5) over 24 h.

throughout the day which was most noticeable early in the morning. B. elegans inflorescences had a slight odour only in the early evening.

3.3.3 Fruit and seed set

Floret numbers per inflorescence of Banksia chamaephyton and B. elegans were 1573 ± 175 (n = 5) and 531 ± 77 (n = 10) respectively. Table 3.8 gives the follicles per 100 florets and the % barren infructescences for each population of each species. The number of follicles per 100 florets for B. chamaephyton infructescences ranged from 0.006 (97.0% of infructescences barren) at a Green Head Road population (6) to 0.136 (57.7% of infructescences barren) in a population on the Brand Highway (4). Only three populations had a value greater than 0.1.

For the 16 populations occurring in the Tathra and Le Sueur Systems a positive correlation was found between the percentage of barren infructescences and longitude ($p < 0.05$) (Figure 3.3). Although the percentage of barren infructescences and the number of follicles per 100 florets were highly correlated ($p < 0.001$), the latter and longitude were not significantly correlated.

Plants in most B. elegans populations had formed no follicles. Three populations had been recently burnt (Lake Arrowsmith (22), Beharra Spring (23) and Lake Indoon (26)) and had not recommenced flowering and fruiting. Although no count could be made at these sites, remnants of follicles were found at each. Two other populations (Lake Logue (24) and north of Lake Indoon (25)) had plants which possessed follicles. The number of follicles per 100 florets was 0.083 (78.0% of infructesences

Table 3.8: Follicles per 100 florets (n = no. of infructescences examined) and the percentage of infructescences which were barren in populations of Banksia chamaephyton (site reference no's. 1-18) and B. elegans (19-29). (n.d. = no data).

Site Ref. No.	Follicles per 100 Florets (n)	% Barren Infructescences
1	0.070 (29)	79.3
2	0.078 (136)	71.3
3	0.070 (81)	80.2
4	0.136 (180)	57.7
5	0.035 (184)	91.3
6	0.006 (101)	97.0
7	0.007 (102)	97.1
8	0.022 (83)	92.8
9	0.008 (38)	97.4
10	0.081 (56)	71.4
11	0.036 (89)	84.3
12	0.123 (104)	61.5
13	0.062 (203)	79.3
14	0.076 (103)	80.6
15	0.089 (229)	74.2
16	0.125 (27)	59.3
17	0.028 (259)	92.3
18	0.098 (104)	75.0
19	0.000 (200)	100.0
20	0.000 (100)	100.0
21	0.000 (100)	100.0
22	n.d.	n.d.
23	n.d.	n.d.
24	0.083 (645)	78.0
25	0.056 (1494)	84.7
26	n.d.	n.d.
27	0.000 (100)	100.0
28	0.000 (100)	100.0
29	0.000 (100)	100.0

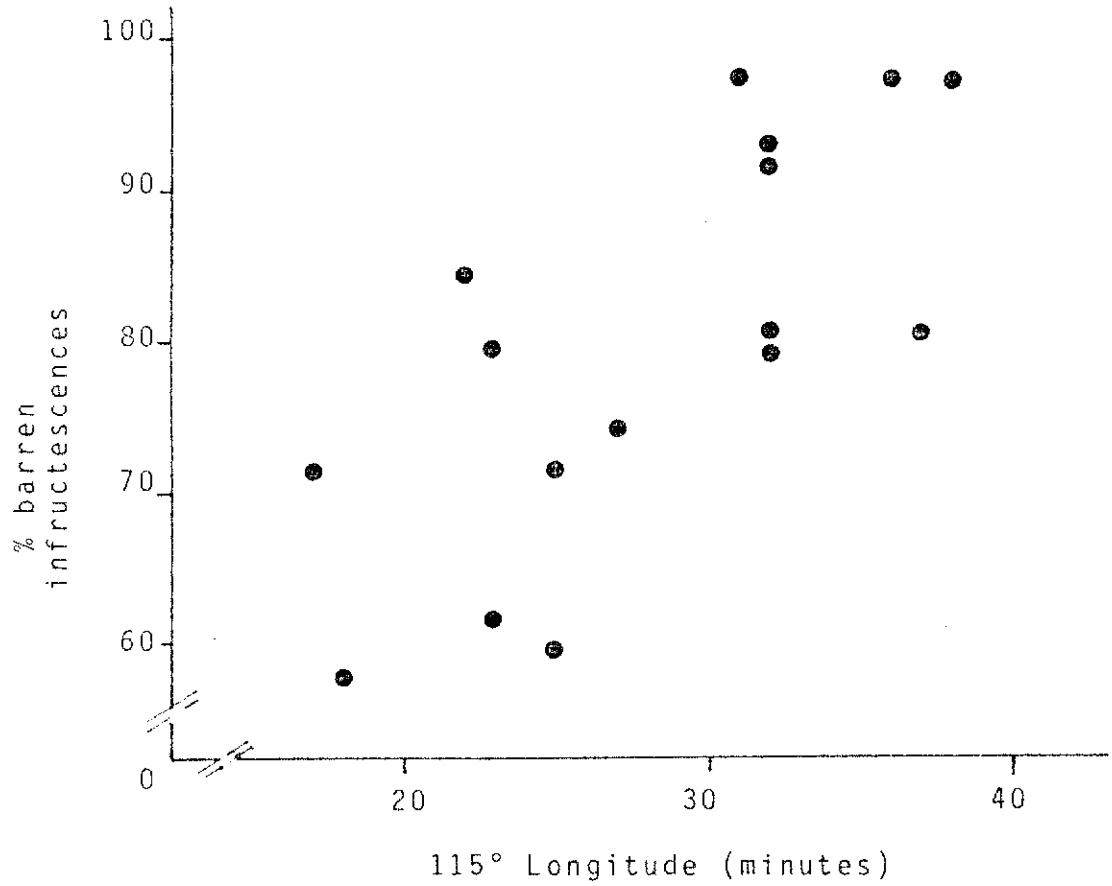


Figure 3.3: The relationship between longitude and the percentage barren infructescences in Banksia chamaephyton in the Tathra and Le Sueur vegetation systems.

barren) and 0.056 (84.7% of infructescences barren) at Lake Logue and north of Lake Indoon respectively.

The proportion of seed which was predated, aborted, non-viable or viable is presented in Figure 3.4 (B. chamaephyton) and Figure 3.5 (B. elegans). Only a small number (1.3%) of B. chamaephyton seed had been predated. No B. elegans seed was predated. Most (87.6%) B. elegans seed had aborted, but only 7.7% of B. chamaephyton seed. Some B. chamaephyton seed collected a year after the previous flowering season was immature suggesting that seed maturation in that species may take two years or more.

In B. chamaephyton, 96% of intact seed germinated and 80% of B. elegans intact seed germinated. The time course of their germination is given in Figure 3.6. No germination in either species occurred before 10 days. No further germination occurred after 30 days in B. chamaephyton and after only 18 days in B. elegans. Survival of B. elegans germinants under greenhouse conditions was poor while B. chamaephyton survived well.

The results of the assay for cyanogenetic glycosides in seed of B. chamaephyton are given in Table 3.9. Cyanogenetic glycosides were found to be only weakly present. Their presence was detected only with emulsin added and over an extended time period. The control species, Grevillea pteridifolia, showed a strong reaction in all treatments.

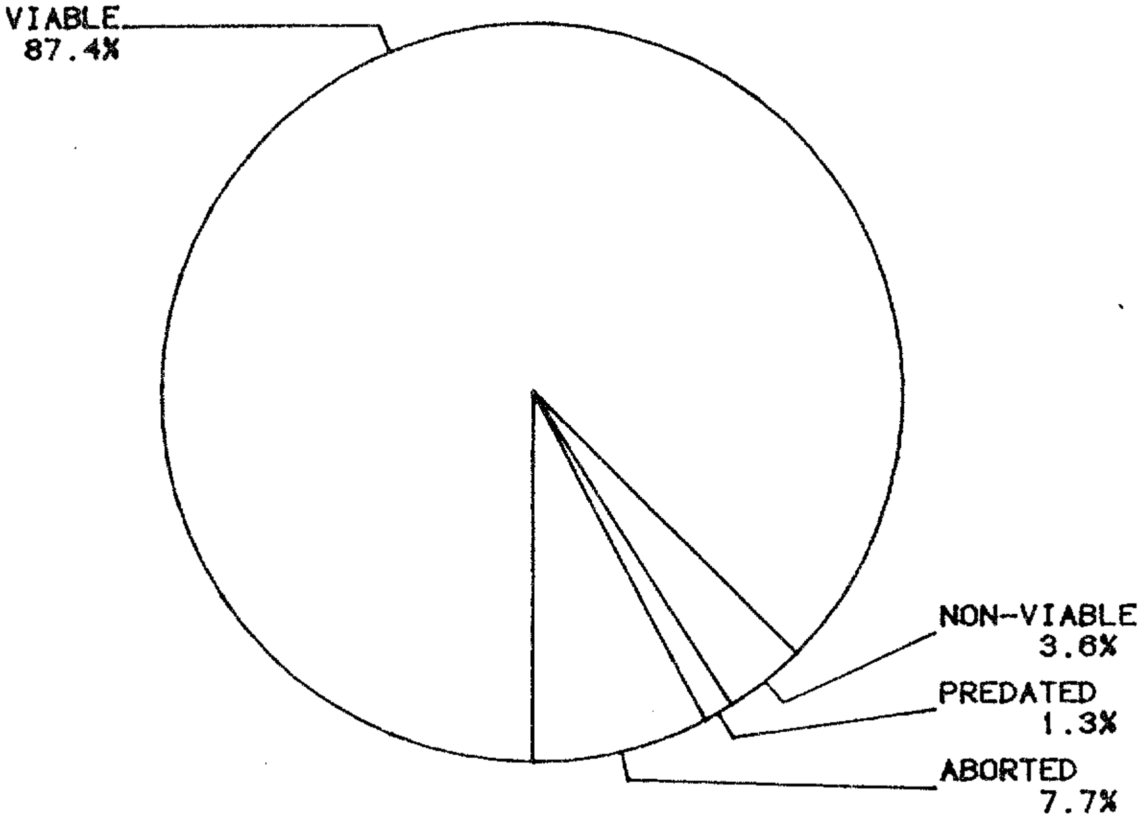


Figure 3.4 Percentage of predated, aborted, non-viable and viable seed in Banksia chamaephyton (n=156).

