Department of Conservation and Land Management
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Population dynamics, reproductive biology and conservation of *Banksia brownii* and *Banksia verticillata*

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July 1995

Cover photos

Banksia brownii	(Maurice McDonald)
Banksia verticillata	(Maurice McDonald)

Population dynamics, reproductive biology and conservation of *Banksia brownii* and *Banksia verticillata*

ANCA ESP Project No 352

By

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FINAL REPORT SUBMITTED TO THE
ENDANGERED SPECIES UNIT
THE AUSTRALIAN NATURE CONSERVATION AGENCY

DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT
AUGUST
1995

Department of Conservation and Land Management
PO Box104, Como, WA 6152

This study (ANCA ESP Project No. 352) was funded by the Endangered Species Program of the Australian Nature Conservation Agency.

Acknowledgements

We thank Brian Collins, Byron Lamont, Denise Day, Helen Galaea, Leonie Monks, Rosemary Rees and Jane Sampson from the School of Environmental Biology, Curtin University for their substantial contributions to our understanding of the conservation biology of these two *Banksia* species. We also thank Anne Cochrane, Malcolm Grant and Brian Shearer for advice, and Carolyn Wills and Grazyna Paczowska for computing assistance.

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1. *BANKSIA BROWNII* Baxter ex R. Brown
Feather-leaved Banksia

1.1 Description

Banksia brownii usually grows as an erect bushy shrub to 2-3m, becoming a low spreading shrub on some peaks of the Stirling Range and an openly branched small tree to 6m in sheltered sites. It has smooth, thin, grey-brown bark and pubescent branchlets that become glabrous after several years. The usually whorled leaves are broadly linear, 3-11 cm long and 5-12 mm wide, glabrous bright green above and woolly below. They are divided almost to the midrib into many linear lobes, giving them a somewhat feather-like appearance. The inflorescences are broadly cylindrical, up to 20 cm long and 10 cm wide at flowering, terminal and often partly hidden by the branchlets which radiate from the base. The flowers are arranged in vertical rows, pale brown at the apex and cream below, with a grey-brown limb. The hooked styles are metallic red with a pale yellow apex. The perianth is up to 31 mm long, hairy outside and glabrous inside except along the upper margins. The pubescent, narrowly elliptic follicles have slightly wrinkled valves and are almost hidden among the persistent dead flowers. *B. brownii* is closely related to *Banksia occidentalis* which has smaller, deep red flowers and narrow, sparsely toothed leaves (George 1981, 1987).

Two forms of *B. brownii* are recognised (Keighery 1988); a northern form confined to the Stirling Range with short thin hard leaves and a southern form with long wide soft leaves occurring north and east of Albany.

1.2 Distribution and Habitat

B. brownii extends in small isolated populations over a range of approximately 90km from the Stirling Range south to Cheyne Beach and Albany (Fig 1.1). In the Stirling Range it grows on mountain tops and slopes, in heath and open mallee, on rocky sand and clay soils. The southern populations occur in heath and woodland communities, on slopes and gullies, in usually sandy soils over laterite or granite. The associated vegetation is rich in proteaceous (*Banksia, Dryandra, Lambertia, Isopogon, Hakea, Adenanthos*) and myrtaceous (*Eucalyptus, Agonis, Kunzea, Beaufortia*) species.

Population data for *B. brownii* are detailed below (Table 1.1). Populations known to have become recently extinct as a result of dieback infection (*Phytophthora cinnamomi*) are also included. Precise locality details are contained in the Department of Conservation and Land Management's Declared Rare Flora database and files.

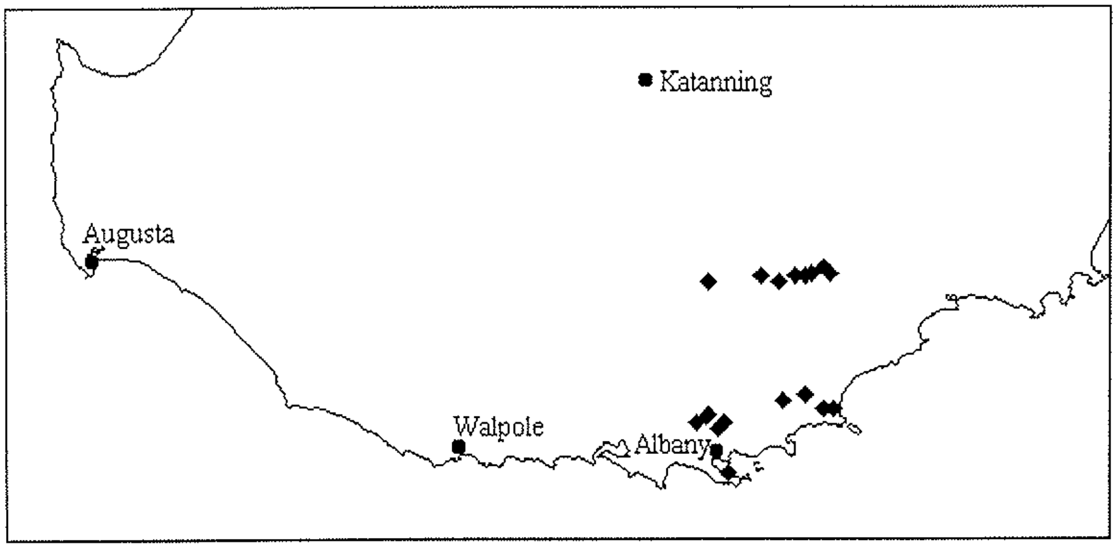


Figure 1.1. Distribution of *Banksia brownii*

LOCATION	CALM POP NO.	NO. OF PLANTS	POPULATION CONDITION
Stirling Range National Park			
Mt Hassell	11	377	dieback *
Yungermere	12	1000+	seedlings, dieback nearby
Bluff Knoll	13	0	postfire, dieback
Mt Success	14	?	postfire, dieback
Mondurup	15	<10	not recently surveyed
Moongoongoonderup	16	several 100	seedlings, postfire, good
Ellen Peak	17	165	seedlings, postfire, dieback
below Ellen Peak	18	6	dieback *
Waychinicup National Park			
Hassell Beach	9	55	seedlings, post fire, dieback *
Hassell National Park			
Hassell Hwy	2	87	seedlings, dieback, ?canker *
Millbrook Nature Reserve			
Millbrook	1	~1000	dieback *
South Sister Nature Reserve			
South Sister	5	~300	dieback *
Shire road verge			
Millbrook Rd	3	~150	dieback, some canker
Hazard Rd	6	7	dieback
Phillips Rd	7	2	dieback
Shire reserve			
N King River	4	4	burnt, dieback
Vancouver Peninsular	8	320	dieback, *Armillaria*, some canker *
Water Reserve			
Waychinicup	10	13	poor, dieback *

Table 1.1. Population data for *Banksia brownii*

* denotes populations treated with phosphonate as at April 1995

1.3 Disease Susceptibility and Control

B. brownii is highly susceptible to *Phytophthora cinnamomi* (McCredie *et al.* 1985) and all but two of the populations are being severely affected by the disease.

The fungicide phosphonate has proved successful in controlling *P. cinnamomi* in *B. brownii* populations. Phosphonate is an aqueous solution of di-potassium phosphonate with the active component of the fungicide being phosphite ion (PO_3^-). It has been proposed that phosphonate not only acts directly on the pathogen within the host but also activates the plant's defence systems, stopping the spread of the pathogen within tissues (Hardy *et al.* 1994). It does not eradicate the pathogen however, and so can only be used to control the spread of the disease.

Research trials at Millbrook Nature Reserve has shown that two foliar applications of phosphonate (0.5%) by hand spraying at six weekly intervals protects plants for up to three years (Brian Shearer, pers. comm.). Subsequent aerial application trials on two populations have also proved promising although final assessment of these trials is still to be carried out (Komorek pers. comm.). At South Sister Nature Reserve 8.8 ha covering the entire *B. brownii* population was aerially sprayed twice with 8.5% phosphonate in a low volume of 26l/ha. Similarly at Milbrook Nature Reserve almost the whole population of *B. brownii* covering some six hectares was aerially sprayed twice with a concentration of 10% phosphonate in a volume of 30 l/ha. In both these aerial spray applications the fine mist of higher concentration phosphonate results in no detectable phytotoxic effects on the plants (Shearer *pers. comm.*). To date almost half of the *B. brownii* populations have been treated with phosphonate either by hand or aerial spraying (Malcolm Grant, pers. comm.; Table 1.1).

Preliminary trials conducted by Galea and Lamont (1993) have shown that phosphonate does not have any phytotoxic effects (0.1% and 0.35%) on *B. brownii* seedlings planted in a *Phytophthora* infected area and hand sprayed at monthly intervals over 4 months.

Armillaria is a potentially significant threat to *B. brownii*, having caused the death of two plants in the population at Vancouver Peninsular. Aerial canker infection has also been recorded at three sites, and while the disease may result in partial limb death under stress conditions, it does not appear to be a significant threat (Robinson and Coates 1995; Malcolm Grant, pers. comm.).

1.4 Fire Ecology

B. brownii is a non-sprouting species that is killed by fire and relies entirely on seed for regeneration (Taylor and Hopper 1988, George 1987, field observations).

Galea and Lamont (1993) assessed the effect of burning living and dead plants on seed release by conducting an experimental burn on the population at Millbrook Road. They found that the number of cones that were totally or partly incinerated by an intense fire was dependent on whether the plant was dead or alive prior to the fire but independent of the dead plants position (Table 1.2). The live, dead upright and dead ground plants differed significantly in the number of follicles that were open prior to the fire, the live plants having very few open follicles at this stage. There was no significant difference in the mean number of open follicles after the fire.

Plant	Intact	Partly incinerated	Completely incinerated	Chi-square	P
Live, upright	62 (95.4)	3 (4.6)	0 (0)	29.67	***
Dead, upright	36 (55.4)	10 (15.4)	19 (29.2)	1.50	ns
Dead, ground	41 (63.1)	11 (16.9)	13 (20.0)		

Table 1.2. Total number of intact, incinerated and partially incinerated cones (percentage of total in parentheses) of a random sample of 65 cones of *Banksia brownii* at Millbrook Road (from Galea and Lamont 1993). Significance by chi-square analysis *P<0.05, **P<0.01, ***P<0.001, ns - not significant.

Seed release from the cones occurred gradually and was completed by 97 days. The percentage of seed released from plants in the three treatments differed significantly, with 45.8%, 24.7% and 3.8% released from the live, dead upright and dead ground plants respectively (Galea and Lamont 1993). Live plants were clearly the best source of seed for post-fire recruitment.

