Conservation Biology of the Rare and Critically Endangered *Synaphea quartzitica* and Common *S. spinulosa*

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ABSTRACT

In 1998, there were 341 taxa of flora recognised as rare (threatened) in Western Australia. One of the recent inclusions to this list was *Synaphea quartzitica*, a small shrub in the family Proteaceae that is endemic to Western Australia. It was later declared Critically Endangered because of its low number of plants, its scattered distribution within and between populations, and threats associated with growing in a specialised habitat. This study investigated key aspects of conservation biology, concentrating on population and reproductive biology, and habitat specificity of *Synaphea quartzitica* compared with the common *Synaphea spinulosa.* Comparisons were made to gain insights into any differences between a rare and closely related common species.

The research involved the recording of data and collection of samples at two populations for each species, located in the Moora-Watheroo district of south-western Australia. Results of the population biology studies suggest that the *S. quartzitica* populations are stable, and the species is most likely fire-tolerant because of its root suckering capabilities. Low numbers of seeds were found in the soil seed bank, which reflects the low seed set observed for both species. The low seed set was attributed to ineffective pollen transfer. The main limitation to potential population growth for *S. quartzitica* was hypothesised to be low seed set. However, results showed that there was no significant difference between the species in seed set. Therefore, low seed-set could not be considered a factor contributing to the rarity of *S. quartzitica*. Overall, *S. quartzitica* and *S. spinulosa* showed no apparent differences that could explain the rarity of *S. quartzitica*, except for its habitat. The results showed that *S. quartzitica* is part of a unique ecological community, growing on a restricted chert substrate, with the surrounding vegetation and litter at low densities. It is concluded that growing in this specialised habitat over a restricted range is the major cause of rarity for *S. quartzitica*. The threats and constraints to population growth were ranked, with habitat loss the most important threat. Seven recommendations for the management of *S. quartzitica* were made in light of the results of this study.

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Gratitude goes to the staff at the Western Australian Herbarium and the Department of Environmental Biology at Curtin University for all their assistance.

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Acacia aprica* and *Acacia cochlocarpa* ssp. *cochlocarpa

1. The research we have done on the Conservation Biology of *Acacia aprica* and *Acacia cochlocarpa* ssp. *cochlocarpa* (see Yates and Broadhurst 2002) demonstrates that both species are in severe decline because across all populations the mortality rate exceeds the birth rate. There are number of reasons for the declines related to life-histories, climate, landscape context, the fire regime and competition with herbaceous weeds.

- Both species are non-sprouters killed by fire or drought, plants are likely relatively short-lived and have seeds with hard integuments that are long lived in the soil.
- The high rates of mortality are most likely a consequence of many plants reaching the end of their life-span. In addition mortality rates in the last three years may be higher because of exceptionally dry winters putting plants under increased stress.
- The low birth rates are not related to reproductive biology but to the availability of the regeneration niche. Both taxa produce fertile flowers and enough seeds to replace themselves independent of population size or landscape context. Seed production varies considerably between years but because seeds are long-lived in the soil there is a "storage effect" whereby years of high seed production compensate for years of low seed production and buffer populations against extinction.
- The low birth rates are most likely a consequence of the availability of the regeneration niche. Our experiments show that germination is an order of magnitude higher following fire or some treatment that simulates fire (exposing seeds to heat). The heat generated in a fire ruptures the hard seed coat allowing the uptake of water and oxygen. Similarly our experiments show that seedling establishment is an order of magnitude higher where competition from weeds is removed. Grazing has a negligible effect on seedling establishment at the two *A. aprica* sites we studied but this needs to be interpreted with caution because the intensity of grazing may be highly site specific.
- The conclusions from this research are that to maintain populations of both species *in-situ* birth-rates need to increase, this can be done either by undertaking plantings with tube stock within populations, or stimulating germination of the soil seedbank in populations with prescribed fire applied at a appropriate scale. Either action would need to be undertaken in conjunction with weed control.

2. Even if we are able to increase birth rates *in-situ*, both species are still at great risk of extinction. *A. cochlocarpa* ssp. *cochlocarpa* is known from a road verge and adjoining small linear remnant on private property and two sites in the same Nature Reserve where it has been translocated. *Acacia aprica* is restricted to highly disturbed narrow road verges, a small remnant on private property and a site where it has been translocated. In all cases the populations are small.

3. The logical action to reduce extinction risk is to increase the number of populations preferably on lands that are vested for nature conservation. A limited number of translocations have been undertaken by Leonie Monks. For each of the species this has primarily been experimental and while reducing the immediate extinction risk of both species, has not improved their conservation status in a ranking context. This was not the primary aim of Leonie's important and effective research that sought to demonstrate that translocations could be done and what were the most effective techniques for doing them. It is my view that translocations of this species are necessary to downgrade them from Critically Endangered to Endangered.

4. It is my view that the priorities for *Acacia aprica* and *Acacia cochlocarpa* are

- to continue to accurately resurvey the populations to determine whether the rate of decline in *A. cochlocarpa* and warrants action to increase birth rates. We have permanently tagged plants which will enable monitoring and trend analysis
- find further translocation sites
- undertake planning for translocations, e.g. workout when seeds need to be collected, when they need to be got to Kings Park I would like to see translocations in the order of

Grevillea althoferorum

1. The research we have done on the Conservation Biology of *Grevillea althoferorum* (see Burne, Yates and Ladd 2003) demonstrates that both the northern and southern populations are probably quite stable

- The species is a sprouter and
- Our research shows that the northern population the Moora District is clonal and was actively recruiting from root suckers. There was no evidence of sexual recruitment.
- The reasons for this are a function of reproductive biology. In *G. althoferorum* at Eneabba mean pollen viability was 9% with on average 62 viable pollen grains per bud. Compare this with *G. synapheae* which is a facultative sprouter that reproduces sexually which had over 99% pollen viability and on average over 4500 pollen grains per bud. The conclusion is that *G. althoferorum* at Eneabba is sterile.
- Therefore not surprisingly no seeds are produced and there was no evidence of a soil seed bank.
- The loss of sexual reproduction is common in plants that have become clonal.
- Because *G. althoferorum* is clonal and can't reproduce sexually, it's population dynamics are most sensitive to the destruction of existing plants.
- Because the population is restricted to a road verge, experience tells us that it is highly susceptible to accidental destruction. Consequently translocating the species would be highly desirable. However, because it is sterile our options for growing plants are limited and would be restricted to vegetative propagation either by cuttings or tissue culture.