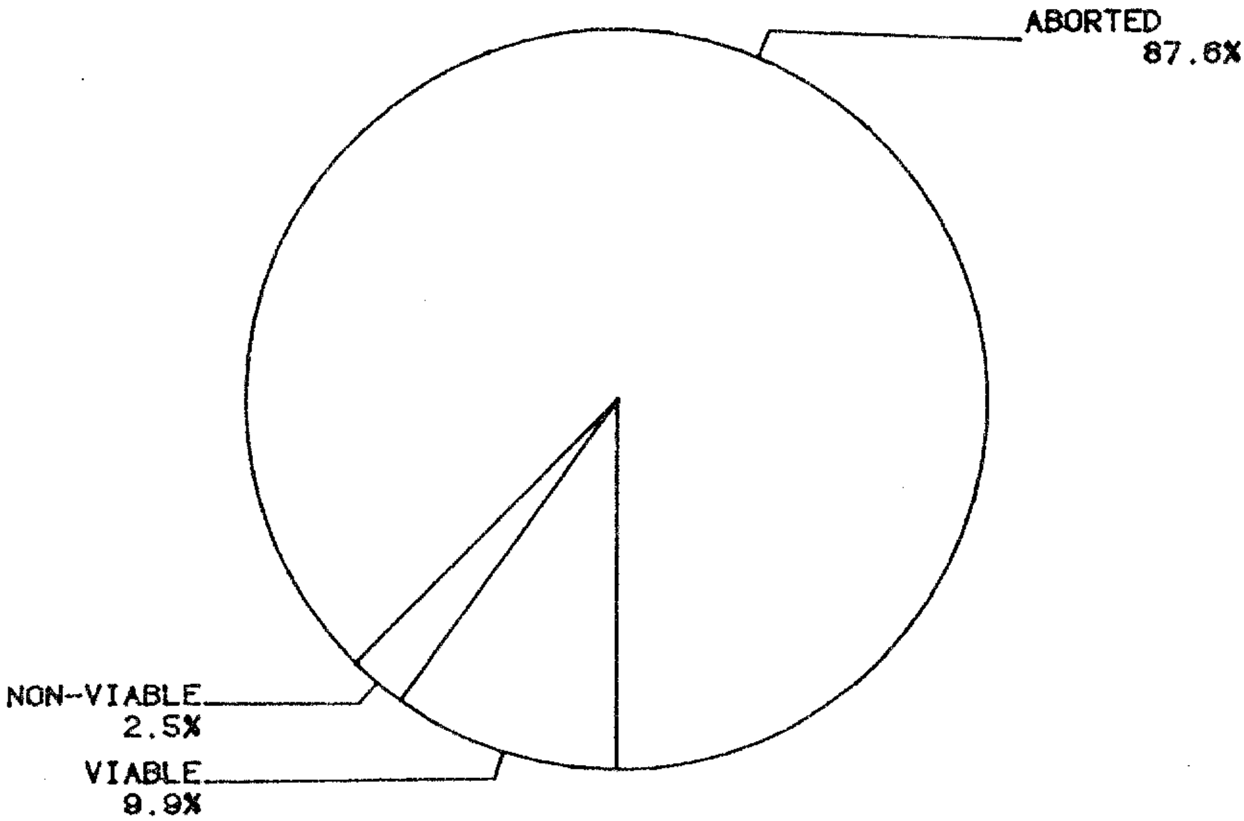


Figure 3.5 Percentage of aborted, non-viable and viable seed in Banksia elegans (n=130).

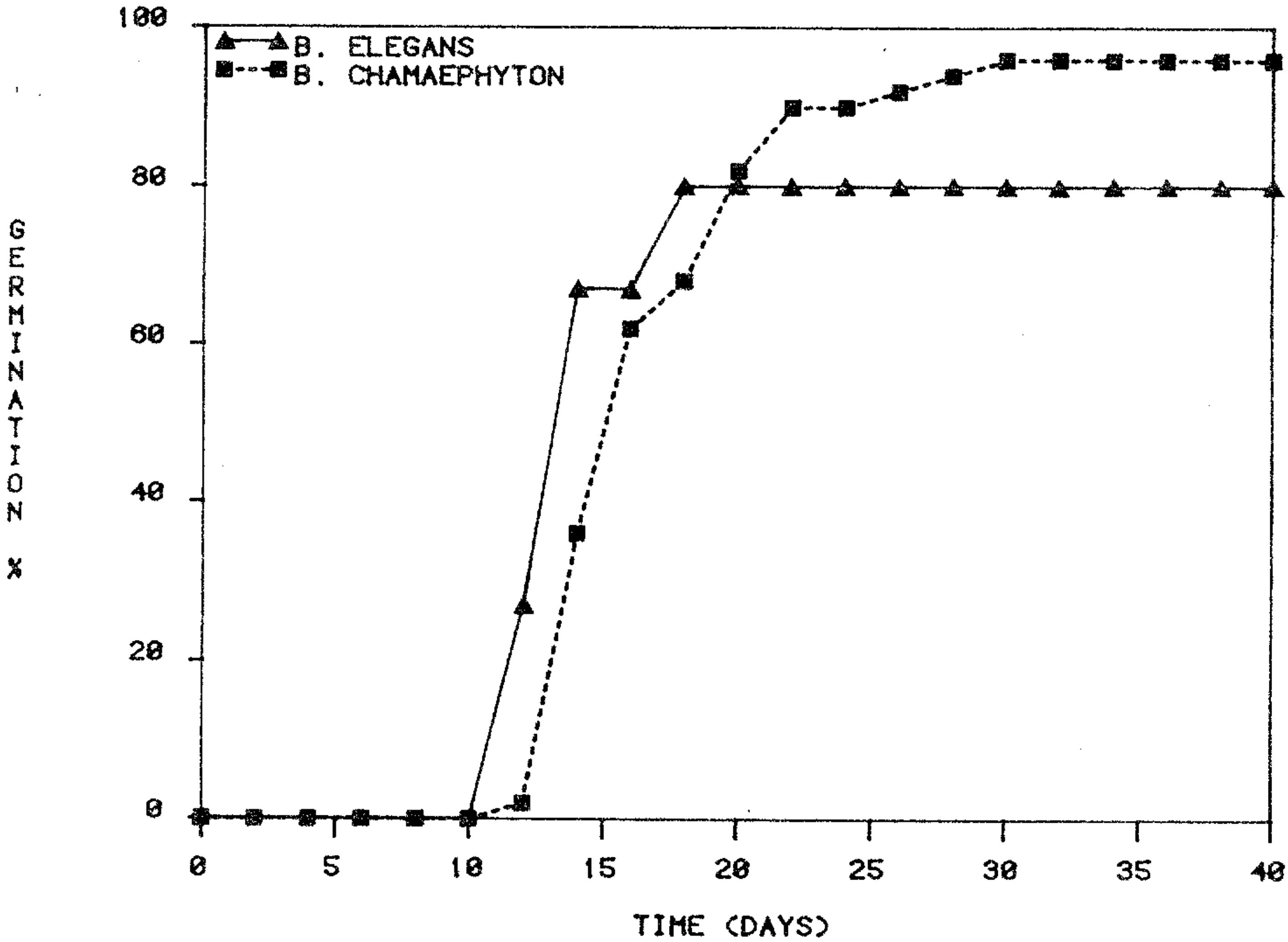


Figure 3.6: Germination of _Banksia chamaephyton_ (n=50) and _B. elegans_ (n=15).

Table 3.9 : Test for presence of cyanogenetic glycosides in Banksia chamaephyton and Grevillea pteridifolia. Key to symbols: - = not present; + = weakly present; ++ = strongly present.

Species	Vial No.	Deionized water(W) or emulsin(E)	Presence of cyanogenetic glycosides	
			After 2h	After 24h
Banksia chamaephyton	1	W	-	-
	2	W	-	-
	3	W	-	-
	4	E	-	+
	5	E	-	+
	6	E	-	+
Grevillea pteridifolia	7	W	++	++
	8	W	++	++
	9	W	++	++
	10	E	++	++
	11	E	++	++
	12	E	++	++

3.4 Discussion

3.4.1 Breeding system

The pollen/ovule ratios of both species indicate that they may be facultatively xenogamous. Furthermore, a preliminary analysis of allozyme polymorphisms in the endosperm of B. chamaephyton (Barrett, unpub.) detected variable isozyme patterns suggesting that pollen vectors may be required for maximum seed set in this species.

Carpenter and Recher (1979) suggested that Banksia species which resprout after fire (as both B. chamaephyton and B. elegans do - Chapter Four) are usually self-compatible although Lamont (1985) failed to find a similar relationship in some South African Proteaceae. There is no evidence in this study that B. chamaephyton or B. elegans are obligate outbreeders but it seems likely that most seed is set following xenogamous fertilisation. In B. elegans, the opportunity of receiving pollen from another individual plant is reduced as plants are often connected by lateral roots and a single genet forms a stand.

3.4.2 Pollination

In B. chamaephyton, anthesis occurs from the bottom of the inflorescence to the top (George, 1981) and the stigma becomes receptive soon after the floret opens. Pollen viability was high and in the range of values given for other Banksia species (Lewis and Bell, 1981). Nectar production peaked in the early morning with little nectar produced at other times. This pattern of production favours pollinators active at that time.

Although the data are limited, *B. chamaephyton* may be bird pollinated. Vertebrate density was low at the *B. chamaephyton* study site and no pollen loads with that species were recorded. Furthermore, no published data are available on vertebrates occurring in the area. Birds, however, are likely to be responsible for most pollen transfer. Keighery (1982) observed that birds could feed at prostrate *Banksia* species while standing on the ground. *B. chamaephyton* has none of the characteristics (including hooked styles, strong odour, open inflorescence structure and nocturnal nectar production) which Carpenter (1978) associated with mammal-pollinated plants. While the nectivorous mammal, *Tarsipes rostratus*, has been suggested as a pollinator of a number of Western Australian *Banksia* species (Wiens *et al.*, 1979; Hopper, 1980) on a daily basis the animal is mostly active when nectar availability in *B. chamaephyton* is low (Vose, 1972). However, *T. rostratus* is known to visit other prostrate *Banksia* species (S. Hopper, pers. comm.) and may play a role in the pollination of *B. chamaephyton*.

Ants were common on inflorescences but it is unlikely they, or any other invertebrates, play a direct role in pollination. The spatial separation of stigmas and nectaries and the absence of any pollen loads on the ants suggest they are not involved in pollen transfer. Their presence may, however, deter more destructive insects and result in higher seed set (Scott, 1982), although Abbott (1985) showed they had no effect on predation of *B. grandis* inflorescences.

B. elegans has a spherical inflorescence opening from the bottom

(George, 1981). Some stigmas appear to become receptive prior to the floret opening as the stigmatic cleft is already slightly open. However, the cleft is often irregularly shaped and becomes increasingly irregular with time. Similar irregularities have not been observed in B. chamaephyton, B. prionotes (Collins and Spice, m/s) or B. tricuspis (van Leeuwen, unpub.). Pollen germination and pollen tube growth were not observed and seem unlikely to occur in the malformed stigma.

The pollen-presenter of B. elegans appears to have glands which secrete a viscous substance. The glands are morphologically similar to those found on Grevillea leucopteris (Lamont, 1982) and other members of the Proteaceae (Dell, 1977) which secrete resin but their function here is not clear. They may help to retain pollen on the pollen-presenter until visited by a pollinator or prevent the desiccation of the pollen. Wiens et al. (1979) reported that the pollen mass of B. attenuata is also viscous but no glands are evident on the pollen-presenter of that species (pers. obs.). Pollen viability is at least 20% lower than that of B. chamaephyton and other Banksia species (Lewis and Bell, 1981).

B. elegans inflorescences are visited by several species of birds. Phylidonyris nigra carried the highest pollen loads and had the longest beak length. Tullis et al. (1982) found long-billed honeyeaters in Banksia woodland feed more on nectar than short-billed honeyeaters which were mostly insectivorous. These data, and the relative number of observations of bird visitation recorded suggest that P. nigra is the most important bird pollinator visiting B. elegans. Nectar production in B. elegans showed peaks of production occurring in the early morning and mid-evening. This pattern of nectar production has been observed in B. telmatiaea (Lewis and Bell, 1981) and B. candolleana (Barrett, unpub.). The morning peak coincides with bird activity but the nocturnal production suggests pollination by nocturnally-active small mammals (Carpenter, 1978). Tarsipes rostratus fed at a B. elegans inflorescence when offerred although the only specimen trapped carried no B. elegans pollen.

No invertebrates were found to be responsible for pollen transfer in B. elegans. Ants occurring on the inflorescences play a similar role as in B. chamaephyton. Visits by Apis mellifera could result in reduced pollen tranfer between plants by harvesting but not transferring pollen and decreasing the available nectar for vertebrate pollinators.