A total of 238 seedlings were recorded after the experimental fire, representing 4.4% of the total pre-fire unopened follicles and 6.1 seedlings per parent plant. Post-dispersal predation of *B. brownii* seed appeared to be high with low germination levels recorded for seed scattered on the ground (4.4%) compared with those buried to a depth of 10mm (46.7%). No granivory was directly observed, however Western Rosellas (*Platycerus icterotis*) were seen feeding on the ground close to the burnt areas (Galea and Lamont 1993).

While seedling recruitment is promoted by fire it does not appear to be dependent on it. Aging of plants by Galea and Lamont (1993) at Millbrook, South Sister and Mt Hassell found that in a sample of twenty plants the modal age was represented by up to only 50% of the plants, and as little as 20% at South Sister. This varied age structure is typical of populations where establishment of seedlings occurs spontaneously in the interfire period (Monks *et al.* 1994).

Field observations indicate that *B. brownii* plants reach reproductive maturity after approximately 5-6 years, which is comparable to juvenile periods recorded for other non-sprouting species such as *Banksia cuneata* (4 years), *B. burdettii* (4-5 years) and *B. prionotes* (4-5 years) (Lamont *et al.* 1991, Lamont and Barker 1988, Cowling *et al.* 1987). Fire frequencies of at least 10 years would therefore be required for adequate seed banks to accumulate. Fire in populations infected by dieback disease could be detrimental as seedling survival is likely to be minimal.

1.5 Pollination Biology

Honeyeaters and small mammals were found to be the major pollinators in *B. brownii* populations at both South Sister and Millbrook Nature Reserves. New Holland Honeyeaters (*Phylidonyris novaehollandiae*) were the most frequently captured honeyeater species at these sites, followed by Western Spinebills (*Acanthorhyncus superciliosus*) and Red Wattlebirds (*Anthochaera carunculata*). Bird capture rates increased sharply once *B. brownii* commenced flowering, reaching a peak in May at Millbrook and in June at South Sister (Fig. 1.2). This is consistent with several other studies that have shown seasonal abundance of honeyeaters to be positively correlated with the density of *Banksia* inflorescences in an area (Ford and Paton 1977, 1982; Ford and Pursey 1982; Collins and Briffa 1982; Vaughton 1990).

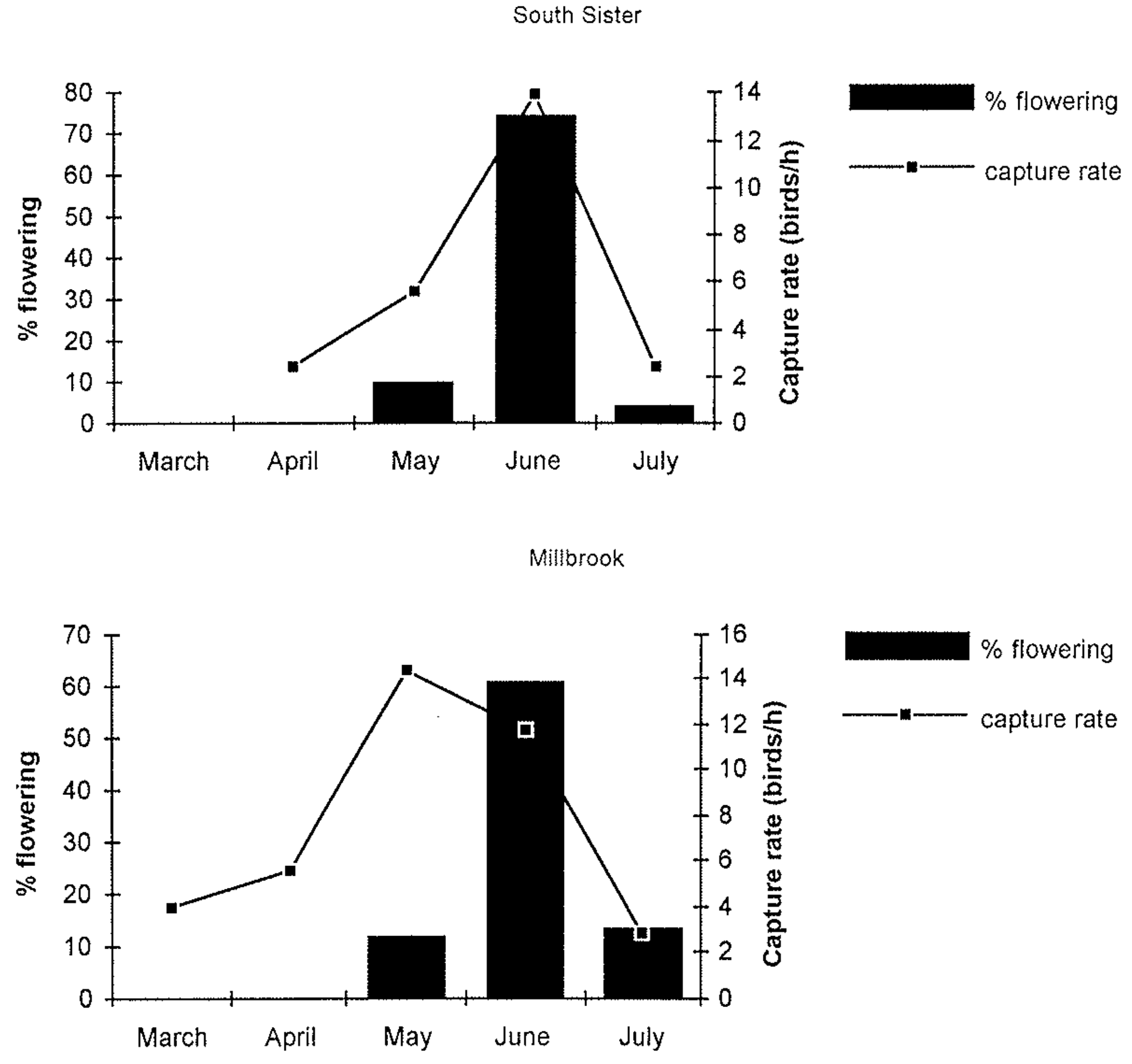
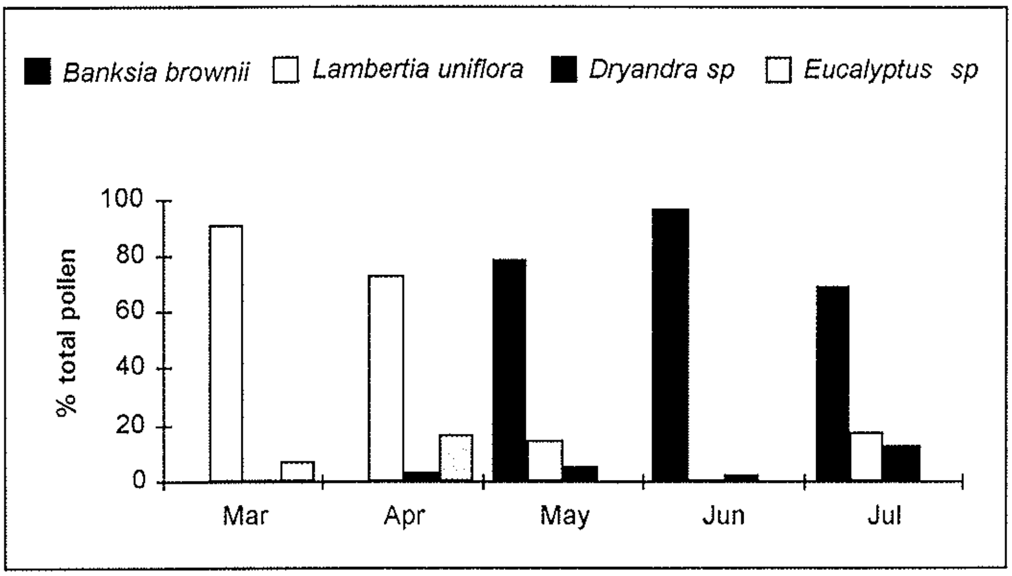


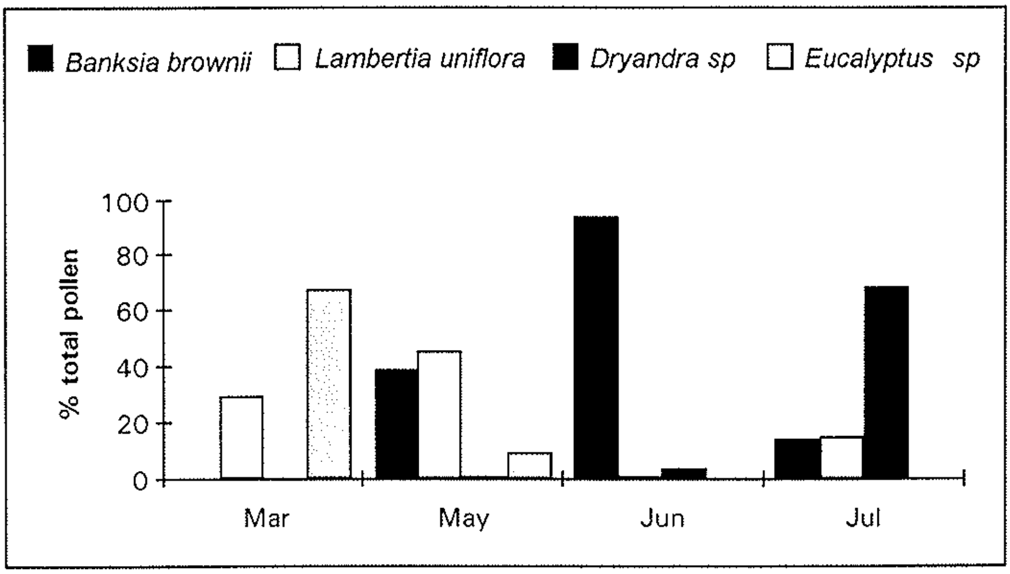
Figure 1.2. Bird capture rates and the percentage of inflorescences in flower at South Sister and Millbrook Reserves during 1993 (from Collins *et al.* 1994). Rates calculated as the average number of birds caught in three nets per hour.

Of the three species caught, only New Holland Honeyeaters and Red Wattlebirds were found to carry significant amounts of *B. brownii* pollen. Pollen smears taken from New Holland Honeyeaters (Fig. 1.3) showed that during peak flowering in June 1993, *B. brownii* pollen accounted for 97% and 94% of total pollen at Millbrook and South Sister respectively (Collins *et al.* 1994). Other plant species *Lambertia uniflora*, *Dryandra* sp. and *Eucalyptus* sp. appear to be important food sources at times of the year when *B. brownii* is not flowering.