2. It is my view that the priorities for *G.althoferorum* are

- to protect the existing population from destruction
- to continue to accurately resurvey the population to determine whether the population is continuing to remain stable. We have permanently tagged plants which will enable monitoring and trend analysis.
- to initiate research on the most effective means of propagating the species

Synaphea quartzitica

It is my view that you should be setting up a works program for the

1. Sets up a fixed point monitoring system to determine whether populations are stable, declining or increasing. If they begin to obviously decline
2. base a works program

CHAPTER 1

GENERAL INTRODUCTION

This study investigated key aspects of conservation biology, concentrating on the population and reproductive biology of the rare and critically endangered *Synaphea quartzitica* compared with the common *Synaphea spinulosa*. The comparative research was designed to provide insights into the factors limiting population growth. This chapter discusses conservation, rarity, other comparative studies, and gives a description of the genus *Synaphea*. Chapter 2 introduces the species, locations and aims of the study. Chapter 3 investigates the population biology and habitat specificity, followed by the reproductive biology in Chapter 4. The final Chapter consists of a general discussion.

1.1 Conservation

Conservation biology is the scientific discipline concerned with the management of biological diversity (Burgman & Lindenmayer 1998). The term biological diversity (or biodiversity) describes the variety of all living things; the different plants, animals and microorganisms, the genetic information they contain and the ecosystems they form (Dept. of Environment 1996). Diversity occurs in distinctive populations and genetic differences, and richness is expressed in the unique and complex ecological communities (Australian & New Zealand 2001).

So why do we need to conserve biodiversity? Knox *et al.* (1994) presents five reasons for conserving biodiversity. The first reason is an ecological one. Organisms play roles in ecological systems that are essential for ecosystem functioning. Processes within the ecosystems are complex, and loss of species may have a substantial impact. The second is a practical one. We use organisms for our own benefit (eg. food, resources). Loss of any of the diverse components may result in lost possibilities, i.e. pharmaceuticals. The third reason for conserving biodiversity is one of aesthetics. We enjoy the beauty of plants and animals, their complexity and

wildness. This 'bond' with nature is often incorporated into recreation and tourism, which is also of economic significance. The fourth reason is a matter of philosophy. Should we allow a species to become extinct if we can save it? Ethical considerations include cultural and spiritual values. The fifth reason is our custodial responsibility. Biodiversity should be conserved as a matter of principle, or moral obligation to future generations.

Australia's biodiversity is a significant national asset and is recognised internationally as of global significance. It has been estimated that Australia possess over 500 000 species, a high percentage of which occur nowhere else (Dept. of Environment 1996). Research to date has concentrated on particular groups within Australia's biodiversity. More than 90 % of Australia's mammals, birds, reptiles and frogs, and some 70 % of its flowering plants, conifers ferns and other vascular plants have been identified (Australian & New Zealand 2001). Priority research aims to list and characterise Australian native species and record their distribution, with the highest priority given to species that are or may be threatened (Australian & New Zealand 2001).

In 1998, there were 341 taxa of flora recognised as rare (threatened) in Western Australia (Atkins 1998). One of the recent inclusions to the list was *Synaphea quartzitica*, a small shrub in the family Proteaceae that is endemic to Western Australia. In November 1998 this species was categorised as Critically endangered (CR) in the International Union for Conservation of Nature's (IUCN) Red List Categories (IUCN 2000). Recently these categories have been revised, and as a result the term rare is no longer used in the classification system. The structure of the new classification system and categories are presented in Figure 1.1.

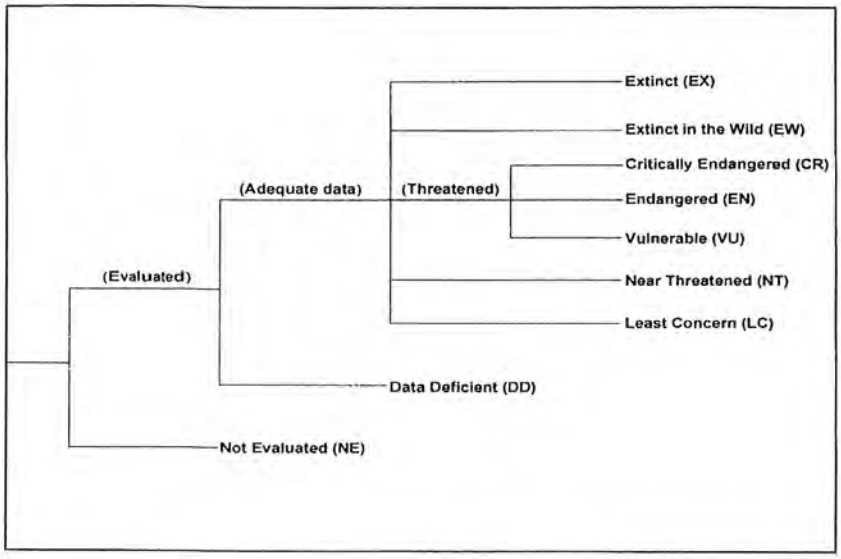

Figure 1.1 Structure of the IUCN Red List Categories (IUCN, 2000).

1.2 Rarity

In population and community biology the term rare generally refers to species that have low abundance, limited distribution (range) or both (Burgman & Lindenmayer 1998, Gaston 1994). Fiedler and Ahouse (1992) suggest that rarity describes three situations in terms of distribution and abundance of a particular species: (1) taxa whose distribution is broad but population sizes are never large where known, (2) those whose distributions is clumped or narrow yet whose populations are represented by many individuals where they are found; and (3) those taxa whose distribution are clumped and whose individual abundance is low where known.

One of the difficulties in recent work on rare plants is confusion between short-term and evolutionary time scales (Fiedler 1986). Because of the short-term nature of most scientific investigations on plant species, certain taxa may be designated rare when, in an evolutionary sense, they are not. They may be undergoing short-term levels of depressed population numbers (Fiedler 1986). As a result of this confusion, Fiedler and Ahouse (1992) classify rarity further using a third parameter, temporal persistence. This classification distinguishes between rare distributions that are

followed or preceded by quite different relative abundances from those that persist as rare over a very long period of time.

Darwin (1859) wrote that rarity was a necessary precursor to extinction and that until the reasons for rarity were established, we could not explain extinction. Fiedler (1986) first proposed a list of factors as necessary and sufficient for the understanding of the causes of rarity in vascular plants, that has been modified since (Table 1.1). Four causal hierarchies derived from these factors serve as the basis for predictive classification (Fiedler & Ahouse 1992). The question of what causes rarity can be addressed by studying in detail the biology, evolutionary and recent history and demographic patterns of the particular species that have been categorised rare and to determine what limits their abundance and range size (Fiedler 1986, Gaston 1994).

Table 1.1 List of probable causes of rarity in vascular plant species (Fiedler & Ahouse 1992).