Rodents, both native and introduced, could play a minor role in the pollination of both species either by pollen transfer or reducing predation of inflorescences. Some rodents are highly insectivorous (Watts, 1977) and could feed on insects occurring among the florets. Lepidopteran larvae are particularly common on some Banksia inflorescences (Scott, 1982) and Ward (1981) found them to be a significant portion of the diet of Mus musculus. M. musculus (introduced) and Pseudomys albocinereus (native) have been recorded carrying pollen of B. candolleana (Barrett, unpub.) and Wiens et al. (1979) suggested Pseudomys and other native mammals may play a role in pollination.

3.4.3. Fruit and seed set

Fruit set in both species is low. *B. chamaephyton* recorded a mean of 0.06 follicles per 100 florets over 18 populations. Except for *B. elegans* and *B. candolleana*, fruit set in *B. chamaephyton* is lower than eight other *Banksia* species from the same geographic area (B. Lamont, unpub.). Eastern populations had more barren infructescences than populations occurring further west. This is likely to be related to annual rainfall which decreases as longitude increases (see Figure 2.4).

Although only limited amounts of *B. chamaephyton* seed are produced, viability is high and the loss of seed through predation prior to dispersal is much lower than in other *Banksia* species (Scott, 1982). The low level of predation may be due to the seeds having some toxicity to herbivores or may be a result of certain physical properties of the inflorescence (closed inflorescence structure) and infructescence (non-deciduous florets; hard, thick follicles; wide dispersal of follicles) (Scott, 1982).

Most *B. elegans* populations did not possess any follicles. These populations occur at extremes (the three most northerly and the three most southerly) of the species range. Furthermore, in those populations which do form follicles much of the seed is aborted. No predation of seed in the follicles was recorded in this study but it has been observed by Scott (1982).

Germination of *B. elegans* seed has also been attempted by Kullmann (1981). He found two seeds took an average of 45 days at ambient temperatures to germinate. Others have successfully grown plants from seed (T. Holl, K. Stuckey, D. Rowley, pers. comm.) and there appears to be no special requirement for germination.

Due to the low availability of seed there have been some attempts to produce plants by alternative means. Tip cuttings have had a poor success rate (C.J. Oliver, R. Ellyard, pers. comm.) but sections of lateral root with a sucker emerging have shown some promise (C.J. Oliver, pers. comm.). Earlier attempts at grafting *B. elegans* were unsuccessful (Wilson, 1982) but more recently a successful graft to *B. integrifolia* has been reported (McCredie *et al.*, 1985).

There are no apparent environmental reasons for the high level of infertility in *B. elegans*. Populations which do not form follicles do not appear to be restricted by resource availability or lack of pollinators. The extremely poor fruit and seed set is almost certainly due to the plants own malfunctioning reproductive system and is not limited by external factors. Further research on this topic appears warranted.

CHAPTER FOUR

RESPONSES TO FIRE

4.1 Introduction

Burnt vegetation is a common feature of the south-west Australian landscape. The flora shows a wide range of strategies for survival after fire (Carlquist, 1974; Bell *et al.*, 1984). Lateritic heathlands, in particular, are prone to fire under natural conditions (Gardner, 1957), usually from lightning strikes. Aboriginal man deliberately burnt large tracts of land for food gathering purposes and this is thought to have had a considerable effect on much of the Australian vegetation (Hallam, 1975). Since the arrival of European man, fires have tended to be more destructive (Beard, 1976).

Fire-associated traits of the flora include high flammability due to essential oils and morphological modifications such as thick bark, lignotubers with dormant buds, fruit opening in response to fire and hard seeds which accumulate in soil and germinate only after fire (Christensen and Kimber, 1975). In the genus *Banksia* the seed is retained in woody follicles. In most taxa (78%) the follicles only open in response to fire (serotiny) and several other taxa are partially serotinous (George, 1981). The follicles rupture when resin joining the valves melts during the fire allowing the valves to reflex (Wardrop, 1983). For some species wet-dry cycles are necessary for the valves to reflex sufficiently to release the seed (Gill, 1976; Cowling and Lamont, 1985). The retention of floral remnants by some species is thought to aid combustion of the infructescence (Lamont and

Cowling, 1984).

Many *Banksia* species (51%) are killed by fire (George, 1981) and they subsequently re-establish themselves through seed release. Other *Banksia* species are capable of producing shoots after fire from lignotubers (lignotuberous shoots), the trunk (epicormic shoots) or both. Soil temperatures several centimetres below the surface are considerably lower than surface temperatures (Beadle, 1940) and thus the soil provides an effective insulation for underground storage organs. Thick bark can protect epicormic buds from fire. *B. elegans* has the additional capacity to produce suckers from lateral roots (George, 1981).

Fire can be used as an inexpensive management tool (Gill, 1977). For the effective management of a plant species for conservation purposes, however, it is necessary to know the pattern of responses to fire displayed by that species. Appropriate prescribed burns can help to augment static or declining populations (Christensen and Kimber, 1975) while wildfires or prescribed burns of an unsuitable intensity, frequency or season can reduce, or in some cases eliminate (McMahon, 1984a; Cowling and Lamont, 1984; Gill and Groves, 1981), populations of some plant species. In South Africa, management programmes have been necessary for rare species under pressure from unsuitable fire regimes and they have produced some encouraging results (Moll and Gubb, 1981; Boucher, 1981). This chapter examines the fire responses of each species with a view to formulating a suitable fire management regime for each.

4.2 Materials and Methods

Due to the limited time available, the uncertain effects of fire on populations of each rare species and administrative problems in obtaining permission to deliberately burn gazetted rare species, no trial burns were conducted. No populations of *Banksia chamaephyton* showed evidence of recent (<5 years) fires and the investigation into that species centred on the response of the infructescence to fire through experimental work in the laboratory. Several populations of *B. elegans* with a known fire history were selected for study.

The level of serotiny in *B. chamaephyton* and *B. elegans* was determined by counting the number of closed and open unburnt follicles at representative sites (south of Badgingarra (15) and Lake Logue (24) respectively). Each population was checked for the presence of seedlings and other fire-associated characteristics of each species were examined.

Ten *B. chamaephyton* infructescences were collected from Badgingarra Agricultural Research Station (14) and tested for:

i) the flame temperature and length of exposure to flames required to rupture follicles; and

ii) the extent of seed release from burnt follicles with and without regular wetting.

The temperature required to rupture follicles was assessed by exposing the follicles to a flame from a bunsen burner and measuring the temperature beside the follicle with a digital pyrometer. The follicles were regarded as ruptured when the valves had visibly reflexed. This was usually signified by a faint click which indicated that the resin at the junction of the valves had been destroyed (Wardrop, 1983). At that point, the temperature and the length of exposure to the flame were recorded. Observations were also made on the role of the persistent florets of B. chamaephyton in the combustion of the infructescence.

The response of ruptured follicles to regular wetting was tested by burning ten infructescences in the manner described above. All infructescences were then maintained on a tray of sand at 20°C. At weekly intervals, five of the infructescences (with a total of 33 follicles) were momentarily immersed in water and allowed to dry on the tray. The remaining five infructescences (38 follicles) were not immersed. The seed release from each infructescence was recorded over time.

For B. elegans, two locations were selected to assess the extent of vegetative regrowth and the recruitment of root suckers after fire. The recovery of plants existing prior to the fire was examined at Beharra Spring (23) which was burnt in January, 1984. Field work was conducted in July 1984. In a plot of approximately 1 ha, the number of plants in each of several post-fire categories was recorded. The categories were:

i) no regrowth (killed by fire);

ii) regrowth from the lignotuber only; and

iii) regrowth from the lignotuber and the trunk.

The trunk diameter at 30 cm of twenty randomly selected plants in each of the above categories was also recorded.

The recruitment of new suckers following fire in B. elegans was assessed at Lake Indoon (26) which was burnt in December, 1982. Field work was conducted in July, 1984. A plot, 20 m x 10 m, was established in the burnt area. Another plot of the same dimensions was established in a small area at the same location which had not been burnt for at least ten years judging by the accumulation of leaf litter and the absence of fire scars. The occurrence of root suckers stimulated by fire was assessed by counting the number of immature suckers (all new growth, no lignotuberous swellings) and the number of more mature plants (none or only some new growth, lignotuberous swellings).

At Lake Arrowsmith (22), burnt January 1984, and Lake Indoon (26), the lateral root systems of several B. elegans plants of varying sizes were excavated in July, 1984. Maps were drawn showing the location of lateral roots and the occurrence of suckers. The number of suckers per 'parent' plant and per metre of lateral root were calculated. The heights of all plants were recorded and the tallest plant of the genet with the largest lignotuber was regarded as the 'parent' plant and all others as suckers derived from the 'parent' plant.

4.3 Results

In *B. chamaephyton*, only five of 321 follicles (1.6%) were open on representative unburnt infructescences south of Badgingarra (15). Infructescences with open follicles appeared to be older than those without any open follicles. Similarly, only 26 of 1,494 *B. elegans* follicles (1.7%) had opened on unburnt infructescences at Lake Logue (24). No seedlings were observed in any population of either species. The floral remnants of *B. chamaephyton* infructescences were not deciduous although there appeared to be a gradual loss over time. *B. elegans* consistently lost its floral parts soon after flowering. *B. elegans* also drops its older leaves which accumulate around the base of the trunk. The trunk of a fallen *B. elegans* near Walkaway (19) was cut to determine the bark thickness. The trunk had a radius of 42 mm and a bark thickness of 17 mm (40.5%).

The temperature beside *B. chamaephyton* follicles at the point of rupture was 660.7 ± 69.3°C (n = 10). Rupture occurred after a mean of 18.1 seconds exposure to the flame. The persistent florets did not appear to assist in the combustion of the infructescence.

Ruptured *B. chamaephyton* follicles which were immersed in water at weekly intervals had reflexed sufficiently to release 64% of their seed after 10 weeks. Burnt infructescences with ruptured follicles which had not been immersed in water had released no seed after 10 weeks.

Almost all *B. elegans* plants burnt at Beharra Spring regenerated from lignotubers with some also producing epicormic shoots from the trunk (Figure 4.1). Burnt infructescences were rarely observed and appeared to be destroyed by fire. Only a small number of plants (2.1%) were killed. Plants killed were small (trunk diameter <1.4 cm) while plants resprouting from the trunk and lignotuber were larger (diameter 5.6-8.0 cm) than those resprouting only from the lignotuber (diameter 2.2-4.6 cm). Regrowth of B. elegans, six months after fire, is shown in Plate 4.1.

The number of immature suckers and more mature plants occurring in two plots at Lake Indoon is shown in Table 4.1. Eighteen months after fire 63% of the plants were immature suckers. No immature suckers occurred in the plot not burnt for at least 10 years. A similar, but less vigorous, response was observed in plants not affected by fire but occurring in disturbed areas such as firebreaks. No seedlings were observed at any of the sites.

Maps showing the lateral roots and the occurrence of suckers in B. elegans at Lake Arrowsmith and Lake Indoon are given in Figure 4.2. A summary of the data is given in Table 4.2. Lateral roots occurred 5-10 cm below the soil surface. Immature suckers at Lake Arrowsmith (plants 1-3) had not broken the soil surface six months after fire (Plate 4.2) but at Lake Indoon (plants 4-6) they had reached a mean height of 62 cm above the lateral root 18 months after fire. Suckers occurring near the 'parent' plant were not significantly taller (ANOVA) than suckers occurring further away. The number of suckers per 10 m of lateral root ranged from 2.5 (plant 2) to 9.5 (plant 5). As suckers matured a lignotuberous swelling formed (Plate 4.3).