New Holland Honeyeaters were the most frequently observed species feeding at *B. brownii* inflorescences (Collins *et al.* 1994). They foraged preferentially at inflorescences with one to two third of flowers open, restricting their feeding to the "advancing front" of open flowers rather than probing randomly over the whole inflorescence. Movements occurred more frequently between inflorescences on the same (58%) rather than different trees (42%).



Millbrook



South Sister

Figure 1.3. Proportions of pollen on facial smears taken from New Holland Honeyeaters (*Phylidonyris novaehollandiae*) captured at Millbrook and South Sister Nature Reserves (from Collins *et al.* 1994).

Bush Rats (*Rattus fuscipes*) and Honey Possums (*Tarsipes rostratus*) were the only trapped mammals carrying significant *B. brownii* pollen loads, with some loads comparable to, or greater than those recorded for some honeyeaters. Neither species was captured at Millbrook, however the trapping time was much shorter at this site. Recaptures of *R. fuscipes* at South Sister indicated that individuals foraged within a range of about 3-4m radius, with some animals showing a preference for particular *B. brownii* trees.

Pollinator exclusion experiments conducted by Collins *et al.* (1994) at the South Sister population showed that *B. brownii* is capable of setting fruit by self fertilization, although greatest levels of fruit set were recorded for inflorescences exposed to vertebrate pollinators (Fig. 1.4). The proportion of inflorescences that set fruit (fruiting success) and flowers that developed into follicles (fruit set) respectively was far greater for the open inflorescences (51.1%, 2.17%) than for those in the total (9.3%, 1.02%) and vertebrate exclusion treatments (19.8%, 1.52%).

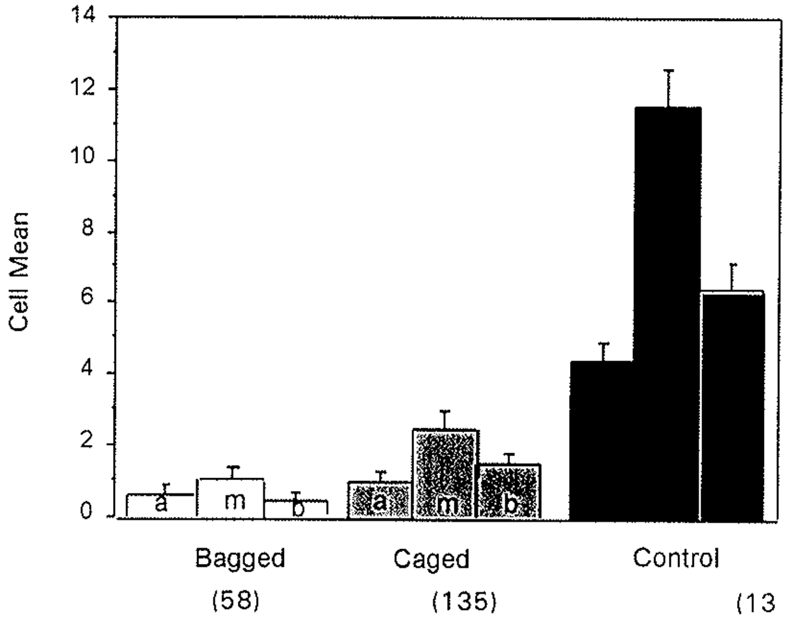


Figure 1.4. Mean number of follicles (± s.e.) in the apical (a), middle (m) and basal (b) thirds of *Banksia brownii* infructescences exposed to total (bagged) and vertebrate (caged) exclusion treatments (from Collins *et al.* 1994). Sample sizes (infructescences) are in parentheses.

Insect foraging activity at the Millbrook and South Sister sites was generally low, possibly as a consequence of *B. brownii* flowering during the coldest months of the year (Collins *et al.* 1994). The Honeybee (*Apis mellifera*) was the only invertebrate observed to come in contact with the stigma and pollen presenter while foraging at the flowers. As *B. brownii* is self-compatible the activity of honeybees may account for some fruit set.

Flower opening commences from the top of the flower spike, with the uppermost flowers usually finished before the basal ones have reached anthesis (George 1981). Collins *et al.* (1994) observed that flower opening occurred predominantly during the day, and that while there was no significant difference in the daytime flower opening rates between sites, the rate during the night was significantly greater at South Sister (table 3). This coincided with increased pollen removal from the flowers (table 4)and may be in response to foraging by nocturnal visitors such as *R. fuscipes* and *T. rostratus.* Increased rates of flower opening have been observed in other *Banksia* species as a result of triggering by animal visitors (McFarland 1985, Ramsey 1988).

Table 1.3. Mean rate of flower opening during the day (0730-1730h) and night (1730-0730h) in *Banksia brownii* (from Collins *et al.* 1994). Values are mean number of pollen presenters emerged per hour, standard errors in parentheses. n = number of inflorescences.

Site	Mean rate of flower opening		
	n	Day	Night
Millbrook	30	4.91 (0.66)	1.30 (0.14)
South Sister	20	5.34 (0.42)	2.53 (0.24)

Assessment of pollen removal rates from inflorescences showed that the importance of different pollinator groups (mammals vs honeyeaters) may vary between sites (Collins *et al.* 1994). At South Sister, nocturnal and diurnal visitors appear to make the same overall contribution to pollen removal while at Millbrook greater levels of pollen removal occurred during the day (Table 1.4). This may be a reflection of the large numbers of birds and the apparent absence, or low numbers, of mammal visitors at the Millbrook site. Both mammal and honeyeaters visitors must be successful in effecting pollination as the difference in pollinator contributions did not influence fruit production.

Table 1.4. Mean proportion of pollen remaining on pollen presenters at the end of the day (0730-1730h) and night (1730-0730h) at Millbrook and South Sister Nature Reserves (from Collins *et al.* 1994). Standard errors in parentheses, n = number of pollen presenters sampled.

Site	Proportion of pollen remaining			
	n	Day	n	Night
Millbrook	366	0.238 (0.013)	330	0.314(0.014)
South Sister	238	0.357(0.019)	217	0.388(0.020)

1.6 Reproductive Biology

Flowering in *B. brownii* has been recorded from March to July (George 1981, field observations) with an isolated record of flowering in January (Taylor and Hopper 1988). At Millbrook and South Sister during 1993 flowering occurred from April through to August, peaking in June both in terms of the number of trees in flower and the number of inflorescences open (Fig. 1.5). Comparison of the percentage of inflorescences in flower each month indicates that peak flowering was concentrated into a shorter period at South Sister than at Millbrook, with 90% and 86% respectively of the total flowers open during June. The length of flowering for individual trees ranged from 4 to 15 weeks (mean 8.57 ± s.e. 0.62) at Millbrook and from 4 to 13 weeks (mean 8.90 ± s.e. 0.45) at South Sister.

Inflorescence production was found to be positively correlated to plant biovolume and mean width at the Millbrook and South Sister sites studied by Collins *et al.* (1994). Despite the similar tree dimensions however, the mean (± s.e) number of inflorescences per tree was found to differ significantly (South Sister 15.30±1.85, Millbrook 9.56±1.73). This may be a result of plants at South Sister having greater access to water due to run-off from the granite outcrops.

Fruiting success (% of inflorescences that set fruit) was not related to the total number of inflorescences per tree, with 45.1% and 51.5% of the inflorescences setting fruit in the Millbrook and South Sister populations respectively (Collins *et al.* 1994). Fruiting success appeared to be dependent on inflorescence length, with a significant difference recorded between the mean lengths of inflorescences that successfully set fruit (141.75 ± 1.86mm) and those that were barren (105.78 ± 1.66mm). Collins *et al.* (1993), Stock *et al.* (1989) and Vaughton (1993) suggest that the availability of resources may determine the levels of fruiting success.

Of those inflorescences that did set fruit, a mean (for both sites) of only 1.87% of the total flowers developed into follicles. This is comparable with results for several other non-sprouting *Banksia* species (Lamont and Barker 1988, Lamont *et al.* 1991, Witkowski *et al.* 1991). Fertile infructescences had a mean (for both sites) of 36.36±1.254 follicles. The number of follicles was significantly correlated to infructescence length, but there was no relationship between inflorescence length and percentage fruit set, which differed significantly between trees (Collins *et al.* 1994).

The abundance of potential pollinators and the rapid removal of pollen from inflorescences indicates that it is unlikely that pollinators limit fruit set. Collins *et al.* (1994) noted however, that inflorescences located in the upper portions of the tree tended to be more successful in setting fruit than those on the lower branches or within the foliage, presumably as a result of them being more obvious and accessible to bird pollinators. It is unlikely that low fruit set in *B. brownii* is due to over-crowding of follicles, as all of the infructescences examined were able to accommodate more follicles. At both sites a large number of *B. brownii* infructescences had evidence of insect damage and of these very few had set fruit, suggesting that inflorescence consumers may be reducing fruit set (Collins *et al.* 1994).

Distribution of follicles was non-random, with most forming in the middle third of the infructescence (Fig. 1.4). This pattern may be related to the behaviour of honeyeaters which tended to forage preferentially at inflorescences with one to two thirds of their flowers open and make more probes in the area of the "advancing front" of opening flowers. A similar pattern of follicle distribution observed in both vertebrate and total exclusion treatments suggests that other factors such as the limitation of resources may also contribute to the distribution of follicles on the infructescence (Collins *et al.* 1994, Vaughton 1993).