1. AGE OF TAXON	8. POPULATION DYNAMICS
2. COEVOLUTION	9. HUMAN USES
3. EARTH HISTORY	10. REPRODUCTIVE BIOLOGY
4. ECOLOGY	11. STOCHASTICITY
5. EVOLUTIONARY HISTORY	12. TAXON GENETICS
6. LAND-USE HISTORY	13. TAXONOMIC HISTORY
7. LIFE HISTORY STRATEGIES	

Rarity is unlikely to be the result of environmental determinants alone. Dispersal, competition, predation and other biotic factors are likely to play a role. Rarity in any specific instance will be an interaction between the fundamental niche of a species, its ecological role in the community and the chance events related to dispersal, reproduction and survival or both (Burgman & Lindenmayer 1998). There is some evidence that the conditions which define the niche of some rare species are unusual, but there is no correlation between local abundance, geographic rage and the range of environmental conditions that a species can tolerate. An understanding of what constitutes habitat for rare species is critical however, given that habitat loss is

considered to be the most important factors leading to the decline of many of the world's extinct, threatened and vulnerable species (Recher & Lim 1990).

Populations of plants are increasingly subjected to size reduction and fragmentation through human action. Recently, human impacts such as fire suppression, direct habitat alteration, increased herbivore population, and horticultural fancy, have been potential causes of rarity (Fiedler 1986). It can be suggested that certain characteristics therefore predispose a species to extinction as a direct consequence of human impact. These may include species whose habitat overlaps with the habitat preferred by people, palatability or other consumption values to humans or livestock, and limited adaptability and resilience to environmental disturbance.

At coarse scales, the concept of rarity is closely allied to that of endemism. Species are endemic to an area if they occur within it and nowhere else. They will thus tend to have smaller range sizes and abundances than those species which are not endemics (Gaston 1994). Endemism and rarity, however, are not interchangeable. Kruckeberg and Rabinowitz (1985) state the narrow or local endemic is the one that best fits the colloquial notion of rarity. However, the term endemism, in its classical biogeographical usage, does not necessarily imply rarity or even a small range (Gaston 1994).

The terms rare and threatened are also not interchangeable. When something is rare it is not necessarily threatened with imminent extinction, just as species that are likely to become extinct in the near future are not necessarily those that are rare, restricted or specialised at present (Burgman & Lindenmayer 1998). However, there are direct relationships between rarity and conservation status that are associated with the elements of rarity .

The terms threat and threatened are collective terms that refer to taxa that face an appreciable risk of decline or extinction. A threatening process is a process that detrimentally affects or may detrimentally affect, the survival, abundance,

distribution or potential for evolutionary development of a native species or ecological community (Burgman & Lindenmayer 1998). Faulk (1990) suggests that usually a decline in natural populations is the result of multiple impacts, and has listed the kinds of threats faced by plants:

1. destruction of habitat,
2. competition by invasive species,
3. loss of pollinators, dispersal agents, host species or symbionts,
4. genetic drift, genetic swamping, inbreeding, demographic variation or other consequences of small population size, and
5. the destruction of individual plants or populations by disease, foraging or collecting.

The causes of rarity, and the threatening processes affecting Western Australia's flora, have been described as continual clearing and habitat destruction, plant diseases (eg. dieback *Phytophthora cinnamomi*), weed invasion, salinity, grazing by feral herbivores, indiscriminate herbicide application, lack of suitable pollinators resulting in poor or no seed set, and inappropriate fire regimes (Brown *et al.* 1998). Fire is a complex factor because the flora of Southern Australia is clearly defined on the basis of its responses to fire (Gill 1981).

Pate & Hopper (1993) recognises five basic categories of life history strategy in relation to fire; (1) obligate seeders, which are destroyed by fire and recruit thereafter solely from seed, (2) resprouters, which have part or all of their above-ground parts killed by fire but which then form new shoots from fire resistant emergency buds in their trunks or rootstock (3) fire ephemerals, which avoid fire in time by germinating exclusively after fire and complete their growth cycle before the likely advent of the next fire, (4) regular ephemerals, which achieve reproductive maturity, reproduce and die within the 6-8 month winter/spring growing season when fires are unlikely to occur, and (5) geophytes which are also strictly winter-active but avoid fire in space and time by perennating by means of various types of underground storage organs. An understanding of the regeneration niche of rare

species appears to be central to explaining their rarity (Pate and Hopper 1993). For example, fire can kill adult plants of many species that are obligate seed regenerators, but used appropriately it can stimulate regeneration (Hopper *et al.* 1990).

Not all causes of rarity in Western Australia are due to human action. Brown *et al.* (1998) states that highly localised distributions, rarity and small population sizes are natural features of many south-western Australian plants, and it is these features that make so many species especially prone to extinction by the threatening processes affecting the Western Australian flora. South-western Australia has a remarkable level of plant species richness, rapid turn over of species across landscapes, and a large number or rare, locally endemic plants (Hopper 1992). Of an estimated 8 000 species of vascular plants in this region, at least 75% are endemic (Hopper 1992). As a result of a long and complex evolutionary history, a significant proportion of this flora consists of relictual species that often have naturally geographically restricted and fragmented or disjunct distributions (Hopper 1979). This significant proportion of species diversity is present in the semi-arid Transitional-Rainfall Zone.

Hopper (1992) states that the Transitional Rainfall Zone flora has had to cope with small population sizes induced by climatic changes, and as a result has a higher concentration of rare and endangered local endemics than most other parts of the world. It is this exceptional concentration of endemic species that are undergoing an exceptional loss of habitat that makes south-western Australia one of 25 'biodiversity hotspots' in the world (Myers *et al.* 2000). Western Australia is thus of international importance in terms of richness and uniqueness of the flora, and number of its flora that is rare or threatened.

1.3 Comparative studies

Comparative studies on the biology of rare and common species are performed to examine any differences that may account for species rareness. A study by Witkowski and Lamont (1997) on two closely related *Banksia*'s were done to

determine if the rare *Banksia goodii* had inferior vegetative or ecological attributes compared with the biology of *B. gardneri*. The results provided few insights as to why *B. goodii* is rare. Differences in present or prehistoric fire regimes, habitat fragmentation, susceptibility to pathogens or impacts on alien invasives could not explain the distribution of *B. goodii* relative to *B. gardneri*. The authors concluded that the rarity of *B. goodii* may be a result of its recent origin, habitat specialisation and the impacts of habitat fragmentation within its current range, rather than inferior vegetative, reproductive and/or ecological attributes.

Fiedler (1987) examined the life history and population dynamics of rare and common Mariopsa lilies (*Calochortus*) and determined that the edaphically restricted rare species differed in some aspects from closely related widespread congeners, but not in others. Two out of the three rare species showed differences in the characteristics that favour the persistence and proliferation of the common species. However, one species appeared at least as sexually robust as the common. The third species was thought to be rare because of its limited geographic distance. It was concluded that rarity in populations of three Mariopsa lilies appears rather idiosyncratic, and few generalisations should be drawn across taxa or conspecific populations.