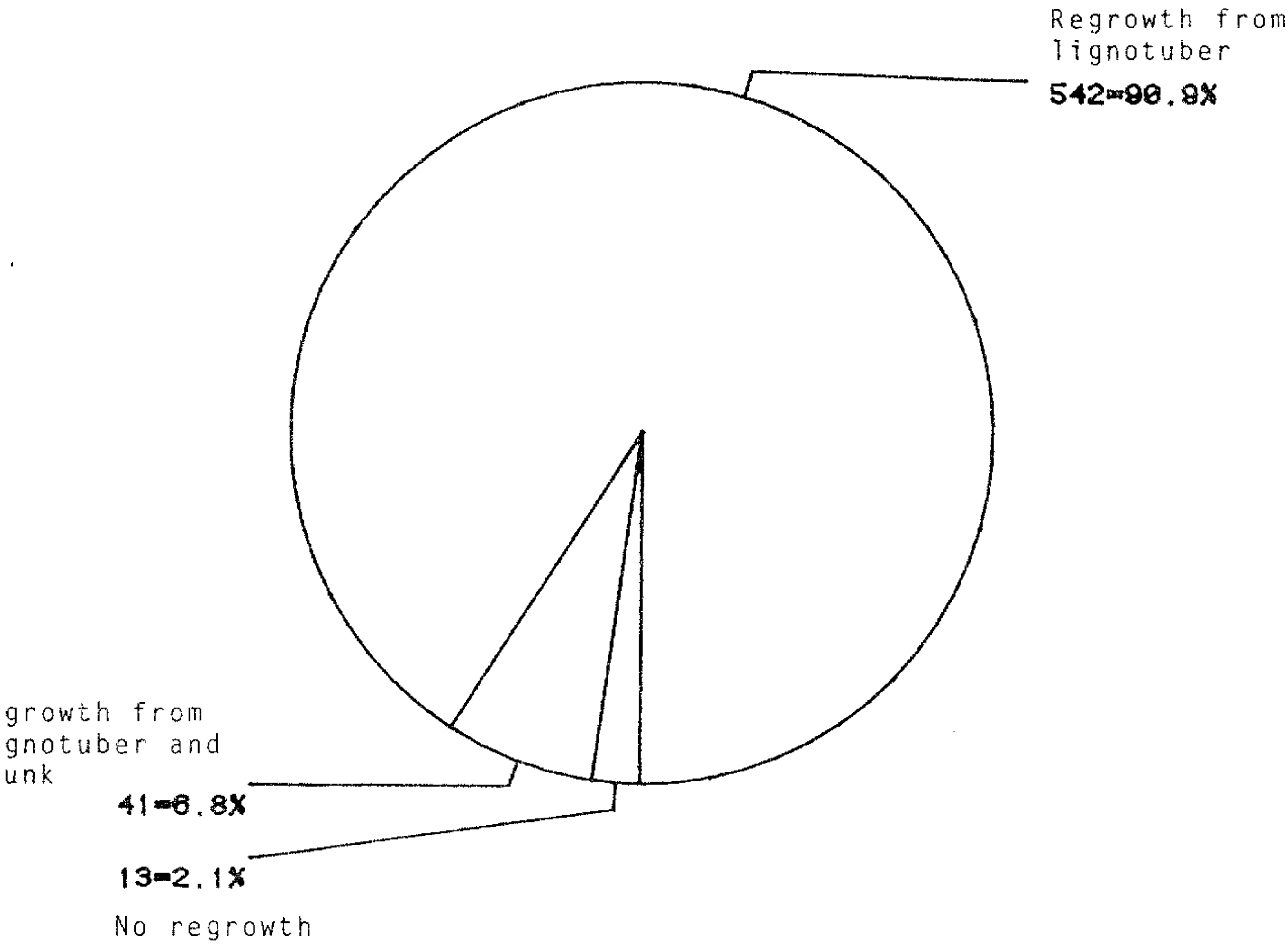


Figure 4.1: Response of Banksia elegans six months after fire at Beharra Spring (n = 596 plants).

(a)

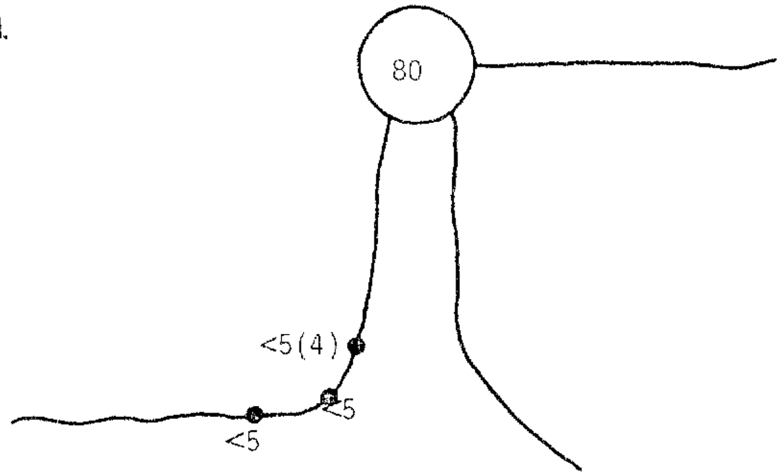
(b)

Plate 4.1: Regrowth six months after fire at Lake Arrowsmith. (a) *Acacia* sp. and *Actinostrobus arenarius* killed but *Banksia elegans* is recovering. *Acacia* sp. seedlings also present. (b) Lignotuberous (L) and epicormic (E) regrowth in *B. elegans*.

Table 4.1: The number of mature plants and the number of immature suckers of Banksia elegans occurring in two plots with different fire histories at Lake Indoon.

Years since fire	No. of mature plants	%	No. of immature suckers	%
1.5	52	37	90	63
10.0+	27	100	0	0

1.



2.

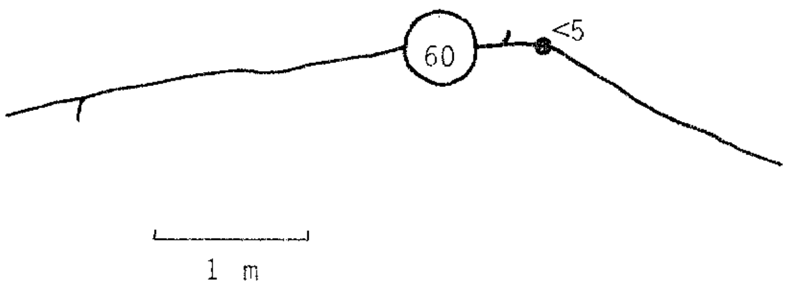


Figure 4.2: Maps of the lateral root systems of six _Banksia elegans_ plants at locations 22 (plants 1-3) and 26 (plants (4-6). Key to symbols:

= 'Parent' or mature sucker with lignotuber. Circle diameter corresponds to width of lignotuber. Figure in centre is height (cm).

5(4) = Sucker with height (cm). Figure in brackets indicates a number of suckers occurring together.

3.

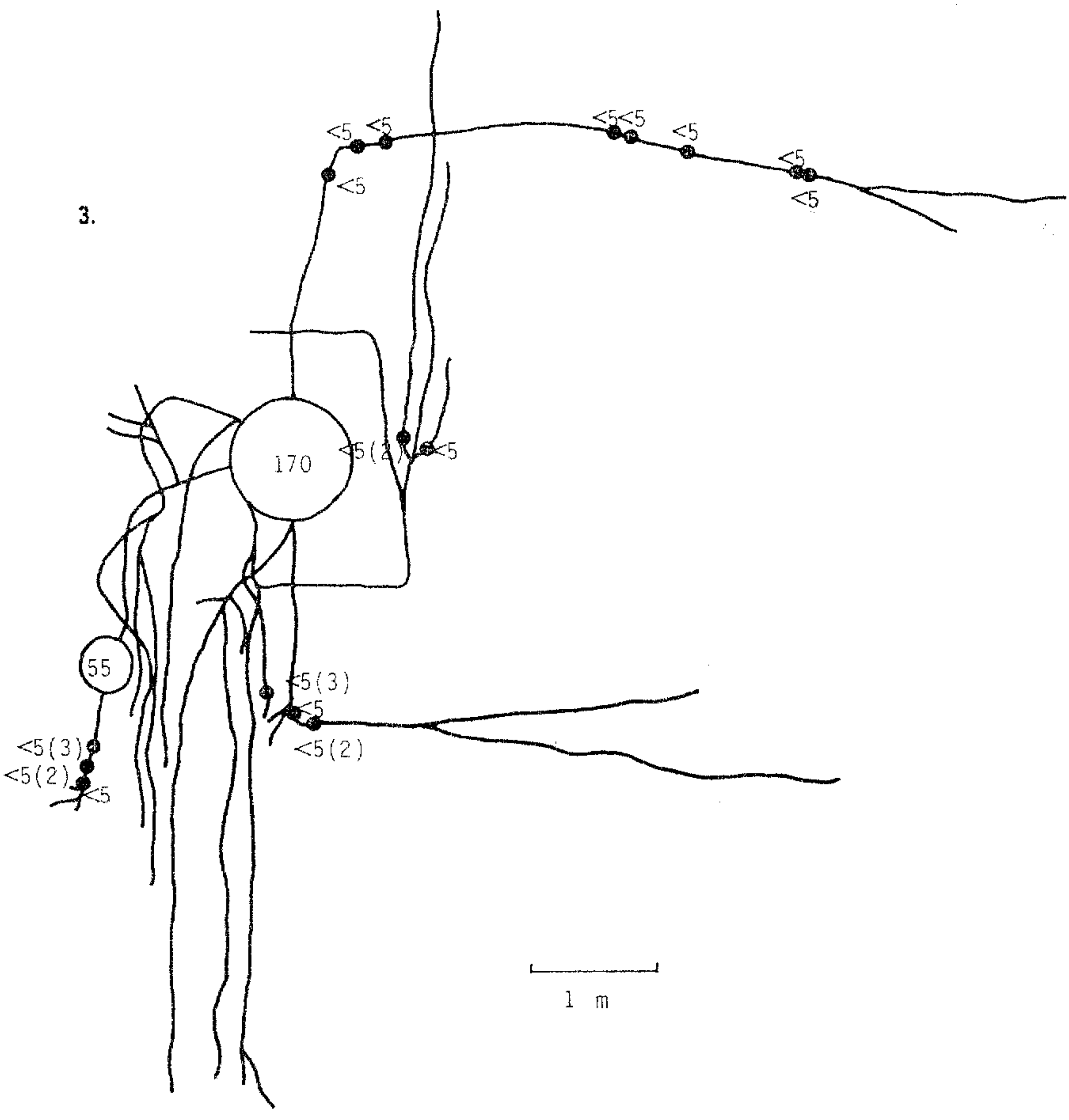


Fig. 4.2 (cont.)