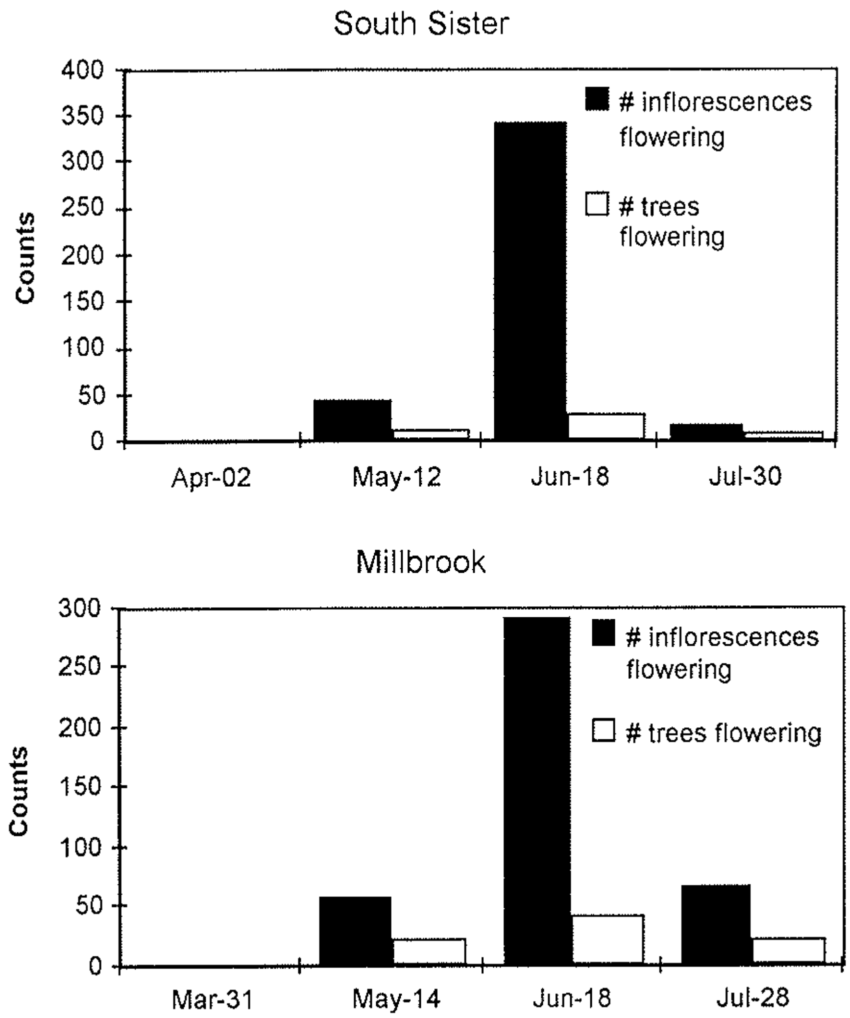


Figure 1.5. Flowering phenology of 30 and 50 *Banksia brownii* trees during 1993 at South Sister and Millbrook Nature Reserves (from Collins *et al.* 1994).

1.7 Seed Biology and *Ex Situ* Storage

Galea and Lamont (1993) assessed the levels of seed storage on living and dead plants in populations at Millbrook, South Sister and Mt Hassell. They found that the populations differed in the average number of viable seeds available on living and dead plants, in all cases the living plants storing far more seed (Table 1.5). The number of follicles per cone did not differ significantly between live and dead plants and was only marginally different between the populations. In all populations dead plants had a higher proportion of seed loss than the live plants. This indicates that if seed collections are to be made from dead plants in dieback affected populations they should be carried out as soon after plant death as possible.

B. brownii is one of the few banksias to produce only one seed per follicle. This may account for the relatively low seed set (Table 1.5) compared to several other non-sprouting species (Cowling *et al.* 1987, Enright and Lamont 1989, Lamont and Barker 1988, Lamont *et al.* 1991, Witkowski *et al.* 1991). Of the populations studied by Galea and Lamont (1993) the older South Sister population had the greatest viable seed store per plant. Seed storage did not always appear to be related to plant age however, with the number of viable seeds per cone and fertile cones per plant at the Millbrook and Mt Hassell populations differing markedly despite their similar age. High levels of seed loss (release, predation, abortion) and the low numbers of fertile cones per plant and viable seeds per cone at Mt Hassell may be related to local site factors and population condition (water and nutrient availability, pollinator activity, disease infection).

		Millbrook	South Sister	Mount Hassell	Significance		
					C	S	C*S
Modal age (years)	live	12	25	11			
	dead	11	21	8			
Fertile cones per plant (X ± std dev.)	live	7.4 ± 7.3	46.2 ± 26.8	2.3 ± 1.5	*	**	ns
	dead	5.2 ± 3.3	29.2 ± 29.4	0.5 ± 0.7			
Follicles per cone (X ± std dev.)	live	23.7 ± 6.0	27.0 ± 8.3	20.0 ± 14.2	ns	*	ns
	dead	27.5 ± 9.6	27.7 ± 6.4	17.6 ± 8.9			
Non-aborted seeds per cone (X ± std dev.)	live	10.8 ± 4.2	8.4 ± 5.8	2.0 ± 2.8	***	***	**
	dead	3.3 ± 2.3	7.6 ± 5.8	1.2 ± 1.3			
Viable seeds per cone (X ± std dev.)	live	9.7 ± 4.4	3.4 ± 5.2	1.9 ± 2.6	***	***	***
	dead	1.5 ± 1.6	5.1 ± 4.5	0.5 ± 0.6			
Viable seeds per plant (X ± std dev.)	live	66.9 ± 60.2	232.9 ± 558.6	5.8 ± 8.6	***	***	***
	dead	7.7 ± 13.6	87.7 ± 98.1	2.9 ± 4.5			

Table 1.5. Modal age and mean contributions to the seed bank of live and dead *Banksia brownii* in three populations during 1993 (from Galea and Lamont 1993). Significance by two-way ANOVA between condition (C) and site (S). *P<0.05; **P<0.01; ***P<0.001; ns not significant. Sample one cone from 20 live and dead plants in each population.

To date seed has been collected and stored from 12 populations. With the exception of material from Bluff Knoll the viability of seed from all collections was generally very good with germinibality ranging from 83% to 100%. Some seed collections (collector DJC, Table 1.6) were stored for up to 7 years at room temperature but still showed no reduction in viability. Seed viability remained high whether storage was as seed at room temperature, in cones at room temperature or as seed at -18°C.

Recent studies Touchell and Dixon (1993) suggest that at least some *Banksia* seed can be readily stored in liquid Nitrogen (cryostorage) at normal moisture content without any significant reduction in germinability. If this approach proves successful for *B. brownii* the collections, particularly in cones, may be placed as seed in cryostorage.

LOCATION (POP NO)	COLLECTION DATE	QUANTITY STORED	INITIAL GERMINATION %	% GERMINATION AFTER STORAGE AT -18°C
Mt Hassell 11	9/8/87 DJC	-18°C 25 seed (I/4)	na	
	24/7/93 JAC	RT 66 cones (I/25)	96% at 7/9/93	98% at 31/3/95
Bluff Knoll 13	2/11/88 DJC	-18°C 149 seed (I/14)	48% at 31/8/93 *	
below Ellen Peak 18	9/9/87 DJC	4°C 41 seed	na	
	20/11/94 JAC	-18°C 193 seed (B/10)	95% at 5/12/94	
Hassell Beach 9	22/8/93 JAC	RT 115 cones (I/15)	90% at 28/10/93	90% at 30/11/94
Hassell Hwy 2	26/11/86 DJC	-18°C 350 seed (B/20)	95% at 2/6/93 *	
	21/4/89 DJC	-18°C 669 seed (I/38)	83% at 20/4/93 *	90% at 19/5/95
Millbrook 1	9/5/86 DJC	-18°C 46 seed (B/8)	100% at 2/6/93 *	
	19/5/93 MM	RT 226 cones (I/41)	89.3% at 31/8/93	93% at 9/12/94
South Sister 5	25/1/93 MM	RT 263 cones (I/22)	85.5% at 1/6/93	79% at 21/9/94
Millbrook Rd 3	14/5/87 DJC	4°C 12 seed (B/3)	na	
Hazard Rd 6	21/8/93 JAC	RT 9 cones (I/4)	97% at 18/5/94	
Phillips Rd 7	21/8/93 JAC	RT 18 cones (I/1)	na	
Vancouver Peninsular 8	? DJC	RT 29 cones (I/29)	na	
	18/5/93 MM	RT 137 cones (I/16)	90% at 3/9/93	64% at 20/12/94
Waychinicup 10	24/8/89 DJC	RT 49 cones (I/49)	na	

Table 1.6 Seed accessions currently available in CALM's Threatened Flora Seed Centre and % germination following different storage regimes.
* denotes seeds that were germinated several years after collection

1.8 Mating Systems

Studies on populations at Millbrook and South Sister found *B. brownii* to have a mixed mating system, being mostly self fertilising, with a small degree of outcrossing and biparental inbreeding (Sampson *et al.* 1994). Outcrossing rates of 0.68±0.04 and 0.75±0.04 were obtained for the two populations respectively (table 6). These levels of outcrossing are amongst the lowest recorded for undisturbed *Banksia* populations to date. Estimates of outcrossing rates of other banksias have been typically high, with species such as *B. menziesii, B. attenuata B. paludosa* and *B. spinulosa* found to be almost completely outcrossing (Scott 1980, Carthew *et al.* 1988). Low levels of outcrossing were reported in a highly disturbed population of *B. cuneata* (Coates and Sokolowski 1992), however in undisturbed populations the outcrossing levels were high.

Table 1.6. Mating system estimates based on the mixed mating model for the Millbrook and South Sister populations of *Banksia brownii* (from Sampson *et al.* 1994). * Significantly different from one (P<0.05). Standard errors in parentheses.

Population	**Locus**				**Minimum variance mean**	**Multilocus**
	Ldh-1	***Sdh-1***	***Est-3***	***Est-4***		
Millbrook	0.53(0.05)*	0.87(0.08)	0.76(0.06)*	0.50(0.05)*	0.67(0.04)*[A]	0.68(0.04)*[A]
South Sister	0.76(0.06)*	0.64(0.07)*	0.78(0.07)*	0.50(0.06)*	0.71(0.04)*[B]	0.75(0.04)*[B]

[A] For Ldh-1, Sdh-1, Est-3

[B] For Ldh-1, Sdh-1

The low outcrossing rate of *B. brownii* appears to be a result of self-fertilisation rather than biparental inbreeding due to population structure. Most self-fertilisation is likely to be the result of pollinator activity, as fruit set in the absence of pollinators was low (Fig. 1.4). This is consistent with observations of foraging activity where honeyeaters tended to visit inflorescences on the same plant more frequently than between plants and made multiple probes at a single inflorescence (Collins *et al.* 1994). The foraging activity of mammals at inflorescences is also likely to result in self-fertilisation.

The low levels of outcrossing in *B. brownii* may be related to fire strategy (Sampson *et al.* 1994), with a non-sprouting species that relies on seed for regeneration, more likely to possess some degree of self-compatibility in order to increase fecundity than highly outcrossed fire tolerant species (Carpenter and Recher 1979). However, as pointed out by Sampson *et al.* (1994) a larger number of estimates of mating system and seasonal fecundity are required to confirm any relationship between outcrossing rate and fire tolerance.