Results of these studies are often used to determine what management practices should be used to conserve the species. For example, Sydes and Calder (1993) studied two morphologically similar sun-orchids, one vulnerable (*Thelymitra circumsepta*) and one widespread species (*T. ixioides*) with respect to their reproductive ecology. The two species differed in floral display, reproductive efficiency and breeding systems. The widespread species was shown to be insect-pollinated which contrasts with the auto-pollinated vulnerable species. *T. circumsepta* has developed a process that assures the production of seed even if insect pollinators are absent. The authors propose that the progeny of auto-pollinated species may be advantaged in terms of loss of variation because they are genetically similar to their parents that have already adapted to local environmental conditions,

especially in a stable habitat. From these results it was concluded that the conservation of the vulnerable species is dependent upon the maintenance of the stable habitat, without the dependence of a biotic pollinator, compared with the widespread species, which requires a habitat that supports a diverse flora and an active community of native bees.

Rarity is a complex issue that often generates confusion. There are many situations that can result in a species being classified as rare, either in terms of distribution and abundance. There have been numerous causes of rarity proposed, with many still yet to be understood. Some comparative studies have suggested causes of rarity of particular species, however, few generalisations can be made across taxa. A sound biological knowledge of ecological and reproductive processes is vital as part of a foundation for conservation. If the constraints and threats to population growth are understood, then there is a greater chance for success in the future. This is important in Western Australia because of the large number of rare or threatened flora.

1.4 Description of the Genus *Synaphea*

Synaphea R.Br. is named from the Greek *synaphe* (a connection) in reference to the column connecting the stigma and the sterile filament. The genus *Synaphea* is a member of the Proteaceae family, in the tribe Conospermeae, one of the most homozygous in the family. The genus is endemic to south-western Australia, comprising 50 recognised species (which is currently under review).

George (1995) describes *Synaphea* as small shrubs, sometimes with a fire tolerant rootstock, and sometimes suckering. Adult leaves are usually pinnatipartite, simple or little divided. Flowers are bisexual, in terminal or axillary spikes, each solitary, subtended on a bract. The perianth is tubular, zygomorphic and yellow in colour. Flowers are scentless or some are possibly faintly scented. Nectaries are absent. At anthesis the anthers and stigma are held tightly under tension; when touched the stigma flicks across and the pollen is ejected. Pollinators are unknown. Partial male sterility is present, in which the abaxial stamen is 2-locular and completely fertile,

while the adaxial is sterile. The two lateral stamens are 1-locular. The lower part of the stigma is flat and expanded; it is produced into two lobes or horn above. The stigmatic surface is lateral and faces away from the fertile stamen, held in position by a membranous outgrowth of the staminode (Venkata-Rao 1971). The ovary is 1-locular with an apical ring or large translucent glands of which the purpose is unknown. The fruit is an obovoid ellipsoidal or cylindrical crustaceous nut.

CHAPTER 2

BACKGROUND, STUDY SITES AND AIMS

2.1 Background

The first known collection of *Synaphea quartzitica* (Figure 1) was from the Moora area in 1908 by Dr. J. Burton Cleland. However, it was not named till 1995 by A.S. George. *S. quartzitica* was declared as Rare Flora by the Western Australian Threatened Species and Communities Unit (WATSCU) in July 1998 (Stack & English 1999). Later that year it was declared Critically Endangered under the IUCN rules because of its low number of plants, its scattered distribution within and between populations, and threats associated with growing in a specialised habitat.

As part of a management program for Declared Rare Flora, staff at the WATSCU have developed an interim recovery plan for *S. quartzitica* which aims to abate and identify threats and maintain viable *in situ* populations to ensure long term preservation of the species in the wild (Stack and English 1999). The rarity of *S. quartzitica* has been exacerbated by the extensive clearing for agriculture that has occurred in the area. Threats to known populations have been identified as mining and gravel extraction, grazing, track maintenance and inappropriate fire regimes (Stack and English 1999). The recovery actions as recommended by Stack and English (1999) are:

1. Coordinate recovery actions.
2. Preserve genetic diversity of the species.
3. Control rabbits.
4. Monitor populations.
5. Investigate biology and ecology.
6. Install Declared Rare Flora (DRF) markers.

7. Develop a fire management strategy.
8. Ensure mining and quarrying do not impact Population 1.
9. Conduct further surveys.
10. Promote awareness.
11. Negotiate to acquire area that contains Population 1.
12. Write full Recovery Plan.

Synaphea spinulosa was chosen as the comparative species because it is closely related to *S. quartzitica,* occurs within the same area and is a common species. It is widespread north of Perth as far as the Eneabba district and south along the coastal plain to Bunbury (George 1995). The flowering periods of the two species are similar, with *S. quartzitica* flowering July-August, and *S. spinulosa* July–October. This made sampling convenient and achievable in the time permitted for this study.

Figure 2.1. *Synaphea quartzitica* in flower. (Tag = 73mm)

Figure 2.2. *Synaphea spinulosa* in flower. (Height approx. 40 cm).

2.2 Study Sites

The quartz-loving *Synaphea (S. quartzitica)* is a sub-shrub present on Noondine (Coomberdale) Chert hills in the Moora-Watheroo area of Western Australia (Figure 2.3). The town of Moora is located 172km North of Perth, and is the administrative centre of the local shire. It is located at the foot of the Darling Scarp, between the Danadaragan and the Great Plateaus (McArthur 1991). The soils are alluvium around the Moore River and its tributaries. West of the alluvium zone the landscape is dominated by sandy surfaced soils that are either remnants of the old lateritic surface, or the weathering products of sediments of the Dandaragan Plateau (McArthur 1991). Moora has a temperate climate with average temperatures ranging 17.2-34.3°C in January and 6.7-17.7°C in July. The annual rainfall is 464 mm, with a mean number of 92 rain days (Bureau of Meteorology 2000).

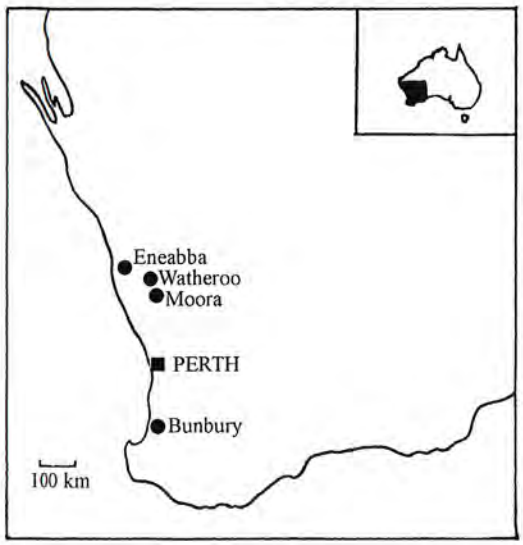

Figure 2.3. South-western Australia showing the locations of the towns mentioned in the text.