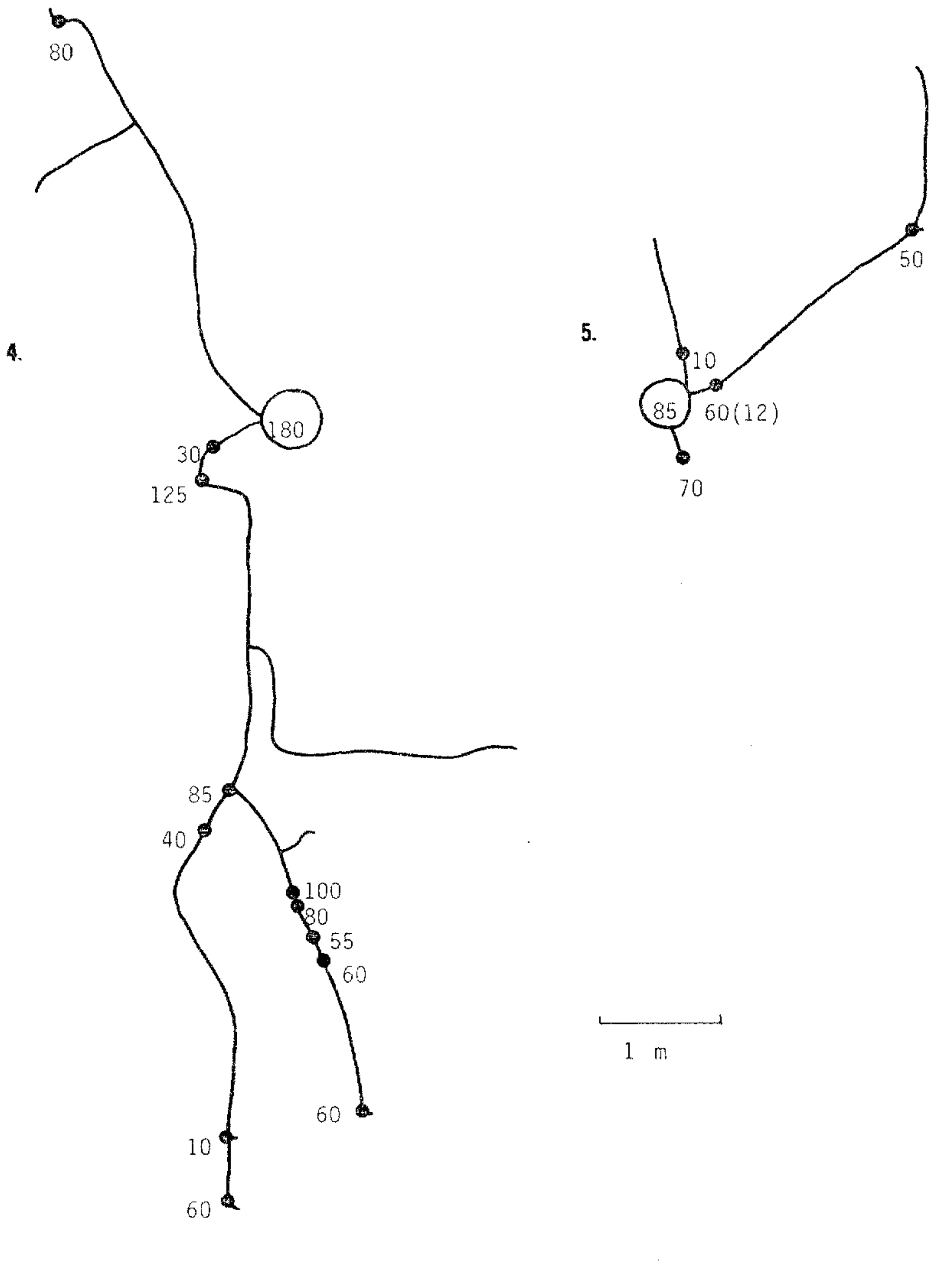


Fig. 4.2 (cont.)


70
60
75
80
10(10)
50
30
105
50
20
70
50
220
35
40
100(2)
50
55
30(10)
10
40(2)
1 m

? (cont.)

Table 4.2: Length of lateral roots and occurrence of suckers in _Banksia elegans_ at Lake Arrowsmith (plants 1-3) and Lake Indoon (plants 4-6).

Plant No.	Total length of lateral roots	No. of suckers	Suckers/ 10 m lateral root	Mean distance from 'parent' plant (m)
1	8.7	6	6.9	1.7
2	4.0	1	2.5	0.5
3	56.5	24	4.2	2.7
4	17.6	12	6.8	4.0
5	4.2	4	9.5	0.9
6	66.8	41	6.1	2.8

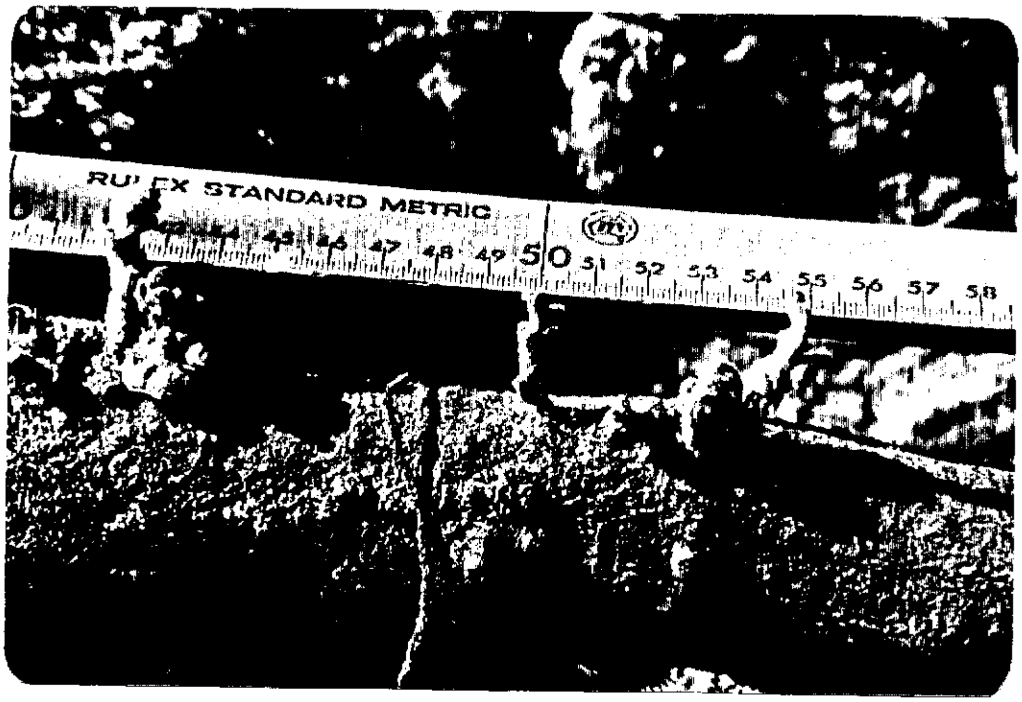


Plate 4.2: Excavation of lateral root of Banksia elegans at Lake Arrowsmith six months after fire. The young suckers were still below the soil surface.

Plate 4.3: Excavation of lateral root of Banksia elegans at Lake Arrowsmith six months after fire. Sucker is regenerating from lignotuberous swelling on lateral root.

4.4 Discussion

Both species are highly serotinous. The limited seed release that does occur in the absence of fire may be a response to predation of the infructescence or death of the plant. Similarly, Gill (1976) found *Banksia ornata* released about 1% of its seed from living, unburnt plants. Seed release in that species is slightly greater in senescing plants (Gill, 1976; Specht *et al.*, 1958).

Seed release in *B. chamaephyton* is not only dependent on fire but also on a subsequent series of wet/dry cycles. Cowling and Lamont (1985) found a similar response in four other *Banksia* species and in *B. leptophylla* noted that temperature was an important factor. The rate of seed release increased as the temperature was lowered from 30 to 15°C. Seed release in *B. chamaephyton*, therefore, is likely to occur at a time independent of time of the fire, as the valves will only reflex sufficiently when conditions are moist and temperatures lower. This would correspond to late autumn or early winter, an ideal time for seedling establishment.

George (1981) records *B. chamaephyton* as able to recover after fire from "epicormic shoots from (the) lignotuber". The lignotuber and rhizomes are insulated from the high temperatures during a fire by the soil. Although no burnt plants were observed in this study several populations were affected by clearing for road verges or agriculture. This involved the above ground removal of vegetation without significant soil disturbance. *B. chamaephyton* regenerated readily after this form of disturbance (Plate 4.4) and fire could be expected to produce a comparable response (Zammit, 1984).

Plate 4.4: Regeneration of Banksia chamaephyton at the Associated Minerals Consolidated lease following the above ground removal of vegetation for a firebreak. Rust coloured leaves are new growth.

The seeding and regenerating characteristics of *B. chamaephyton* suggest that it may be classified as an autoregenerating, long-lived resprouter (Bell *et al.*, 1984). Features of these plants include limited seed production and slow growing seedlings but high success rates in self replacement of their individuals. This fire response strategy is common among Proteaceae in the northern sandplains (Bell *et al.*, 1984).

B. elegans may be classified as an obligate vegetatively-reproducing sprouter (Bell *et al.*, 1984). The species showed a strong regenerative capacity after fire. Most plants recover well although the form of recovery, and the recovery itself, is dependent on the size of the plant. Fire stimulates the growth of new root suckers but seedling recruitment was never observed. Epicormic buds in the trunk of *B. elegans* are well insulated from fire by thick bark in larger plants and buds in the lignotuber and lateral roots are protected by the soil. The suckering habit is rare in the genus with only *B. marginata* and *B. integrifolia*, endemic to eastern Australia, possessing this ability (George, 1981). *B. marginata* also reproduces only rarely from seed but readily produces suckers in response to fire (Specht *et al.*, 1958).

Fire management programmes may be formulated by determining the most suitable season and frequency for each species. Season is critical to achieve the optimal recruitment. In *B. chamaephyton*, seed germination and seedling survival is likely to be greater under moist, cool conditions. The seed of most *Banksia* species do not require a period of dormancy prior to germination (George, 1981; pers. obs.). Seeds left exposed on the ground without germination will soon lose viability (Cowling and Lamont, 1985) and the likelihood of their loss through decay or predation is increased (Bond, 1984). For maximum seedling recruitment an autumn burning programme has been recommended for other Banksia species (Cowling and Lamont, 1984; Bradstock and Myerscough, 1981) and members of the South African Proteaceae (Bond et al., 1984). For B. chamaephyton, a spring burn may be followed by sufficient rainfall to allow seed release but the ensuing dry, hot summer would be a poor environment for seed germination and seedling growth. Furthermore, seedling predation by invertebrates can be minimised by avoiding the burning of small areas only (Whelan and Main, 1979). Fire season may be less crucial to B. elegans as seedling recruitment is negligible. However, the rate of vegetative regeneration is likely to be optimised when moisture availability is high.

Fire intervals should be longer than the primary juvenile period but shorter than the life span (Gill and Groves, 1981). The "natural" fire frequency of the Badgingarra area is every 8-15 years (van der Moezel, 1981). For fire to be conducive to population growth in B. chamaephyton, the interval must be sufficient to permit the commencement of flowering in new plants (up to 8 years after germination - George, 1984), seed maturation (2 years - Chapter Three) and the accumulation of adequate seed reserves. Cowling and Lamont (1984) found seed in infructescences up to 9 years old to form an important part of the overall seed reserves of two resprouting Banksia species. Some seed will be produced by regenerating plants which may recommence flowering one or two years after fire (Bell et al., 1984). The minimum fire interval for B. chamaephyton, therefore, would be four years, allowing for the recommencement of flowering in existing plants and the maturation of seed from the initial flowering. Any interval less than four years would probably reduce the population as weaker plants may be killed and no new plants could be initiated. Intervals of 10 years or more would probably result in an increase in the population given suitable conditions for seedling growth.

In *B. elegans*, suckers stimulated by fire would require several years in order to form a lignotuber and considerably longer to acquire a trunk from which epicormic shoots could emerge. Too frequent fires could exhaust the dormant bud reservoir (Christensen and Kimber, 1975). An interval of 10 years or more should allow *B. elegans* suckers sufficient time to form a lignotuberous swelling and resist further fires.

In either species, long intervals without fire would decrease growth rates and possibly seed set and diminish rates of recovery when fire does eventually occur (Bond, 1980). As plants senesce they may be replaced by other species resulting in irreversible changes to the communities in which each species occurs.

Given a suitable fire regime for each *Banksia* species, it should be borne in mind that any particular regime which favours one species may be deleterious to another (Gill, 1977). Van der Moezel (1981) proposed a policy of controlled burning in a mosaic pattern at intervals which simulate the "natural" fire frequency of an area.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Banksia chamaephyton

Banksia chamaephyton occurs in low heath in sand over laterite. The species has a range of 140 km with most populations occurring in the Tathra and Le Sueur Systems of the Irwin Botanical District. The region is not well known botanically and *B. chamaephyton* appears to be more widespread than herbarium collections and recorded observations had previously indicated.