The mating system parameters presented by Sampson *et al.* (1994) indicate an absence of genetic structure within both populations of *B. brownii.* This suggests that gene dispersal is high enough to prevent any significant structure from developing within populations. Although honeyeaters were found to forage more frequently at inflorescences on the same tree, some pollen transfer would occur between trees. This pollen carry over, together with post-germination selection against inbred individuals, may account for the absence of structure in both *B. brownii* populations.

The effective breeding unit size for *B. brownii* was not determined by *Sampson et al.* (1994) although by considering the effective selfing rate and the true selfing rate they point out it must be greater than the 120 individuals represented by the sub population sample from the Milbrook Nature Reserve and the 200 individuals represented by the sub population from South Sister Nature Reserve. This indicates that the effective breeding units in the these larger populations are greater than the size of many of the remaining *B. brownii* stands. *Sampson et al.* (1994) consider that the small populations of *B. brownii* will be more prone to inbreeding particularly if the adjacent vegetation has been cleared or highly modified by infection with *Phytophthora cinnamomi* dieback.

1.9 Conservation and Management Actions

B. brownii is currently one of the State's most threatened species because of its extreme susceptibility to dieback disease (*Phytophthora cinnamomi*). Less than 3000 individuals are confined to 18 populations, only two of which appear to be free of the disease. *Armillaria* presents an additional threat, having caused the death of two plants in a population near Albany.

Major considerations and recommendations for the conservation and management of this species are outlined below.

1. Control of disease particularly *Phytophthora cinnamomi* is the greatest concern in relation to the short term survival of this species. Phosphonate application either on individual plants or the population and associated community has proved successful in controlling the spread of dieback disease in a number of *B. brownii* populations. This should be carried out on all infected populations with repeat applications every three to four years.

2. Pollination and mating system studies suggest that *Banksia brownii* is dependent on bird and mammal pollinators to effect cross pollination and maximise seed production and viability. These pollinators, in turn, rely on associated plant species both within and adjacent to the populations, for food and shelter. Changes in habitat composition and structure primarily due to loss of species susceptible to *P. cinnamomi* may lead to a reduction in pollinator numbers and diversity (Wills and Keighery 1994). This indicates that *P. cinnamomi* control should not only target *B. brownii* but all susceptible species in the vicinity of the population.

3. *Banksia brownii* reaches reproductive maturity after 5-6 years and probably 9-10 years are required for adequate seed banks to accumulate. In pristine dieback free populations fire frequencies should be no less than 10 years. Where feasible dieback infected populations should be protected from fire as seedling survival on these sites is likely to be minimal. If this is not possible the immediate application of phosphonate to post fire seedlings should be carried out.

4. The establishment of new populations of *B. brownii* in disease free sites may need to be considered in the future. Seed for this purpose has been collected from representative populations throughout its range, and is being held in long-term storage at the Threatened Flora Seed Centre at the WA Herbarium. Such recovery action will require further research on seedling survival under different edaphic and environmental conditions.

5. Keighery (1988) suggests there are two forms of *B. brownii*, one confined to the Stirling Ranges and the other to the south around the Albany-Cheyne Beach area. Allozymes provided insufficient variable markers to confirm the genetic distinctness of these two forms and it is recommended that other molecular markers be utilised to investigate the proposed differences.

The critical nature of many *B. brownii* populations indicates that the immediate preparation of a Recovery Plan is warranted. Management and research actions specifically targeting disease control and population re-location should be given the highest priority.

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2. *BANKSIA VERTICILLATA* R.Brown
Granite Banksia

2.1 Description

B. verticillata is a bushy shrub, or more rarely a tree, with a short thick branching trunk and grey fissured bark. It usually grows to a height of 3m, although has been recorded up to 5m in sheltered habitats. In coastal sites where it is exposed to strong winds it may become prostrate. The leaves are whorled or sometimes scattered, narrowly elliptic to oblong, 3-9cm long and 7-12mm wide. They are entire, bright green above and conspicuously matted with white hairs below. The inflorescences are terminal, golden yellow, to 20cm long and 6.5cm wide at flowering. The perianth is up to 30mm long, pubescent outside and inside along the upper margins. The follicles on the infructescence are narrowly elliptic and the old flowers are persistent but finally deciduous (
+George 1981, 1987).

B. verticillata is closely related to the Swamp Banksia, *B. littoralis*, which differs in its usually tree habit, longer serrate leaves, more hirsute perianth inside and thinner infructescence with more exserted follicles. The River Banksia, *B. seminuda,* is also similar being a tree with thin, usually serrate leaves, strongly recurved styles and perianth with a glabrous limb (George 1987).

2.2 Distribution and Habitat

B. verticillata occurs in disjunct population groups over a range of approximately 170km, from west of Walpole to Cheyne Beach east of Albany (Fig. 2.1). It grows on or adjacent to granite outcrops in shallow rocky soils of loam or sand. *Agonis marginata*, *A. flexuosa*, *Andersonia sprengelioides* and *Hakea* species dominate the associated scrub and heath. All but one of the populations are located within 2km of the coast.

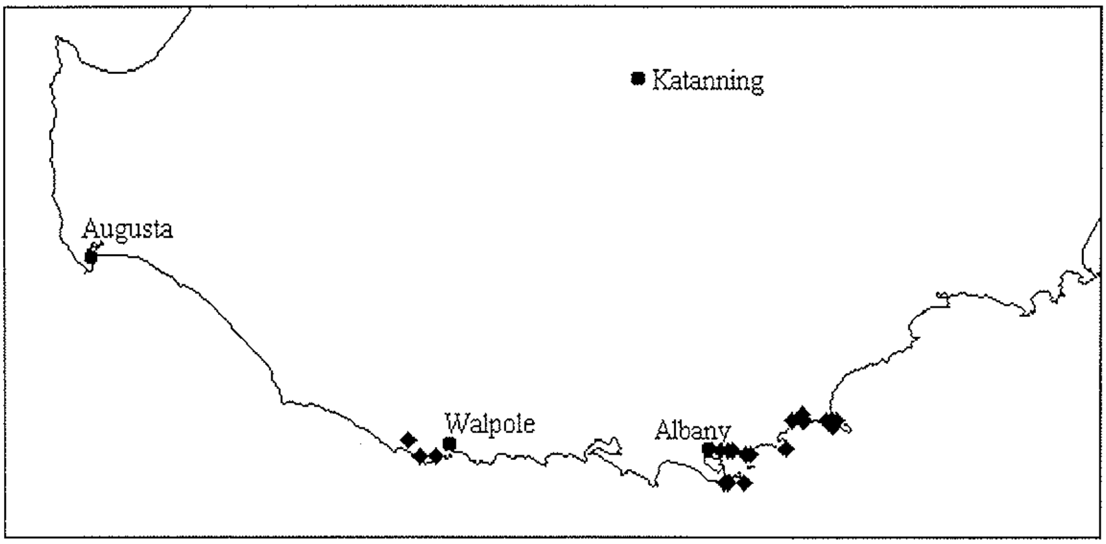

Figure 2.1. Distribution of *Banksia verticillata*

LOCATION	CALM POP NO.	NO. OF PLANTS	POPULATION CONDITION
Manypeaks National Park			
Manypeaks	1, 2, 16, 17, 22	<10	dieback; some pops dead
Normans Beach	11	0	dead
Torndirrup National Park			
Stony Hill	3	400-500	good
Stony Hill east	13	+200	fair
Isthmus Hill	12	100+	
Bald Head	4	70	undisturbed
Gap	9	35	
Peak Head	10	+180	generally good, small *Armillaria* infection
Newhills	19	128	canker
Niggerhead Rock	24, 25, 26	200+	undisturbed
Two Peoples Bay Nature Reserve			
Two Peoples Bay	5	2	dead
Waychinicup National Park			
Cheyne Beach	7, 8, 18	+2000	undisturbed
Cheyne Beach west	23	187	good
Mermaid Pt	28	133	fair
Channel Pt	30	108	undisturbed
Waychinicup west	32	<10	?canker, 50+ dead
Gull Rock National Park			
Herald Point	27	0	dead
Ben Dearg Pt	29	7	dieback nearby
Walpole-Nornalup National Park			
Poison Hill	31	300	dieback
Mt Hopkins	6	300	good
State forest			
Woolbale Hills	15	400	dieback

Table 2.1. Population data for *Banksia verticillata*

Population data for *B. verticillata* are detailed below (Table 2.1). Populations known to have become recently extinct as a result of dieback infection (*Phytophthora cinnamomi*) are also included. Precise locality details are contained in the Department of Conservation and Land Management's threatened flora database and files.

2.3 Disease Susceptibility and Control

McCredie *et al.* (1985) describe *B. verticillata* as having a medium susceptibility to *P. cinnamomi*, although recent field observations indicate high susceptibility. Several populations have already been infected by *P. cinnamomi* and others are in areas which are at high risk of infection.

The fungicide phosphonate has proved successful in controlling *P. cinnamomi* in *B. brownii* populations but has yet to be applied to *B. verticillata* populations. Phosphonate is an aqueous solution of di-potassium phosphonate with the active component of the fungicide being phosphite ion (PO_3^-). It has been proposed that phosphonate not only acts directly on the pathogen within the host but also activates the plant's defence systems, stopping the spread of the pathogen within tissues (Hardy *et al.* 1994). It does not eradicate the pathogen however, and so can only be used to control the spread of the disease.

Research on several *Banksia* species has shown that two foliar applications of phosphonate (0.5%) at six weekly intervals protects plants for up to three years (Shearer, *pers. comm.*). Subsequent aerial application trials on two *B. brownii* populations (section 1.3, this report) have also proved promising although final assessment of these trials is still to be carried out (Komorek *pers. comm.*). In both these aerial spray applications the fine mist of higher concentration phosphonate, 8.5% phosphonate in a volume of 26l/ha and 10% phosphonate in a volume of 30 l/ha, results in no detectable phytotoxic effects on the plants (Shearer *pers. comm.*). Aerial application of phosphonate may need to be considered for some *B. verticillata* populations particularly in the Walpole area.

Aerial canker infection (*Zithiostroma* sp) also presents a significant threat to *B. verticillata* populations and is the cause of large scale deaths in newly discovered populations at Waychinicup (M. Grant, *pers. comm.*). The same pathogen has been found to cause limb but not significant plant death in *B. baxteri* (Shearer, *pers. comm.).* Symptoms of aerial canker infection, not confirmed to be due to *Zithiostroma* sp, have also been observed in one of the populations in Torndirrup National Park, although the plants appear to have subsequently recovered (Robinson and Coates 1995).