The Coomberdale Chert forms low rocky hills covered by open low woodland, and is part of the Victoria Plains System (Beard 1979). The system, as described by Beard (1979), is a catena comprising of *Allocasuarina* thickets on residual sandplains, woodlands of *Eucalyptus loxophelba* and *E. salmonophloia* on red soils of lower ground, and mosaics of woodland, tea tree and samphire on salt flats. In addition there are patches of yellow Aeolian sandplain at low levels adjoining salt flats, and low woodland on the rocky hills of the Coomberdale Chert. The chert woodland is said to comprise of *Acacia acuminata* and *Allocasuarina huegeliana* with shrubs of *Dryandra sessilis* and X*anthorrhoea preissii*, or alternatively thickets of *Allocasuarina campestris*.

Only four known populations of *S. quartzitica* are known, with a total of less than 200 plants (Stack & English 1999). Of the four populations, only two were chosen as study sites as they comprised sufficient numbers of plants. These were CALM population 1, known as Cairn Hill, and CALM population 2 at Watheroo National

Park (NP). The populations will hereafter be referred to as *S. quartzitica* Cairn Hill and *S. quartzitica* Watheroo NP.

Cairn Hill is 10 km north of Moora in the Wheatbelt of Western Australia. The land is owned freehold by Westrail, and its condition is described as slightly modified (Hamilton-Brown 2000a). However, the Moora Shire has extracted gravel from the base of the hills in previous years. The habitat of Cairn Hill is described as heath dominated by one or more of *Regelia meagacephala, Kunzea praestans* and *Allocasuarina campestris* on ridges and slopes of the chert hills of the Coomberdale floristic region (Hamilton-Brown 2000). Cairn Hill is recognised as a Threatened Ecological Community (TEC) and supports a number of declared rare and priority flora. The population *S. quartzitica* at Watheroo NP is located on the lower eastern side of the park 12 km north of the town of Watheroo (Figure 2.4). The main portion of the study site appears to some extent modified, which is adjacent to a gravel track that separates the park from private cleared property.

Study sites of *S. spinulosa* were located within Watheroo NP. Two locations were chosen for the study, and are referred to as *S. spinulosa* Population 1 and *S. spinulosa* Population 2. However, Population 1 did not flower in time for this study, and therefore a third population had to be established to complete the reproductive biology investigations. All three populations are situated on the lower western side of the park, off Watheroo West Rd, south of the town of Watheroo.

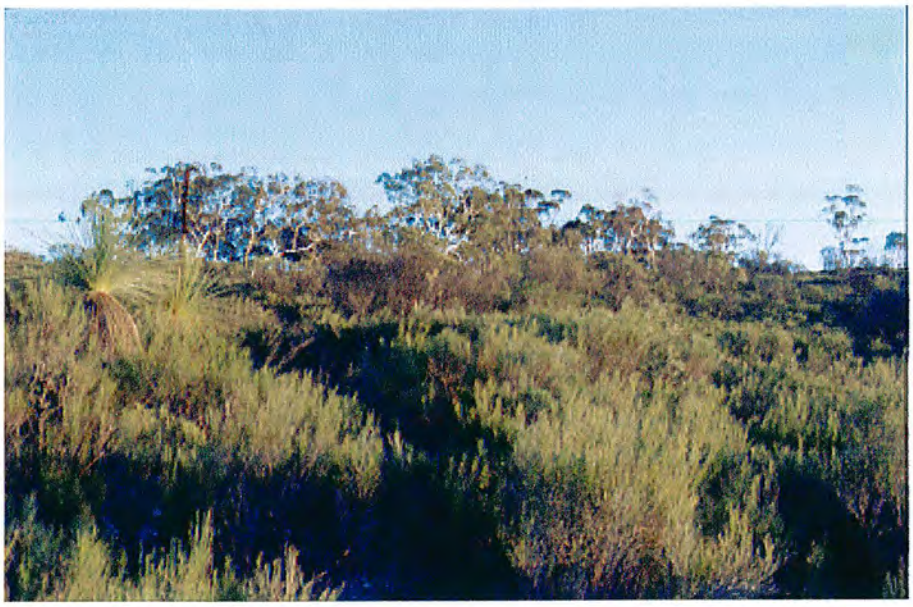

Figure 2.4. Population *Synaphea quartzitica* Cairn Hill (Height of plants in foreground approx. 1.5m).

Figure 2.5. Population *Synaphea quartzitica* Watheroo National Park. (Note centre of photo - *S. quartzitica* in flower).

2.3 Aims and Hypotheses

McMichael (1982) states that the most useful research aims to understand the species life cycle and breeding biology, together with details of its habitat requirements and any other factors affecting its survival. My study forms part of the Recovery Plan for *S. quartzitica*, under the recovery action to investigate the biology and ecology of the species. The specific aims of my study were:

1. To determine the population structure for *S. quartzitica,* and compare it with *S. spinulosa* to gain insights into any difference between a rare and a common species.

   Ho1: The population structure of *S. quartzitica* is the same as *S. spinulosa.*

2. To determine the number of seeds of *S. quartzitica* in the soil seed bank and compare it with *S. spinulosa* to gain insights into any difference between a rare and common species.

   Ho2: The number of *S. quartzitica* seed stored in the soil seed bank is the same as the number of *S. spinulosa* seed stored.

   Ho3: The number of seedlings observed in response to the application of smoke water is the same as the control (water only).

3. To determine if habitat specificity is a constraint to population growth of *S. quartzitica.*

Ho4: There is no difference in the nutrient status of the soils where the species does, and does not occur within its community.

4. To investigate the flowering and pollination biology of both species and hence determine any limitations to population growth.

   Ho5: The main limitation to population growth is of *S. quartzitica* is low seed set.

   Ho6: Seed set in *S. quartzitica* is very low because it is limited by the availability of suitable pollinators.

5. To rank the threats and constraints to population growth of *S. quartzitica* so that better informed decisions can be made in terms of its management.

CHAPTER 3

POPULATION BIOLOGY AND HABITAT SPECIFICITY

3.1 INTRODUCTION

A population is defined as a group of organisms of one species that is usually separated in some degree from other groups of the same species by geographical or topographical barriers (Solomon 1969). Populations experience fluctuations in numbers, but most tend to have to a characteristic size and number over a period, so that we can say a species is relatively common or rare. Species most at risk of extinction are those with small geographic ranges and small population size (Chapter 1). Therefore, it is important to determine whether a rare population is declining, increasing or stable. Demography deals with the quantitative aspects of birth, growth, reproduction and death in a population (Solbrig 1980). Accurate demographic data provides essential information to determine whether populations are declining, increasing or stable (Maschinski *et al.* 1997).