Though many plants have undoubtedly been lost through clearing for agriculture, 18 populations of varying size were located in this study. The species is well represented in Alexander Morrison National Park. A number of other populations, however, are not secure as they occur on road verges which may become degraded over time through physical disturbance or weed incursion. The two most southern populations are isolated from all other known populations and both are vulnerable. The species is not affected by the wildflower trade.

Further locations with populations of *B. chamaephyton*, or suitable alternative sites, may be identified by using other species which are indicative of the ecosystem in which *B. chamaephyton* occurs. Suggested indicator species are given.

B. chamaephyton appears to be xenogamous and is probably bird-pollinated although small mammals may also play a role. Invertebrates do not appear to play any direct role in pollination. Fruit set is very low but varies considerably between populations. As rainfall decreases with increasing longitude, more infructescences are barren. Seed viability, however, is high and is not subject to the extensive predation which occurs in other Banksia species.

B. chamaephyton infructescences retain almost all their seed until burnt. Thereafter, seed is not released until completion of a series of wet/dry cycles. Seedling recruitment is likely to be optimised by an autumn burn which would ensure release of seed under conditions suitable for germination and establishment. Fire intervals of four years or less would probably decrease population size. Only intervals of ten years or more are likely to result in a population increase while total absence of fire is likely to be detrimental to population size.

With respect to B. chamaephyton, the following recommendations are made:

1. Conservation Status.

The legislative protection currently given to B. chamaephyton should be maintained. The species still fulfils the criteria necessary for gazettal and the authorities responsible for its management would retain control over all populations. The legislation is flexible in that permits may be granted to take or destroy the species while individual populations which are of particular importance, such as those which are geographically isolated, may be protected.

Although the species is reasonably well represented in areas set aside for conservation towards the north of its range, some populations to the south are vulnerable. Their loss would considerably reduce the range of the species and possibly reduce the gene pool.

2. Fire Management.

A fire regime of autumn burning at a minimum interval of ten years should be instituted. This is the recommended regime for B. chamaephyton only as the adoption of any particular regime will affect the numbers of individuals of other species occurring at the same site.

5.2 Banksia elegans

B. elegans occurs in scrub or thickets in deep, yellow sands and usually near lakes or winter-wet depressions. The species has a range of 130 km and predominantly occurs in the Eridoon System of the Irwin Botanical District. This study located 11 populations, two of which occurred in flora and fauna reserves and one in a national park. Most populations were relatively undisturbed but the two northernmost were severely affected by clearing for agriculture. These populations have larger inflorescences than other populations. No flower or foliage harvesting for the wildflower trade was evident, but seed is sought because of its rarity.

Fruit and seed set is extremely poor in B. elegans. Most of the populations had only barren infructesences. In those populations which did produce follicles, almost 90% of the seed was aborted. The inflorescences are visited by several bird species and the

White-cheeked Honeyeater (*Phylidonyris nigra*) was found to carry comparatively high pollen loads of *B. elegans*. However, the stigma appears to be malformed in most florets and this is likely to be the cause of the poor seed set. The malformed stigma is probably a symptom of a genetic aberration. Another unusual feature is the pollen-presenter which is covered with glands and the pollen is viscous. The function of the glands, however, is not clear.

B. elegans is serotinous but seedling recruitment after fire, or at any other time, is negligible. After fire, most plants recover by resprouting from the lignotuber and larger plants also resprout from the trunk. In addition, lateral roots produce suckers in response to fire. Due to the lack of seedling recruitment, the fire regime is less crucial than in *B. chamaephyton*. However, vegetative regrowth is likely to be optimised by autumn burning at intervals of not less than ten years, while little regeneration occurs in the absence of fire.

With respect to *B. elegans*, the following recommendations are made:

1. Conservation Status.

Gazettal of *B. elegans* as a rare species should be considered. The species is not well represented in areas set aside for conservation although it may be reasonably common at other locations. Gazettal would give the authorities control over populations of special interest while allowing some flexibility in the management of the species as a whole. In particular, there is a need to conserve a population towards the northern extremity of the range of the species. These plants appear to represent a size variant within the species and are extremely vulnerable.

2. Fire Management.

A fire regime of autumn burning at minimum intervals of ten years should be instituted although this is more flexible than in other Banksia species because of its ability to regenerate vegetatively and the negligible seedling recruitment.

3. Future Research.

Further research should be conducted into sexual reproduction in the species. Fruit and seed set are abnormally low in relation to other members of the genus. Future research should focus on aspects of the genetics and breeding system of the species which could lead to abnormal sexual reproduction.

Alternative methods of propagating the species should be further investigated. Although some success with cuttings and grafts has been achieved to date, a reliable method for the production of plants in numbers is required.

5.3 General Comments

Two points have come to light during the course of the study which have a bearing on future studies of rare species. The first is the recording of locality data on herbarium records. Some relatively recent collections viewed by the author had very imprecise location data. It is important that precise locations be given wherever possible. Even if no other data is recorded, the population can at least be located again on a subsequent visit.

Secondly, it was also evident that the knowledge of flora occurring in national parks and reserves in the Irwin Botanical District is poor. This impedes the identification of the species which are the most vulnerable and in need of conservation. A knowledge of the flora in areas set aside for conservation would give a sound basis for decision-making about the conservation requirements of individual species. While acknowledging the limited resources of the relevant government authorities, greater use could be made of the staff and students of tertiary institutions and interested private organisations and individuals.

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APPENDIX ONE

Herbarium specimens of *Banksia chamaephyton* and *B. elegans*

Source abbreviations: WAH (Western Australian Herbarium), KPH (Kings Park Herbarium) and UWA (University of Western Australia Herbarium). Records obtained from Griffin (1981) were not present in the herbaria visited.

Location	Comments	Collector	Date	Source
1. *Banksia chamaephyton*:				
West of Winchester		C. Chapman	22.11.70	WAH
± 30 miles west of of Winchester on Green Head Rd.		C. Chapman	Dec. 1970	WAH
W. Coorow reserve	Sand heath, gravel under	A.S. George 11190	14.11.71	WAH
15 miles east of Mt. Peron		F.A. Grigson 9435	26.09.49	WAH
20 km south of Eneabba	White sand heath	P. Armstrong 89	16.09.79	WAH
Western Titanium leases, 7 km south of Eneabba	Low open heath, shallow white sand over laterite	E.A. Griffin 975	03.08.77	WAH
Badgingarra, west of Research Station		C.A. Gardner	19.01.62	WAH
5 miles west of Mogumber townsite	Sand over laterite, in low heath	A.S. George 11204	15.11.71	WAH
Mogumber district	Low heath, sandplain	I.R. Dixon S4803	01.11.82	KPH
Moore River Mission Station		N.H. Brittan	August 1958	UWA
Mogumber, near mission	Gravel, low scrub	A.S. George 6201	12.04.64	Griffin (1981)
2 km north of Coorow-Green Head Rd., along Willis Rd.		A.S. George	27.03.77	Griffin (1981)

Location	Comments	Collector	Date	Source
McNamara Rd., Badgingarra	White sand, laterite gravel	R.J. Cranfield 107	19.07.78	Griffin (1981)
Badgingarra	Lateritic sand	A.S. George 2345A	25.04.61	Griffin (1981)

2. Banksia elegans:

Location	Comments	Collector	Date	Source
Lake Indoon, north shore	Gentle southern slope above lake. Sand. Fringing woodland. Rare.	B. Barnsley 888	24.01.79	WAH
Diamond Spring, north of Hill River	Scrub heath	H. Steedman	Dec. 1935	WAH
Near Diamond Springs	Sand	K. Newbey 2385	08.01.66	WAH
7 m W of Geraldton Hwy., at a point 9 m N of Dongara	Scrub heath	J.S. Beard 7225	31.10.74	WAH
0.5 km N of Lake Indoon	Low woodland. Yellow sand.	E.A. Griffin 622	14.10.76	WAH
N of Arrowsmith Lake		A.S. George 9775	16.10.69	WAH
Nr. Lake Indoon	Sand	A.S. George 11192	14.11.71	WAH
Greenough River		Ferd. von Mueller	Nov. 1877	WAH
Diamond of the Desert Spring nr. Mt. Peron		C.A. Gardner	Jan. 1940	WAH
Property of E. Hamersly, Walkaway	Sand plain	A.C. Burns 27	07.10.77	WAH
Vicinity of Three Springs		C.A. Gardner 12075	10.01.59	WAH
34 km N of Eneabba on Brand Hwy.	Heath dominated by Banksia hookerana on yellow sand plain.	A. Strid 20871	11.10.82	WAH

Location	Comments	Collector	Date	Source
Three Springs, near Diamond of the Desert Springs	Red sand	C.A. Gardner 8486	16.10.46	WAH
Three Springs		C.A. Gardner 9385	25.08.44	WAH
4 m past Eneabba on Three Springs-Eneabba Rd. down side road near lake		Mrs ? Theak S382	12.02.68	KPH
40 m S of Dongara		F. Lullfitz L4366	03.11.65	KPH
Lake, Eneabba		H. Demarz D174	29.05.68	KPH
Lake Indoon		B.M.J. Hussey	07.04.74	Griffin (1981)
Arrowsmith, S of Dongara		E. Humphreys	Sept. 1970	Griffin (1981)

APPENDIX TWO

Locations of sites with Banksia chamaephyton (site reference no's. 1-18) and B. elegans (19-29) examined in this study.

Site Ref. No.	Location	Latitude S	Longitude E
1	On Eneabba-Carnamah Road, 1.2 km east of Road 36, south side of road and adjacent to Tathra National Park.	29°48'	115°32'
2	On Associated Minerals Consolidated mining lease, Eneabba, 500 m east of nursery.	29°51'	115°17'
3	On Willmott Road, 7.8 km east of Willis Road, on north side of road.	29°57'	115°37'
4	On Brand Highway, 8.8 km north of Brand Highway-Green Head Road intersection, near parking bay and on both sides of road.	29°59'	115°18'
5	On Willis Road, 2.0 km north of Green Head-Coorow Road, on west side of road.	30°02'	115°32'
6	On Green Head-Coorow Road, 200 m west of Clarke Road, on north side of road.	30°04'	115°38'
7	100 m north of Green Head-Coorow Road, 4.6 km east of Willis Road.	30°04'	115°36'
8	On Green Head-Coorow Road, 100 m west of Willis Road, on south side of road.	30°04'	115°32'
9	On Green Head-Coorow Road, 2.0 km west of Willis Road, on south side of road.	30°03'	115°31'
10	Property of D. and J. Williams, Tootbardi Road.	30°06'	115°25'
11	On Brand Highway, 11.8 km north of Jurien Bay Road, on eastern side of road.	30°07'	115°22'
12	On Tootbardi Road, 1.2 km east of Brand Highway, on both sides of road.	30°08'	115°23'
13	On Jurien Bay Road, 1.0 km west of Brand Highway, on both sides of road.	30°13'	115°23'
14	Badgingarra Agricultural Research Station, 50 m south of intersection of Watheroo and McKays Roads.	30°19'	115°32'
15	100 m west of Brand Highway, 20 km south of Badgingarra.	30°31'	115°27'

Site Ref. No.	Location	Latitude S	Longitude E
16	On Wongonderrah Road, 3.6 km west of Brand Highway, on south side of road.	30°33'	115°25'
17	Entrance to Mogumber Mission, 1.0 km north of Mogumber West Road.	31°00'	115°56'
18	On Mogumber West Road, 9.0 km west of Mogumber on south side of road.	31°01'	115°57'
19	Property of Mrs E. Hamersly, "The Dale", Walkaway.	28°58'	114°49'
20	On Mt. Horner West Road, 11.0 km east of Brand Highway, on south side of road.	29°07'	115°01'
21	On Mt. Adams Road, 6.7 km east of Brand Highway, on both sides of road.	29°24'	115°06'
22	At Lake Arrowsmith, 200 m east of Brand Highway and south of lake.	29°33'	115°05'
23	100 m north of Beharra Spring.	29°33'	115°09'
24	On Leeman Road, 12.0 km west of Brand Highway, near Lake Logue.	29°51'	115°09'
25	500 m north of entrance to Lake Indoon.	29°51'	115°10'
26	Entrance to Lake Indoon.	29°52'	115°10'
27	200 m west of Yanget Lake.	29°54'	115°08'
28	500 m west of Green Lake.	29°56'	115°07'
29	100 m east of Diamond of the Desert Spring.	30°07'	115°06'

APPENDIX THREE

The sources of locality data for sites with Banksia chamaephyton (site ref. no's. 1-18) and B. elegans (19-29).