Another pathogen, *Armillaria leuteobubalina* has been found causing limited plant death in the Peak Head population. Although it is not currently considered to be a threat to plants on the granite outcrops it is likely to have a significant impact on the plants on the rock margins.

The control of either *Zithiostroma* sp or *Armillaria leuteobubalina* is at present problematical. Fire has been considered one possibility in the control other aerial cankers such as *Cryptodiaporthe* stem canker on *Banksia coccinea*. However, the fire frequencies required to control cankers before they cause plant death would probably not be appropriate given the length of time it takes *B. verticillata* to reach sexual maturity (13-17 years, Table 2.3). Phosphonate application may provide a means of controlling *Armillaria leuteobubalina* although preliminary studies indicate much higher concentrations are required than for *Phytophthora cinnamomi* and phytotoxic effects may preclude its use (Shearer *pers. comm.)*

2.4 Population Age Structure

Monks *et al.* (1994) investigated the pattern of population recruitment in six populations of *B. verticillata* across its known range. Analysis of plant age within populations showed that recruitment is linked to major events such as fire, but that significant recruitment also occurs independently of these events. Thus when age of plants was graphed against number of plants all six populations studied tend to show a normal distribution indicating a major recruitment event but with significant recruitment on either side of this event. This is unusual among non-sprouting *Banksia* species which usually occur as single-aged stands with the peak corresponding to the last fire (Cowling *et al.* 1987, Lamont and Barker 1988, Lamont *et al.* 1991). Both senescent and live plants contribute seed to interfire establishment as follicles on live plants open in the absence of fire after several years. When relating age class to fire history they found that in some populations the peak in recruitment probably corresponded to the second generation after fire.

Since *B. verticillata* is found on both granite outcrops and their margins Monks *et al.* 1994 hypothesised that plants on the rock may be subjected to different (less frequent burning) fire regimes and therefore show a different age structure. They found no significant difference in age of plants growing in the two different areas (Table 2.2) and provided two possible explanations. Firstly, both rock and margin could have the same fire history with plants on the outcrop just as exposed to fire as plants on the margins. Alternatively interfire establishment may play a greater role than fire in population recruitment and that recruitment patterns are the same for both rock and margin plants.

Table 2.2. Summary of mean age, height and volume for six populations of *Banksia verticillata* according to location on the rock or at the margin (from Monks *et al.* 1994). Different letters denote population means that are significantly different from each other by Tukey - Kramer test.

Population		Mt Hopkins	Poison Hill	Torndirrup burnt	Torndirrup unburnt	Cheyne Beach	Waychinicup burnt
Sample size	rock margin	101 51	100 50	102 50	100 50	67 40	100 50
Plant age (yrs) (X ± std. dev.)	rock margin	21.7^{a} ± 4.6 21.7^{a} ± 4.5	12.5^{d} ± 5.4 12.8^{d} ± 6.4	19.4^{b} ± 4.6 18.4^{b} ± 4.1	15.3^{c} ± 6.4 16.5^{c} ± 8.2	19.6^{b} ± 5.3 19.0^{b} ± 5.4	13.0^{d} ± 6.6 14.3^{d} ± 7.5
Fertile cones per fertile plant (X ± std. dev.)	rock margin	54 ± 73 76 ± 114	59 ± 86 80 ± 118	82 ± 91 43 ± 48	44 ± 65 70 ± 67	51 ± 75 127 ± 142	87 ± 150 107 ± 154
Height (cm) (X ± std. dev.)	rock margin	318^{a} ± 148 366^{a} ±148	169^{c} ± 96 186^{c} ± 104	217^{b} ± 69 249^{b} ± 55	172^{c} ± 92 199^{c} ± 112	241^{b} ± 76 235^{b} ± 71	167^{c} ± 82 205^{c} ± 126
Volume (m^3) (X ± std. dev.)	rock margin	25.0^{ab} ± 27.6 34.8^{a} ± 41.7	5.5^{d} ± 10.8 9.6^{cd} ± 21.6	13.8^{bcd} ± 13.6 13.7^{bcd} ± 13.4	10.3^{cd} ± 12.8 14.4^{bcd} ± 17.0	19.0^{bc} ± 20.8 17.1^{cd} ± 16.6	9.6^{cd} ± 18.4 17.6^{cd} ± 32.6

Other comparisons between rock and margin plants showed that margin plants had significantly greater height and volume, and had a consistently greater mean number of fertile cones (Table 2). This may be the result of greater access to moisture and nutrients, an effect that has been described for road-edge plants of *Banksia hookeriana* and *B. menziesii* (Lamont *et al.* 1994a, b). Alternatively, margin plants may be better protected from the strong coastal winds than the plants exposed on the granite.

The mean plant height and volume for *B. verticillata* was dependent on age, with the older Mt Hopkins population showing the greatest mean height and volume (Table 2.2). The significant difference in age between populations could be attributed to a range of factors such as fire, climate and edaphic differences between sites.

Maximum plant age recorded in all populations studied by Monks *et al.* (1994) was 27-32 years. The mean age of dead and live plants within a population did not differ significantly, suggesting that premature death of plants is common. Premature death may result from factors such as summer drought, disease infection or uprooting by strong winds. The granite rock habitat and presumably shallow root system make *B. verticillata* particularly susceptible.

An estimate of the minimum age to first seed production can be obtained by determining the x-axis intercept on a regression of age versus seed production for each populations studied (Monks *et al.* 1994). The mean age to first seed production varied from 13 to 17 years (Table 3) indicating a much longer juvenile period than other non-sprouters such as *Banksia cuneata* (4 years), *B. burdettii* (4-5 years), *B. leptophylla* (3 years) and *B. prionotes* (4-5 years) (Lamont *et al.* 1991, Lamont and Barker 1988, Cowling *et al.* 1987). This long juvenile period suggests that populations of *B. verticillata* would probably not be able to survive fires in quick succession because of the time needed to accumulate sufficient seed reserves for the postfire regeneration of a viable population

Population	Age at onset of seed production
Mt Hopkins	15
Poison Hill	14
Torndirrup burnt	14
Torndirrup unburnt	14
Waychinicup unburnt	17
Waychinicup burnt	13

Table 2.3 Age to first production of seeds for six populations of *B. verticillata* (from Monks *et al.* 1994)

2.5 Fire Ecology

B. verticillata is usually killed by fire (George 1987, Monks *et al.* 1994) although occasional observations of resprouting after fire have been made (Taylor and Hopper 1988). Populations rely on seed for regeneration, and while inter-fire seedling establishment has been observed, the majority of recruitment into a population occurs after fire. Monks *et al.* (1994) observed that after a mild fire in a population at Torndirrup National Park burnt cones released twice as many seeds as unburnt cones, and that burnt plants were ten times more likely to have seedlings growing under their crown than unburnt plants. For those burnt plants with seedlings there was a mean of 25.2 seedlings per plant. This is comparable with post-fire recruitment recorded for other non-sprouting *Banksia* species (Enright and Lamont 1989, Cowling and Lamont 1987).

The long juvenile period of *B. verticillata* (Table 2.3) indicates that a fire frequency of more than twenty years is necessary to enable adequate seed banks to accumulate. The granite outcrop habitat appears to offer some protection against fires, with plants growing at the rock margin more likely to be burnt by a mild fire than plants on the rock (Monks *et al.* 1994). This may not be the case in a hot fire where all plants are likely to be burnt.

2.6 Pollination Biology

Research by Reeves and Collins (1994) has shown that New Holland Honeyeaters (*Phylidonyris novaehollandiae*) are the major pollinators of *B. verticillata* populations at Stony Hill and Newhills in Torndirrup National Park. They were the most commonly captured honeyeaters at both sites, with White-cheeked Honeyeaters (*Phylidonyris nigra*) and Western Spinebills (*Acanthorhyncus superciliosis*) caught only at very low frequency. All captured honeyeaters carried heterospecific pollen loads, with *Adenanthos sericea* being the most common pollen type for all species. However, significant levels of *B. verticillata* pollen were found only on New Holland Honeyeaters (Fig 2.2).

Field observations confirmed that New Holland Honeyeaters appear to be the only honeyeater which forages on *B. verticillata* inflorescences in these populations (Rees and Collins 1994). Partly-open inflorescences, particularly those with up to two thirds of their flowers open, were visited more often and for longer periods than either buds or fully-open inflorescences. New Holland Honeyeaters foraged from either the top or side of the inflorescence, probing all over the inflorescence rather than restricting their foraging to a particular region. Individual birds were observed moving distances of up to 15m between inflorescences on different plants, although most consecutive movements occurred between inflorescences on the same plant.

Failure to recapture significant numbers of New Holland Honeyeaters, frequent observations of birds moving into and out of the sites and the presence in facial smears of large quantities of pollen from *Adenanthos sericea*, a plant species that did not occur at either site, suggests that most individuals were transients rather than residents (Rees and Collins 1994). Pollen transfer between neighbouring populations and between plants within populations may therefore be common, although the occurrence of heterospecific pollen loads on the bodies of pollen vectors may reduce the effectiveness of pollination.

Small mammals do not appear to be important pollinators of *B. verticillata* with only one Bush Rat (*Rattus fuscipes*) and seven mice (*Mus musculus*) captured over 45 trap nights at the Stony Hill and Newhills study sites (Rees and Collins 1994). Significant amounts of *B. verticillata* pollen were present in all smears, although larger loads of *Adenanthos sericea* were present for six of the eight animals. Honey Possums (*Tarsipes rostratus*) were not captured at either site, although they are known to be important pollinators for other banksias near the south coast (Collins *et al.* 1994). Honey Bees (*Apis mellifera*) were the only invertebrate observed collecting pollen, however they are not likely to be effective pollinators.