For many plant species, especially those that are perennial, the fate of an individual is not so much dependent on its absolute age, as on its size or stage of growth (Begon & Mortimer 1986). Abrahamson (1980) states that it is difficult, if not impossible to know the age of vegetatively propagating plants, therefore size and not age is more reliable for making predictive statements concerning the death, survival or reproduction of individuals. Solbrig (1980) states that unravelling the various aspects of the life cycle is crucial to an understanding of a population. Individuals may be classified by their life history stage – seed, seedling, juvenile, mature - as this recognises the potential for population growth. Factors that limit population growth have been identified as poor seed germination, low seedling survivorship and low reproductive output (Pavlik & Manning 1993). Therefore, plant distribution and

abundance may be determined by the number of seedlings that emerge from the soil (Harper 1977).

The store of seeds buried in the soil (the soil seed bank) is an important component of the potential of a plant community to respond to conditions in the present and the future (Coffin & Lauenroth 1989). Dormant viable seeds stored in a soil seed bank are the major source of new recruits for many plant species of fire-prone Mediterranean-type communities, such as the heathlands and open sclerophyll forests of southern Australia (Bell *et al.* 1993). Many seeds of species native to South-western Australia are adapted to germinate in response to one or more of the physical and chemical cues provided by fire (Bell *et al.* 1993), with smoke the most striking factor (Dixon *et al.* 1995). Lloyd *et al.* (2000) showed that concentrated smoke products (CSP) are effective in stimulating germination of soil seed banks. The use of CSP on undisturbed soil seed banks increased total seedling numbers 10-fold, while species richness more than doubled over untreated controls.

The population size of an endangered plant species can be limited by the production of viable seeds, particularly when the species does not reproduce asexually (Pavlik *et al.* 1993). Asexual or clonal growth is the vegetative production of modules which may achieve physiological independence (Mogie & Hutchings 1990). Two kinds of 'individuals' are usually recognised in clonal plants: genets and ramets (Harper 1977). A genet includes all tissue originally developed from one zygote, which consists of one or several potentially independent ramets (Eriksson & Jerling 1990). Population dynamics can thus be viewed at two levels, with the genet level inclusive of the ramet level. It is of importance to recognize this distinction, as the genet level is the primary level of genetic variation. Population genetics shows that high genetic diversity in natural populations means outbreeding and evolutionary capability (James 2000). Thus, maintaining numbers and genetic variation must be a central theme of plans for long-term population management (Lande & Barrowclough 1987).

Small populations, populations with limited environmental tolerance, and populations with specific habitat requirements are more likely to become extinct because they are closer to extinction at the outset or because they are less able to tolerate extreme environmental conditions (Burgman & Lindenmayer 1998). Stack & English (1999) suggest that *Synaphea quartzitica* is probably naturally restricted due to it occurring in a specialised habitat with a restricted range. *S. quartzitica* is present on the Noondine chert hills in the Moora-Watheroo area of Western Australia. The chert substrate is highly restricted, and supports a unique heath community in the Coomberdale (Noondine) floristic region (Hamilton-Brown 2000a).

The Interim Recovery Plan gives the total number of plants present at the four known populations of *S. quartzitica* as less than 200 (Stack & English 1999). Seed set in most *Synaphea* species is low, including many that are fire sensitive (George 1995). Staff of CALM's Threatened Flora Seed Centre had unsuccessfully attempted to collect seeds of *S. quartzitica* in 1997 and 1998. The aims of the research reported in this chapter were to determine the population structure and the presence of a soil seed bank for *S. quartzitica,* and compare it with *S. spinulosa* to gain insights into any difference between a rare and a common species. This chapter also aims to determine if habitat specificity is a constraint to population growth of *S. quartzitica.*

Hypotheses:

Ho1: The population structure of *S. quartzitica* is the same as *S. spinulosa.*

Ho2: The number of *S. quartzitica* seed stored in the soil seed bank is the same as the number of *S. spinulosa* seed stored.

Ho3: The number of seedlings observed in response to the application of smoke water is the same as the control (water only).

Ho4: There is no difference in the physical properties and nutrient status of the soils where the species does, and does not, occur within its community.

3.2. MATERIALS AND METHODS

3.2.1 Population structure

All plants of *S. quartzitica* located at Cairn Hill were numbered and tagged. Measurements were taken of plant width (north-south and east-west) and height in centimetres. I considered that a plant was a ramet if it was within a 0.5 m radius of a larger plant. The plant was designated as the genet if it was the largest in size and/or had the thickest stem. This was based on preliminary excavations that showed this to be so. Soil excavations around the roots of plants were also done at *S. spinulosa* populations to determine if the species was also clonal. The number of leaves and old flower spikes were counted. The distance to the nearest plant was measured, and notes on the health of the plant were recorded. These methods were repeated for *S. quartzitica* at the Watheroo National Park population. At the *S. spinulosa* populations 100 plants were randomly tagged and measured using the same methods previously described. The data collected was used to calculate an index of size for each plant, where plant size = $(4/3 \pi ((w1 + w2 + 2h) / 3 \times 2)^3) / 2$. A histogram of the size of plants measured at each population was created to show the structure of the population and t-tests were used to determine if the sizes of the populations were significantly different within populations.

3.2.2 Soil seed bank

A soil sample (10 × 10 × 10 cm) and leaf litter immediately surrounding the plant was collected from 10 plants per population. The sample was placed into a labelled calico bag and taken back to the lab. The soil was dry sifted through one coarse and one fine (1.4 mm mesh size) sieve. The retained matter was searched for seeds of *Synaphea* under a dissecting microscope. Whole, husks and damaged seeds were collected. A general linear model analysis of variance was performed to determine any differences in the number of seeds between populations and species.

3.2.3 Smoke water investigation

20 plants were chosen at each population for each treatment. Preparation involved cutting back the surrounding vegetation to ground level using secateurs to clear an area of 1 m^2 around the plant. The area was marked by placing a hoop with a circumference of 3.5 m around the plant. Half of the plants were sprayed with 1 L of smoke water solution (concentration of 100mL smoke water / Litre water), the other half with 1 L of water only. The cleared area around the plant was sprayed evenly, and plants were covered with a plastic bag to prevent leaf scorch. Nine weeks after the treatment, the number of seedlings that were present in the cleared area was counted. A general linear model analysis of variance was performed to determine any differences in the number of seedlings observed for each treatment, population and species.

3.2.4 Seed trial

Two 0.5 m × 1 m plots were marked using metal pegs to mark an area of 0.5 m^2 at two sites per population. Sites for plots were chosen where there was a clearing in the vegetation. 18 seeds of *S. petiolaris* were sown per plot in rows of three, at a depth of 1 cm. This species was chosen because seeds of both *S. quartzitica* and *S. spinulosa* were unavailable. One of the plots was sprayed using a pump action spray, with half a litre of smoke water at a concentration of 100 ml / L^{-1}. The other plot was sprayed with water only. After a period of 9 weeks, the plots were examined for seedling emergence, with the numbers per plot counted and compared.