Site Ref. No.	Source			
	Herbarium specimen	Personal communication	Publication	Field Work this study
1				April 1984
2	Griffin 975	D. Brooks		
3			Griffin (1981)	
4	Armstrong 89			
5	George			
6)		B. Lamont		
7)				September 1984
)	Chapman (2)			
8)				April 1985
9)				September 1984
10	Grigson 9435	E. Griffin		
11		B. Lamont		
12				September 1984
13		S. van Leeuwen		
14	Gardner			
15			van der Moezel(1981)	
16			Beard (1979a)	
17	(Brittan (George 6201			
18	George 11204			
19	Burns 27			
20	Beard 7225			
21		R. Cowling		
22	(George 9775 (Strid 20871 (Lullfitz L4366 (Humphreys			

Site Ref. No.	Source			
	Herbarium specimen	Personal communication	Publication	Field Work this study
23		Mrs K. McQueen		
24				May 1984
25	Grifffin 622			
26	(Barnsley 888 (George 11192 (Demarz D174 (Hussey			
27			Griffin (1981)	
28			Griffin (1981)	
29	(Steedman (Newbey 2385 (Gardner			

APPENDIX FOUR

Description of vegetation, topography and soils at sites with Banksia chamaephyton (site reference no's. 1-18) and B. elegans (19-29).

Site Ref. No.	Vegetation	Topography	Soil			
			Stratum (cm)	Texture	Colour	pH
1	Low Heath C with Banksia candolleana and patches of Eucalyptus todtiana and Hakea obliqua	Near crest of rise on a gentle slope with a northern aspect	0-10 10-70 70+	Fine-coarse sand Very fine-coarse sand Laterite	Light grey (10YR 7/2) Pinkish white (7.5YR 8/2)	4.6 4.8
2	Low Heath D between Dryandra sp. aff. falcata on slope above and Hakea obliqua and slope below.	On gentle slope with a western aspect.	0-20 20-70 70+	Fine-coarse sand Fine-coarse sand Laterite	Light brownish grey (10YR 6/2) Light grey (10YR 7/2)	4.3 4.5
3	Low Heath C with Lambertia multiflora, Xanthorrhoea reflexa and Daviesia quadrilatera.	On gentle slope with a north-western aspect.	0-20 20+	Medium sand Laterite	Light grey (10YR 7/1)	4.6
4	Low Heath C with Lambertia multiflora, Banksia attenuata, Eucalyptus todtiana, Xanthorrhoea reflexa and Adenanthos cygnorum.	Near base of gentle undulation between two hills with eastern and western aspects.	0-40 40+	Medium-fine sand Laterite	Light grey (10YR 7/2)	4.4
5	Low Heath C with Lambertia multiflora and Adenanthos cygnorum interspersed with tall shrubs or small trees: Eucalyptus todtiana, Banksia menziesii and Xylomelum angustifolium.	Flat area between slight undulations.	0-15 15-70 70-100	Medium sand Medium sand Fine-medium sand	Light brownish grey (10YR 6/2) White (10YR 8/2) Very pale brown (10YR 8/4)	4.6 4.9 5.1
6	Low Heath C with Lambertia multiflora, Hakea obliqua and Daviesia quadrilatera.	Flat area between slight undulations.	0-15 15-50 50+	Fine-medium sand Fine-medium sand Laterite	Light grey (10YR 7/2) White (10YR 8/1)	4.6 4.5
7	Low Heath C with Banksia attenuata and Adenanthos cygnorum.	Very slight slope with a southern aspect.	0-10 10-55 55+	Medium sand Fine-medium sand Laterite	Light brownish grey (10YR 6/2) White (10YR 8/1)	4.4 4.5
8	Low Heath D with Lambertia multiflora and Banksia candolleana.	Very slight slope with a northern aspect.	0-10 10-55 55+	Medium sand Fine-medium sand Laterite	Light grey (10YR 7/2) White (10YR 8/1)	4.4 4.6
9	Low Heath C with Banksia candolleana, Xanthorrhoea reflexa interspersed with Eucalyptus todtiana.	Near top of rise on gentle slope with a south-western aspect.	0-20 20+	Medium-fine sand Laterite	Light grey (10YR 7/2)	4.5
10	Low Heath C with Dryandra sessilis, D. sp. aff. falcata and Xanthorrhoea reflexa with nearby stand of Eucalyptus pendens.	On top of steeply declining lateritic breakaway with an eastern aspect.	0-5 5+	Fine sand Laterite	Light brownish grey (2.5YR 6/2)	4.8
11	Low Heath C with Lambertia multiflora, Banksia incana and Dryandra sp. aff. falcata on upper slopes.	On slope with a western aspect below lateritic ridge.	0-10 10+	Fine-medium sand Laterite, occasionally outcropping.	Light brownish grey (10YR 6/2)	5.0
12	Low Heath C with Banksia candolleana and Lambertia multiflora.	On slope with northern aspect.	0-10 10-40 40+	Medium sand Medium-fine sand Laterite	Light brownish grey (10YR 6/2) Light grey (10YR 7/1)	4.5 5.0
13	Low Heath D with Lambertia multiflora and Xanthorrhoea reflexa.	Slight slope with a southern aspect below laterite outcrop.	0-10 10+	Medium sand Laterite	Grey (10YR 5/1)	4.8
14	Low Heath D with Lambertia multiflora.	Gentle slope with a northerly aspect.	0-10 10+	Fine-medium sand Laterite, occasionally outcropping.	Light grey (10YR 7/1)	4.0

Site Ref. No.	Vegetation	Topography	Soil			
			Stratum (cm)	Texture	Colour	pH
15	Low Heath C with *Lambertia multiflora*.	Slope with eastern aspect.	0-15 15+	Medium sand Laterite	Pale brown (10YR 6/3)	4.5
16	Low Heath C with *Lambertia multiflora*, *Xanthorrhoea reflexa* and *Allocasuarina humilis*.	Very slight slope with a southern aspect.	0-5 5-40 40+	Fine-medium sand Fine-medium sand Laterite	Grey (10YR 5/1) Light grey (10YR 7/2)	4.7 4.6
17	Low Heath C with *Hakea prostrata*, *H. auriculata*, *Dryandra pteridifolia*, *Xanthorrhoea reflexa* and *Patersonia occidentalis*.	Gentle slope with a south-eastern aspect.	0-10 10+	Medium sand Laterite	Light grey (10YR 7/2)	4.6
18	Low Heath D with *Xanthorrhoea reflexa* and *Allocasuarina humilis*.	Slope with an eastern aspect.	0-15 15+	Fine-medium sand Laterite	Light brownish grey (10YR 6/2)	4.5
19	Thicket with *Banksia elegans*, *B. attenuata* *B. menziesii* and *Acacia rostellifera*.	Base of slope with an easterly aspect.	0-20 20-100	Medium sand Medium coarse sand	Brown (7.5YR 5/2) Reddish yellow (7.5YR 6/5)	4.7 5.2
20	Scrub with *Banksia attenuata*, *B. prionotes* and *Grevillea* sp.	Flat plain	0-30 30-100	Medium sand Medium-fine sand	Grey (10YR 5/1) Very pale brown (10YR 7/3)	5.1 5.8
21	Heath B with *Banksia hookerana* and *B. attenuata*.	On a slight slope with a southerly aspect.	0-20 20-100	Medium-coarse sand Medium sand	Yellowish brown (10YR 5/4) Reddish yellow (7.5YR 6/6)	4.1 5.5
22	Thicket with *Banksia elegans*, *B. menziesii* and *B. attenuata*.	On a slight slope with a north-westerly aspect above a winter-wet depression.	0-10 10-30 30-100	Medium-coarse sand Medium-coarse sand Medium sand	Reddish grey (5YR 5/2) Pinkish grey (7.5YR 7/2) Pinkish white (7.5YR 8/2)	5.2 4.9 4.7
23	Scrub with *Banksia elegans*, *B. attenuata* *B. menziesii* and *Acacia* sp.	Gentle slope around a winter-wet depression.	0-10 10-60 60-100	Coarse-medium sand Coarse-medium sand Coarse-medium sand	Brown (7.5YR 5/2) Reddish yellow (5YR 6/6) Reddish yellow (7.5YR 7/6)	4.7 4.5 5.4
24	Dense thicket with *Acacia rostellifera*, *Banksia prionotes*, *B. attenuata* and *B. menziesii*.	Slight slope with a north-westerly aspect above lake.	0-5 5-20 20-100	Medium sand Medium sand Medium sand	Pale brown (10YR 6/3) Light grey (5YR 7/1) Very pale brown (10YR 8/4)	4.4 4.5 4.2
25	Scrub with *Banksia prionotes*, *B. elegans*, *Acacia rostellifera* and *Jacksonia sternbergiana*.	On slight slope with a northerly aspect above winter-wet depression.	0-10 10-100	Fine-very fine sand Fine-very fine sand	Grey (10YR 6/1) White (7.5YR)	4.8 5.0
26	Thicket with *Banksia elegans*, *B. menziesii*, *B. attenuata*, *Xanthorrhoea reflexa* and *Macrozamia riedlei*.	On slight slope with a north-easterly aspect near lake.	0-20 20-100	Medium-coarse sand Medium-coarse sand	Light yellowish brown (10YR 6/4) Yellow (10YR 7/6)	4.3 4.8
27	Scrub with *Banksia prionotes*, *B. attenuata* and *Xanthorrhoea reflexa*.	On gentle slope with an easterly aspect above winter-wet depression.	0-25 25-100	Coarse sand Coarse-medium sand	Yellowish brown (10YR 5/4) Yellow (10YR 7/8)	5.0 5.7
28	Scrub with *Banksia prionotes*, *B. attenuata* and *Jacksonia sternbergiana*.	On gentle slope with westerly aspect near lake.	0-25 25-100	Coarse sand Coarse sand	Pale brown (10YR 6/3) Yellow (10YR 7/6)	4.6 5.1
29	Thicket with *Banksia prionotes*, *B. menziesii*, *B. attenuata* and *Eucalyptus todtiana*.	On gentle slope with a westerly aspect near winter-wet depression.	0-20 20-100	Medium-coarse sand Medium sand	Grey (10YR 5/1) Light grey (10YR 7/1)	4.5 4.9

APPENDIX FIVE

Species co-occurring with *Banksia chamaephyton*

List of 217 species occurring in four plots around populations of *Banksia chamaephyton*. Ubiquity, absolute dissimilarity and inclusion values are given. The absolute dissimilarity values are based on the number of co-occurrences with *B. chamaephyton*. Authorities for species follow J.W. Green (1981).