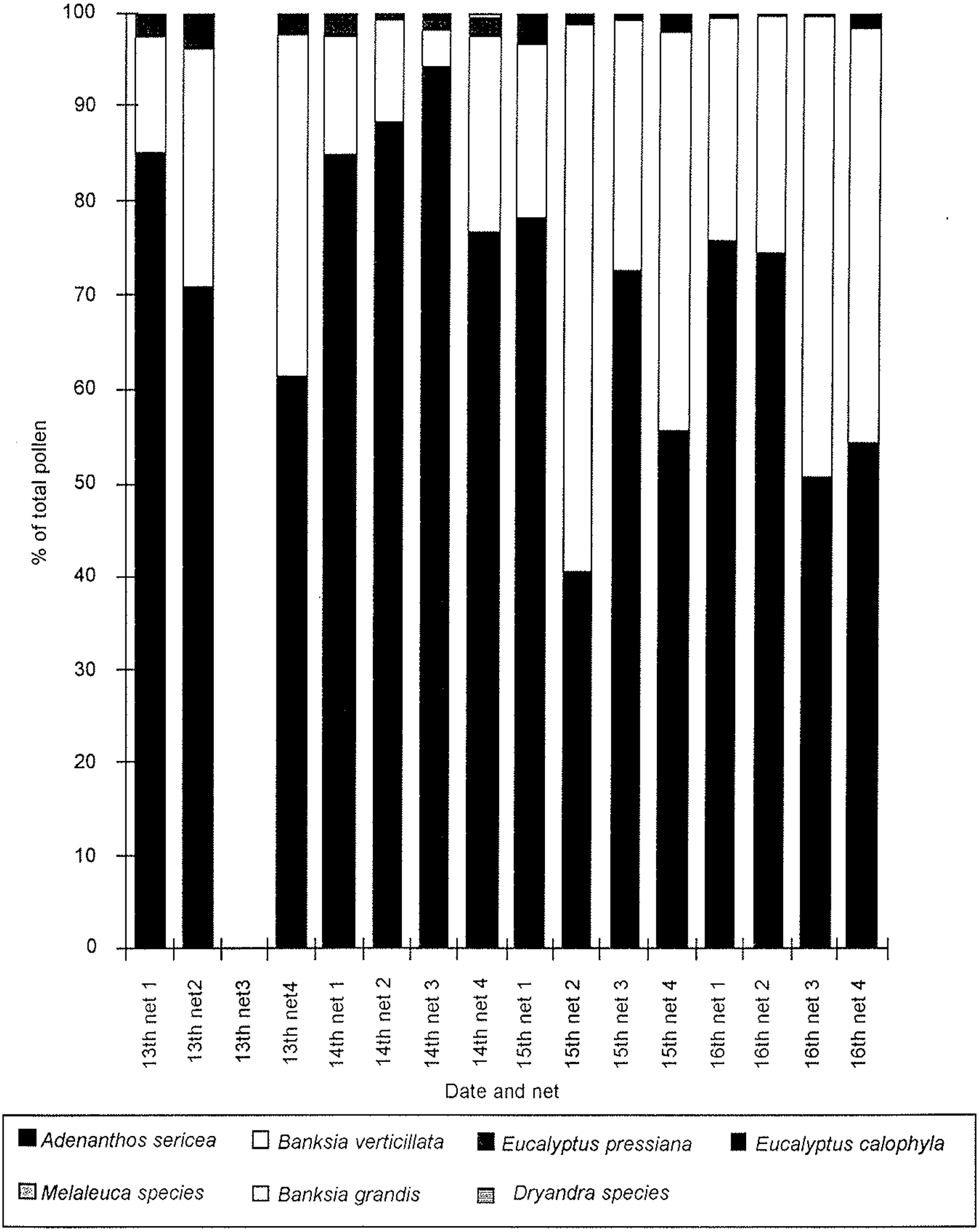

Figure 2.2. Pollen present in smears taken from New Holland Honeyeaters captured in Torndirrup National Park between 13th-16th February 1994 (from Rees and Collins 1994).

2.7 Reproductive Biology

Flowering in *B. verticillata* occurs between January and April (George 1981, Taylor and Hopper 1988, field observations). Flower opening commences from the base of the inflorescence, although random flowers or patches of flowers on the most exposed sides of inflorescences often open out of sequence (Rees and Collins 1994). Diurnal and nocturnal anthesis rates (% of flowers opening per hour) at the Stony Hill study site did not differ significantly and an estimated 9.5 days were needed for all flowers on a given inflorescence to open.

		Newhills	Stony Hill	Significance
Inflorescences / plant	1992 (est)	27.5 ± 5.3 (24)	17.1 ± 2.6 (20)	ns
	1993 (act)	19.4 ± 2.9 (40)	7.7 ± 1.3 (40)	***
	1994 (act)	24.8 ± 3.4 (40)	11.0 ± 1.9 (40)	***
Infructescences / plant	1992 (act)	10.1 ± 1.6 (40)	8.2 ± 1.0 (40)	ns
	1993 (est)	11.0 ± 2.3 (34)	4.7 ± 1.3 (37)	*
	1994 (est)	14.2 ± 2.7 (34)	6.7 ± 1.8 (37)	*
Total infructescences / plant			54.3 ± 2.6 (40)	
Mean follicles / infructescence	1992	89.1 ± 4.1 (81)	95.8 ± 3.3 (80)	ns
	1993	67.7 ± 6.0 (41)	80.3 ± 5.0 (34)	ns
Fruiting success %		43.1 ± 6.1 (34)	38.7 ± 6.8 (37)	ns
Fruit set 1993 %		8.4 ± 0.6 (41)	11.4 ± 0.6 (34)	***
Mean plant height (m)		1.9 ± 0.1 (40)	1.7 ± 0.1 (40)	**
Biovolume (m^3)		12.8 ± 1.9 (40)	6.9 ± 0.6 (40)	**

Table 2.4. Inflorescence and infructescence production, fruiting success and biovolume for *Banksia verticillata* at the Newhills and Stony Hill study sites (from Rees and Collins 1994). Values indicated are means ± standard errors. Sample sizes are given in parentheses. Differences were either not significant (ns), or significant at the P<0.05 (*), P<0.01 (**), or P<0.001 (***) levels.

Rees and Collins (1994) recorded a positive, linear relationship between biovolume and both inflorescence and infructescence production at the Newhills and Stony Hill populations during the 1992-1994 flowering seasons. The significantly greater biovolume of plants at the Newhills population was reflected in the greater inflorescence and infructescence production at this site in two out of the three recording years (Table 2.4). A similar linear relationship between tree size and inflorescence production has been demonstrated for other *Banksia* species, with increased reproductive effort by larger plants thought to be a consequence of superior access to nutrient, water and photosynthetic resources (Collins *et al.* 1993, 1994; Lamont *et al.* 1994a, b). Changes in the availability of these resources may account for the seasonal variations observed in inflorescence production.

High levels of fruiting success (% of inflorescences that develop into fertile infructescences) were recorded for *B. verticillata* with 43.1% and 38.7% of the inflorescences produced at the Newhills and Stony Hill sites during 1993 developing follicles (Rees and Collins 1994). Collins and Rebelo (1987) reported fruiting success ranging from 5-97% for sixteen *Banksia* species. In comparing rock and margin plants Monks *et al.* (1994) found that for all but one population the margin plants had a greater (although not significantly different) number of fertile cones per fertile plant (Table 2.2). As mentioned previously an edge effect resulting from greater access to moisture and nutrients, as has been described for road-verge plants of *Banksia hookeriana* and *B. menziesii* (Lamont *et al.* 1994a, b), may be contributing to the greater seed production of margin plants. There was no significant difference in the number of fertile plants occurring on the rock and margin (Monks *et al.* 1993).

The mean fruit set (percentage of florets that developed into follicles) for fertile infructescences at the Newhills (8.4%) and Stony Hill (11.4%) populations (Table 2.4) was relatively high compared to values calculated for other *Banksia* species which ranged from 0.1-7.2% (Collins and Rebelo 1987). Spatial constraints did not limit the number of follicles that developed (table 5), with reproductive success likely to be limited by a combination of factors such as pollen availability and quality, nutrient resources and disease or predation (Rees and Collins 1994).

	Mean ± s.e.	Sample size
Infructescence surface area (mm^2)	13 926.06 ± 792.90	36
Follicle surface area (closed) (mm^2)	57.30 ± 1.99	31
Follicle surface area (open) (mm^2)	79.22 ± 2.68	29
Actual % fruit set	12.69 ± 0.73	36
Maximum possible % fruit set (closed)	32.93 ± 1.30	31
Maximum possible % fruit set (open)	24.17 ± 0.91	29

Table 2.5. Surface area of *Banksia verticillata* infructescences, and associated open and closed follicles, collected from Torndirrup National Park (from Rees and Collins 1994).

A significant positive linear relationship between inflorescence production and percentage fruiting success was evident at the Stony Hill site during 1993, although there were no significant relationships between biovolume and fruiting success or mean fruit set, or between inflorescence production and mean fruit set, at either site (Rees and Collins 1994). The number of follicles per infructescence, mean inflorescence and infructescence lengths, number of florets per inflorescence and fruiting success did not vary significantly between sites, although the percentage fruit set on sample inflorescences was significantly greater at the Stony Hill study site during 1993 (Table 2.4).

In *B. verticillata* significantly more follicles occur in the middle third of the infructescence than in either the apical or basal thirds (Fig. 2.3). This non-random distribution of follicles may be a consequence of factors such as preferential pollinator visits to partly-open inflorescences and differential resource allocation due to inter-ovary competition in the apical portion (Collins and Spice 1986, Collins *et al.* 1993, Vaughton 1993).

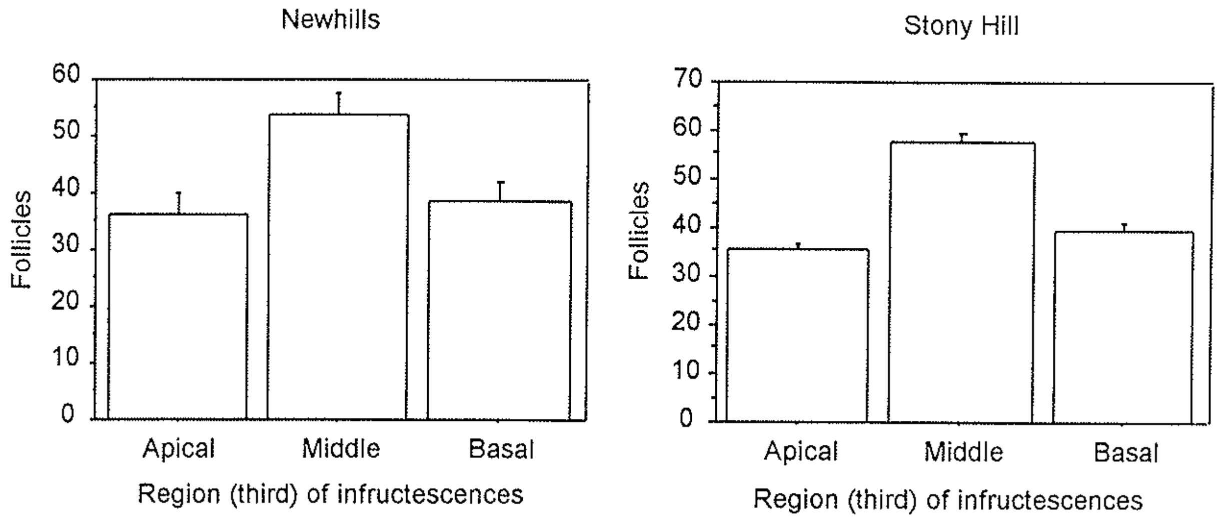

Figure 2.3. Distribution of follicles along the length of *Banksia verticillata* infructescences collected from the Newhills and Stony Hill study sites (from Rees and Collins 1994).