3.2.5 Habitat

The slope and aspect of the populations were recorded using a compass and clinometer. A 10 m transect was set up at sites within the population where *Synaphea* was present. The percentage cover of leaf litter within a 1 m quadrat along the transect was recorded. The density of the vegetation was estimated using a spherical densiometer (P. Lemmon, Forest Densiometers, USA Model C) at 2 m intervals along the transect. The specified method was modified for use in a heath

situation (the densiometer was held a ground height). Five soil samples were collected at every 2 m along the transect. A sample (10 × 10 × 10 cm of soil) was taken using a hand trowel and placed into a labelled bag. The soil samples were analysed at CSBP Laboratories, Bibra Lake for gravel, colour, conductivity, pH and a range of nutrients. Two transects were completed at sites where *Synaphea* was present. This was repeated at sites where *Synaphea* was absent. Statistical analysis involved a two-way ANOVA comparing sties where the species was present and absent, and populations for the vegetation density and leaf litter data. A principal component analysis on the soil variables was completed to determine any differences in the soil properties where the species was present and absent.

3.3 RESULTS

3.3.1 Population structure

The number of plants that were tagged at Cairn Hill totalled 97. Of these 87 were located on the northern side of the slope, including two dead (Table 3.1). The other 10 were on the southern side of the slope near the crest of the hill. At Watheroo National Park, 125 were tagged (on the western slope) and a further 85 were measured but not tagged (eastern slope).

Table 3.1. Location and number of plants (genets and ramets) of *Synaphea quartzitica* counted during previous and current surveys.

Location	Population (CALM number)	Number of plants (last survey)	Number of Plants (my survey – 2001)
Cairn Hill	1	79 (1998)	97
Watheroo NP	2a	156 (2000)	210
Total		**235**	**307**

Plant dimension measurements showed that plants at Cairn Hill were on average larger than plants at Watheroo NP ($t = 6.02$, $p = 0.0000$). *S. spinulosa* data also showed that one population has larger plants than the other ($t = 3.67$, $p = 0.0003$). When comparing the two species, *S. quartzitica* is smaller than *S. spinulosa*. The data of the size classification for both species was skewed to the right, due to a few very large (old) plants (Figures 3.1-4).

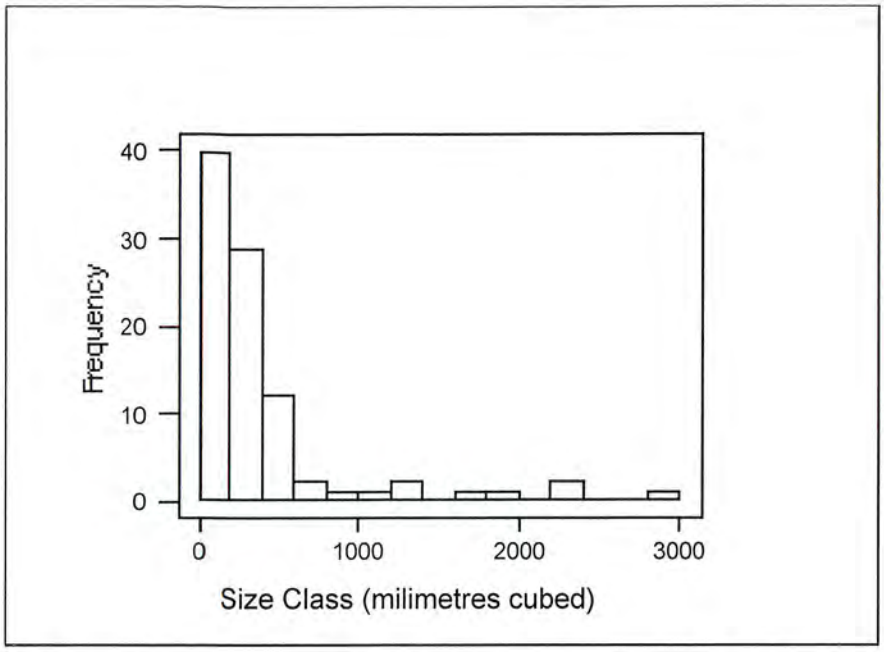

Figure 3.1. Histogram of plant sizes of *Synaphea quartzitica* at Cairn Hill. (Two values above 3000 omitted)

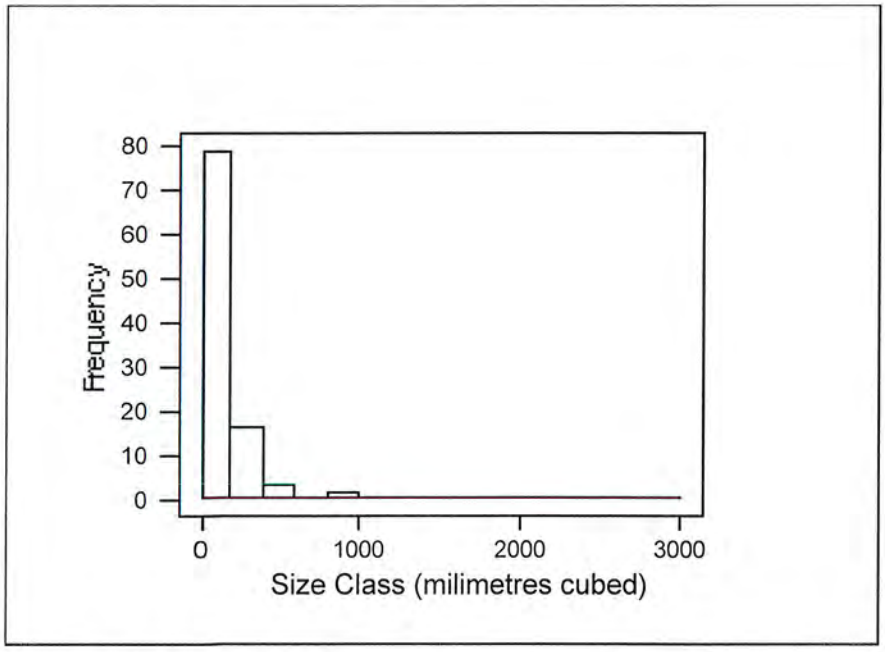

Figure 3.2. Histogram of plant sizes of *Synaphea quartzitica* at Watheroo NP. (One value above 3000 omitted).