Species	Ref. No.	Ubiquity	Absolute Dissimil- arity Value	Inclusion Value
CUPRESSACEAE				
Actinostrobus acuminatus Parl.	138	23	57	-2
POACEAE				
Amphipogon turbinatus R.Br.	101	4	52	3
Neurachne alopecuroidea R.Br.	181	1	53	2
CYPERACEAE				
Caustis dioica R.Br.	40	74	58	-3
Lepidosperma angustatum R.Br.	211	2	54	1
L. scabrum Nees	95	33	59	-4
Mesomelaena stygia (R.Br.) Nees	52	65	65	-10
M. tetragona (R.Br.) Benth.	46	71	57	-2
Schoenus sp. aff. *andrewsii* W.V. Fitzg.	201	3	49	6
S. caespititius W.V. Fitzg.	136	5	49	6
S. curvifolius (R.Br.) Benth.	50	19	53	2
S. sp. aff. *grandiflorus* (Nees) F. Muell.	179	21	57	-2
S. pedicellatus (R.Br.) Benth.	197	3	55	0
RESTIONACEAE				
Ecdeiocolea monostachya F. Muell.	67	21	65	-10
Lepidobolus chaetocephalus F. Muell.	47	30	66	-11
Loxocarya cinerea R.Br.	146	23	61	-6
L. fasciculata (R.Br.) Benth.	89	80	50	5
L. sp. nov.	160	27	51	4
Lyginia barbata R.Br.	51	81	63	-8
Restio sphacelatus R.Br.	183	13	57	-2
Sp. indet. 1	153	2	50	5
Sp. indet. 2	214	1	53	2
LILIACEAE				
Burchardia umbellata R.Br.	56	11	57	-2
Calectasia cyanea R.Br.	115	44	46	9
Dasypogon bromeliifolius R.Br.	122	7	53	2

Species	Ref. No.	Ubiquity	Absolute Dissimilarity Value	Inclusion Value
Johnsonia pubescens Lindl.	114	25	61	-6
Laxmannia omnifertilis Keighery	59	18	56	-1
Lomandra preissii (Endl.) Ewart	102	28	52	3
Thysanotus patersonii R.Br.	97	6	50	5
T. spiniger N.H. Brittan	33	21	61	-6
Xanthorrhoea reflexa Herbert	24	97	61	-6
HAEMODORACEAE				
Anigozanthos humilis Lindl.	85	3	49	6
Conostylis aculeata R.Br.	54	40	56	-1
C. aurea Lindl.	49	45	69	-14
C. crassinervia J.W. Green	187	30	62	-7
C. teretifolia J.W. Green	163	35	49	6
C. sp.	45	26	66	-11
Haemodorum paniculatum Lindl.	79	42	44	11
Macropidia fuliginosa (Hook.) Druce	106	29	53	2
ORCHIDACEAE				
Elythranthera brunonis (Endl.) George	209	1	53	2
Prasophyllum ?ovale Lindl.	83	1	51	4
P. sp. aff. parvifolium Lindl.	149	1	53	2
CASUARINACEAE				
Allocasuarina humilis (Otto et Dietr.) L. Johnson	66	77	53	2
A. microstachya (Miq.) L. Johnson	90	36	52	3
PROTEACEAE				
Adenanthos cygnorum Diels	120	7	57	-2
A. drummondii Meisn.	35	10	54	1
Banksia attenuata R.Br.	31	1	53	2
B. candolleana Meisn.	145	13	59	-4
B. chamaephyton A.S. George	1	52	-	-
B. grossa A.S. George	107	13	51	4
B. incana A.S. George	22	77	53	2
B. lanata A.S. George	94	2	52	3
B. micrantha A.S. George	203	11	55	0
Conospermum incurvum Lindl.	28	9	57	-2
C. nervosum Meisn.	159	43	55	0
C. triplinervium R.Br.	6	30	62	-7
Dryandra carlinioides Meisn.	180	8	50	5
D. sp. aff. falcata R.Br.	68	58	66	-11
D. kippistiana Meisn.	3	107	71	-16
D. nana Meisn.	132	51	45	10
D. nivea (Labill.) R.Br.	196	20	60	-5

Species	Ref. No.	Ubiquity	Absolute Dissim-ilarity Value	Inclusion Value
D. sp. aff. nivea (Labill.) R.Br.	121	12	50	5
D. shuttleworthiana Meisn.	23	4	54	1
D. subulata C.A. Gardner	158	48	60	-5
D. tridentata Meisn.	41	11	55	0
D. vestita (Kipp.) Meisn.	30	40	52	3
Grevillea synapheae R.Br.	109	31	37	18
Hakea auriculata Meisn.	4	30	54	1
H. baxteri R.Br.	74	35	57	-2
H. candolleana Meisn.	73	12	58	-3
H. cinerea R.Br.	216	1	53	2
H. conchifolia Hook.	75	71	49	6
H. corymbosa R.Br.	65	2	50	5
H. incrassata R.Br.	80	42	54	1
H. megalosperma Meisn.	125	3	50	5
H. obliqua R.Br.	205	4	54	1
H. smilacifolia Meisn.	188	18	56	-1
Isopogon adenanthoides Meisn.	117	54	58	-3
I. linearis Meisn.	63	73	57	-2
I. teretifolius R.Br.	178	2	52	3
Lambertia multiflora Lindl.	2	99	63	-8
Persoonia rudis Meisn.	70	19	53	2
P. ?rufiflora Meisn.	210	1	51	4
Petrophile brevifolia Lindl.	42	75	63	-8
P. drummondii Meisn.	5	38	54	1
P. macrostachya R.Br.	29	21	65	-10
P. serruriae R.Br.	176	20	62	-7
P. shuttleworthiana Meisn.	118	35	47	8
Stirlingia latifolia (R.Br.) Steud.	91	28	62	-7
Strangea cynanchicarpa F. Muell.	124	9	55	0
Synaphea polymorpha R.Br.	151	51	67	-12
SANTALACEAE				
Leptomeria empetriformis Miq.	154	20	58	-3
LAURACEAE				
Cassytha glabella R.Br.	87	26	56	-1
C. pubescens R.Br.	123	6	54	1
DROSERACEAE				
Drosera barbigera Planchon	116	12	46	9
D. leucoblasta Benth.	53	28	68	-13
D. macrophylla Lindl.	113	27	47	8
D. menziesii R.Br.	55	21	67	-12
D. stolonifera Endl.	62	52	50	5

Species	Ref. No.	Ubiquity	Absolute Dissim-ilarity Value	Inclusion Value
BYBLIDACEAE				
Byblis gigantea Lindl.	206	9	57	-2
LEGUMINOSAE (MIMOSOIDEAE)				
Acacia auronitens Lindl.	58	16	56	-1
A. sp. aff. *barbinervis* Benth.	202	8	58	-3
A. pulchella R.Br.	96	6	46	9
A. sphacelata Benth.	172	12	52	3
A. stenoptera Benth.	127	12	52	3
LEGUMINOSAE (CAESALPINIOIDEAE)				
Labichea punctata Benth.	128	19	49	6
LEGUMINOSAE (PAPILIONOIDEAE)				
Daviesia divaricata Benth.	13	4	56	-1
D. epiphylla Meisn.	137	6	50	5
D. juncea Sm.	39	12	60	-5
D. nudiflora Meisn.	18	43	51	4
D. pectinata Lindl.	86	23	61	-6
D. pedunculata Benth.	17	85	71	-16
D. quadrilatera Benth. ex. Lindl.	98	2	52	3
Gastrolobium bidens Meisn.	111	24	50	5
Gompholobium knightianum Lindl.	134	15	51	4
G. tomentosum Labill.	141	1	53	2
Hovea stricta Meisn.	15	31	53	2
Jacksonia floribunda Endl.	10	37	67	-12
J. restioides Meisn.	186	16	62	-7
Oxylobium capitatum Benth.	148	13	59	-4
O. reticulatum Meisn.	140	6	50	5
Sphaerolobium macranthum Meisn.	168	4	54	1
S. medium R.Br.	177	4	50	5
RUTACEAE				
Boronia crassifolia Bartl.	112	14	46	9
B. ramosa (Lindl.) Benth.	195	1	53	2
Eriostemon pinoides P.G. Wilson	182	2	50	5
E. spicatus A. Rich	129	29	53	2
TREMANDRACEAE				
Tetratheca confertifolia Steetz.	139	4	48	7
POLYGALAEAE				
Comesperma acerosum Steetz.	161	16	44	11

Species	Ref. No.	Ubiquity	Absolute Dissimilarity Value	Inclusion Value
EUPHORBIACEAE				
Monotaxis grandiflora Endl.	155	4	54	1
Stachystemon axillaris George	212	1	53	2
STACKHOUSIACEAE				
Stackhousia brunonis Benth.	152	3	51	4
RHAMNACEAE				
Cryptandra humilis (Benth.) F. Muell.	76	6	56	-1
STERCULIACEAE				
Lasiopetalum drummondii Benth.	104	10	48	7
DILLENIACEAE				
Hibbertia acerosa (R.Br. ex DC) Benth.	150	21	55	0
H. crassifolia (Turcz.) Benth.	21	102	60	-5
H. sp. aff. helianthemoides (Turcz.) F. Muell.	9	5	51	4
H. huegelii (Endl.) F. Muell.	38	28	56	-1
H. sp. aff. hypericoides (DC.) Benth.	37	83	75	-20
H. mylnei Benth.	108	34	44	11
H. subvaginata (Steud.) F. Muell.	190	11	57	-2
VIOLACEAE				
Hybanthus floribundus (Walp.) F. Muell.	189	3	53	2
THYMELAEACEAE				
Pimelea sulphurea Meisn.	57	42	60	-5
MYRTACEAE				
Baeckea camphorosmae Endl.	164	44	58	-3
Beaufortia elegans Schau.	27	47	67	-12
B. eriocephala W.V. Fitzg.	171	46	54	1
Calothamnus quadrifidus R.Br.	143	2	50	5
C. sanguineus Labill.	25	66	58	-3
C. torulosus Schau.	105	48	38	17
Calytrix flavescens A. Cunn.	198	13	59	-4
C. leschenaultii Schau.	175	2	50	5
C. sp.	92	1	51	4

Species	Ref. No.	Ubiquity	Absolute Dissim-ilarity Value	Inclusion Value
Leucopogon conostephioides DC.	16	73	73	-18
L. cordatus Sond.	131	26	58	-3
L. polymorphus Sond.	192	37	61	-6
L. strictus Benth.	135	11	47	8
L. striatus R.Br.	69	48	47	8
Lysinema ciliatum R.Br.	36	30	58	-3
CHLOANTHACEAE				
Pityrodia bartlingii (Lehm.) Benth.	78	6	58	-3
LAMIACEAE				
Hemiandra pungens R.Br.	34	8	54	1
RUBIACEAE				
Opercularia vaginata Labill.	184	1	51	4
GOODENIACEAE				
Dampiera carinata Benth.	215	1	51	4
D. linearis R.Br.	200	4	50	5
D. oligophylla Benth.	43	15	55	0
D. spicigera Benth.	169	15	51	4
Scaevola paludosa R.Br.	81	6	52	3
STYLIDIACEAE				
Stylidium adpressum Benth.	217	26	42	13
S. bulbiferum Benth.	133	1	51	4
S. crossocephalum F.Muell.	48	37	67	-12
S. inversiflorum Carlquist	162	10	48	7
S. junceum R. Br.	199	3	55	0
S. maitlandianum E. Pritz.	173	2	55	0
S. miniatum Mildbr.	84	27	53	2
S. nonscandens Carlquist	193	15	61	-6
S. repens R.Br.	60	19	61	-6
INDETERMINATE SPECIES				
Sp. indet. 1	156	1	53	2
Sp. indet. 2	207	1	51	4