Rees and Collins (1994) estimated that only 19.6% of the seed produced at Stony Hill during 1993 was viable. This result is comparable with viability calculated by Monks *et al.* (1994) for another population in Torndirrup National Park (Table 2.6). Based on this value the mean viable seed production per plant at Stony Hill during 1993 was 149. Assuming that the percentage of viable seed is similar, mean viable seed production per plant at the Newhills site during 1993 would be 299. The total viable seed stores are likely to be much greater as seed is retained in the canopy for several years until a disturbance such as fire triggers mass seed release.

	Mt Hopkins	Poison Hill	Torndirrup burn	Torndirrup unburnt	Cheyne Beach	Waychinicup burn
Age	21.7^{a} ± 4.6	12.5^{d} ± 5.4	19.4^{b} ± 4.6	15.3^{c} ± 6.4	19.6^{b} ± 5.3	13.0^{d} ± 6.6
% seeds released	15.6^{abc} ±23.5	26.4^{ab} ± 19.1	31.1^{a} ± 34.7	8.7^{bc} ± 11	23.0^{abc} ±23.8	6.9^{c} ± 13.3
% seeds decayed/eaten	32.2^{a} ± 22.6	20^{a} ±12.8	29.2^{a} ± 19.7	33.1^{a} ± 24.7	29.5^{a} ± 12.0	30.4^{a} ± 13.9
% seeds aborted	38.2^{ab} ± 21.8	40.0^{a} ± 7.7	26.2^{b} ± 16.1	35.9^{ab} ± 18.5	31.4^{ab} ± 9.7	37.8^{ab} ± 8.9
% seeds (firm) viable	4.2^{d} ± 9.3	10.5^{cd} ± 15.7	9.1^{cd} ± 16.4	19.7^{ab} ± 9.2	12.7^{bc} ± 12.4	21.9^{a} ± 9.2
% seeds (firm) non-viable	9.3^{a} ± 19.9	3.1^{a} ± 4.8	4.3^{a} ± 9.5	2.5^{a} ± 5.9	3.3^{a} ± 5.5	3.0^{a} ± 8.4

Table 2.6. Mean percentage of released, decayed/eaten, aborted, viable and non-viable seeds in cones from six populations of *Banksia verticillata* (from Monks *et al.* 1994). Values are given as mean ± standard deviation (from arcsin transformed data). Different letters denote population means that are significantly different from each other.

In the populations studied by Monks *et al.* (1994), seed viability did not appear to be directly correlated with plant age, with both older (Mt Hopkins, Torndirrup burn, Cheyne Beach) and younger (Poison Hill) populations experiencing low levels of viability (Table 2.6). It may be that as plants mature they reach a peak in fertility followed by a reduction as they get older. Alternatively, viability levels may be determined by other factors such as local habitat conditions, disease infection, population size and levels of inbreeding, and pollinator numbers and behaviour.

The proportion of aborted seed was high, with five of the six populations experiencing between 30% and 40% abortion. Seed release varied considerably between populations, and did not appear to be directly related to age. Highest levels of seed release were recorded for the burnt Torndirrup population. While all calculations for this population were made from unburnt plants it is possible that the heat of the nearby fire triggered the opening of follicles and the release of seed (Monks *et al.* 1994).

The proportion of decayed/eaten seed did not differ significantly between the populations (Table 2.6) suggesting that the causes of decay or granivory operate to similar degrees in all populations. A weevil, *Myossita sublineata* (Order Coleoptera, Family Curculionidae) was found to be predating the seed of *B. verticillata* (Monks *et al.* 1994).

2.8 Seed Viability and *Ex Situ* Storage

LOCATION (POP NO)	COLLECTION DATE	QUANTITY STORED	INITIAL GERMINATION %	% GERMINATION AFTER STORAGE AT -18°C
Manypeaks (2 pops)	27/9/94 LW	4°C 6 cones (B/5)	na	
Stony Hill 3	6/4/93 MM	RT 63 cones (I/15)	47% at 28/6/93	
	20/4/94 JAC	RT 74 cones (I/13)	92% at 5/5/94	
Stony Hill east 13	10/5/86 DJC	-18°C 385 seed (I/13)	96% at 3/6/93 *	93% at 15/7/94
	12/12/92 MM	RT 199 cones (I/10)	70.5% at 28/6/93	23% at 15/9/94
Isthmus Hill 12	28/8/94 JAC	RT 115 cones (I/13)	100% at 15/9/94	
Gap 9	10/5/86 DJC	-18°C 425 seed (I/12)	na	96.5% at 15/7/94
Newhills 19	18/9/92 RW	RT 13 cones (B/6)	77% at 1/9/93	
Two Peoples Bay 5	1/1/93 CJR	RT 5 cones (I/1)	na	
Cheyne Beach 7,8,18	26/11/86 DJC	-18°C 395 seed (I/20)	42.5% at 3/6/93 *	
	23/8/93 JAC	RT 74 cones (I/16)	92% at 28/10/93	94% at 23/12/94
Mermaid Pt 28	9/1/94 JAC	RT 96 cones (I/13)	97% at 28/1/94	
Channel Pt 30	4/4/93 MM	RT 111 cones (I/25)	96% at 3/8/93	92% at 18/8/94
	23/8/93 JAC	RT 66 cones (I/8)	100% at 28/10/93 *	97% at 8/12/94
Waychinicup west 32	26/4/95 JAC	RT 65 cones (I/6)	97.5% at 5/5/95	
Ben Dearg Pt 29	28/4/95 JAC	RT 108 cones (I/12)	100% at 3/5/95	
Poison Hill 31	1987 DJC	-18°C 349 seed (I/9)	100% at 27/5/93	96% at 15/7/94
Mt Hopkins 6	1987 DJC	-18°C 160 seed (I/6)	30% at 20/4/93 *	
	1/6/87 DJC	-18°C 700 seed (I/19)	na	67% at 15/7/94
Woolbale Hills 15	7/4/93 MM	-18°C 508 seed (I/25)	67.5% at 12/8/93	73% at 7/10/94

Table 2.7. Seed accessions currently available in CALM's Threatened Flora Seed Centre and % germination following different storage regimes. * Denotes seeds that were germinated several years after collection

To date seed has been collected from 16 populations covering the known range for *B. verticillata*. The viability of seed within the first one or two years of collection and storage at room temperature, 4c or -18 c is generally very good showing >90% germinability (Table 2.7). However, seed collections made some 10 years ago from Cheyne Beach and Mt Hopkins where extracted seed was stored for some time at room temperature before being transferred to -18c show a marked reduction in viability. This contrasts with *B. brownii* where seed stored under similar conditions for up to 10 years generally showed no reduction in viability.

2.9 Transplant Experiments

Preliminary field germination trials conducted by Monks *et al.* (1994) showed that there was no significant difference in the percentage germination of *B. verticillata* in deep sand and granite sites. This indicates that establishment of populations in dieback free sites away from the granite outcrops may be possible, although more detailed research on seedling survival over time is required.

2.10 Conservation and Management

B. verticillata is known from a total of more than 4500 plants. It is well represented in conservation reserves throughout its range but is under threat due to its susceptibility to dieback disease (*Phytophthora cinnamomi*) and *Zithiostroma* sp aerial canker. Several of the populations have become extinct or are in decline, and many other populations are vulnerable to infection.

Major considerations and recommendations for the conservation and management of this species are outlined below.

1. Control of disease due to *Phytophthora cinnamomi* and *Zithiostroma* sp, and to a lesser extent *Armillaria leuteobubalina* is a major concern in relation to the short term survival of this species. Phosphonate application for the control of *P. cinnamomi* is required on some populations such as Woolbale Hills with a follow up spray every three to four years. Research is required into the control of *Zithiostroma* sp and *Armillaria leuteobubalina.*

2. Pollination studies suggest that *B verticillata* is dependent on bird pollinators particularly New Holland Honeyeaters to effect cross pollination and maximise seed production and viability. These pollinators, in turn, rely on associated plant species particularly *Adenanthos sericea* in areas adjacent to the populations, for food and shelter. Studies on pollinator movement suggest that they do not maintain a permanent presence within the *B. verticillata* population but rely more on the adjacent vegetation for permanent food and shelter. Changes in habitat composition and structure primarily due to loss of species susceptible to *P. cinnamomi* may lead to a reduction in pollinator numbers and diversity (Wills and Keighery 1994). This suggests that *P. cinnamomi* control should not only target *B. verticillata* but all susceptible species (i.e. *Adenanthos sericea)* in the vicinity of the population.

3. The fire management regime of *B. verticillata* needs special consideration given the long juvenile period and reliance on seed for regeneration. A fire frequency of no less than twenty years is recommended. Interfire seedling establishment appears to be unusually common, indicating that population recruitment could be maintained in the absence of fire.

4. The establishment of new populations of *B. verticillata* may need to be considered in the future. Seed for this purpose has been collected from representative populations throughout its range, and is being held in long-term storage at the Threatened Flora Seed Centre at the WA Herbarium. Preliminary studies indicate that establishment of populations in dieback free sites away from the granite outcrops may be possible Such recovery action will require further research on seedling survival under different edaphic and environmental conditions.

5. *B. verticillata* has two disjunct groups of populations which may be genetically distinct and warrant recognition as discrete units for conservation and management. As with *B. brownii* allozymes have proven not suitable for detecting genetic differences between populations and it is recommended that other molecular markers be utilised to investigate any possible differences.

Although most populations of *B. verticillata* are in reasonably good condition the presence of *Phytophthora cinnamomi* dieback and *Zithiospora* sp aerial canker in some populations poses a significant threat. The immediate preparation of a recovery plan is not recommended but close monitoring of disease status in populations of this species is needed. If there is any significant increase in disease threat to populations the preparation of a recovery plan may need to be reconsidered. Management and research actions specifically targeting disease control and population re-location should be given the highest priority.

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