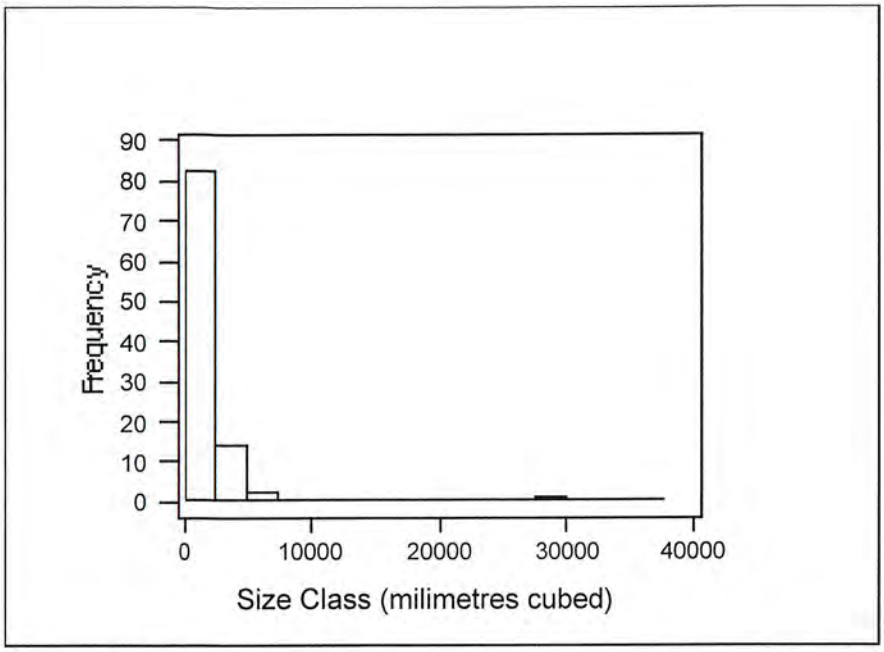

Figure 3.3. Histogram of plant sizes of *Synaphea spinulosa* at Population 1.

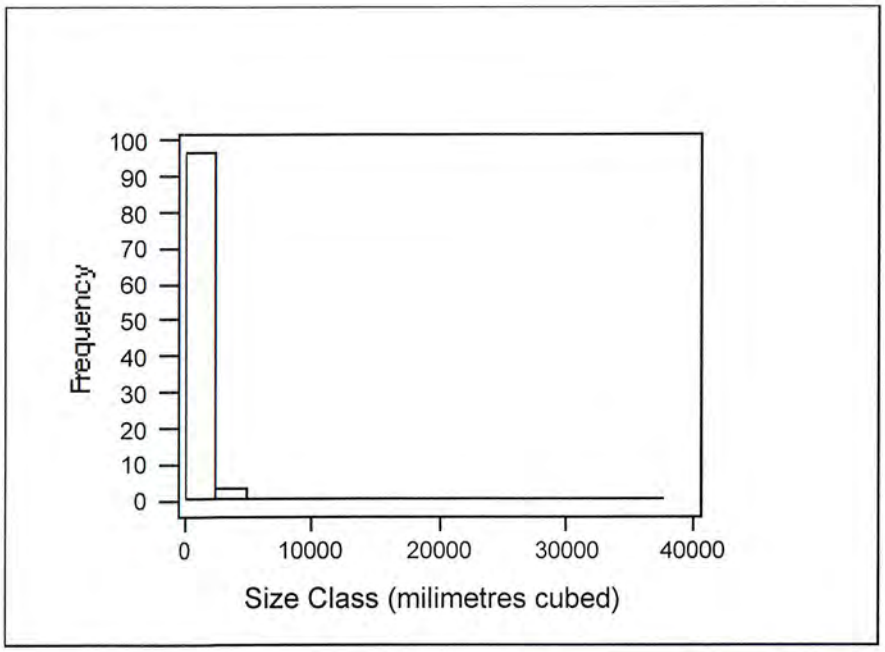

Figure 3.4. Histogram of plant sizes of *Synaphea spinulosa* at Population 2.

The distribution of *S. quartzitica* plants is mostly in clumps. However, *S. spinulosa* is more evenly distributed. The distance to nearest plant for both populations of *S. quartzitica* was on average 2 m. *S. spinulosa* appears to not produce root suckers. However, *S. quartzitica* does. Of the 97 plants counted at Cairn Hill, 68 were identified as genets, with 14 containing either 2 or 3 ramets. Of the 210 plants at Watheroo NP, 98 were identified as genets, with 16 comprising of a range of 2-5 ramets. Although most plants were classified into the smallest size class, the majority were mature plants. At Cairn Hill, 6 plants were identified as juveniles (those that were small in size and did not have any old flowering spikes). At Watheroo NP 16 juveniles were counted. *S. spinulosa* Population 1 and 2 had 16 and 32 juveniles respectively. The plants in general were in good health. However, *S. quartzitica* had very yellow leaves during the summer months that remained until May. The leaves had turned green by July.

3.3.2 Soil seed bank

The search for seeds in the soil showed very few numbers of whole, undamaged seeds for *S. quartzitica*. Samples from Cairn Hill did not contain any whole undamaged seeds, or any signs of husks or damaged seeds (Table 3.2). Damage to seeds was mostly in the form of small holes. *S. spinulosa* had more samples that contained seeds at both populations, with half the samples containing seeds. One sample from Population 2 also had a very high number of seeds (30), ten times the number of most samples. *S. spinulosa* Population 2 had more husks and damaged seeds than any other population. Results showed no significant difference between the populations ($F= 1.55$, $p = 0.221$) and the species($F = 2.17$, $p = 0.150$).

Table 3.2. Number of seeds of *Synaphea quartzitica* and *S. spinulosa* in the soil seed bank (mean).

Species	Population	No. of samples that contained seeds (n =10)	No. of Seeds / sample that contained seed	No. of husks / sample	No. of damaged seeds / sample
S. quartzitica	Cairn Hill	0	0.0	0.0	0.0
	Watheroo NP	2	2.5	0.0	0.0
S. spinulosa	Population 1	4	1.6	0.0	2.0
	Population 2	5	8.2	8.0	3.2

3.3.3 Smoke water investigation

The results of the investigation showed only one species had seed germinating in response to the smoke water application. This was *S. quartzitica*, which had two seedlings at one sample at Cairn hill. The application of water only resulted in 1 seedling for *S. quartzitica* at Cairn Hill and 4 for *S. spinulosa* at population 1. There were no significant differences observed in the number of seedlings between treatments, populations or species.

3.3.4 Seed trial

The seed trial failed to show any seeds germinating in any treatment, population or species.

3.3.5 Habitat

S. quartzitica is present mainly on the chert slopes, particularly near the crests. At Cairn Hill some plants are located on the crest itself, but are not present in the gully. Thick stands of *Allocasuarina campestris* occur on the crests of the hills at both Cairn Hill and Watheroo NP populations. The slopes at Cairn Hill are much steeper than the hills at Watheroo NP (Table 3.3).

Table 3.3. Slope and aspect of the Chert hills where *S. quartzitica* populations are located.

Population	Aspect	Slope
Cairn Hill	West	9°
	North	10°
Watheroo NP	West	5°
	East	2°

The vegetation was denser at locations where *S. quartzitica* was absent than where they were present (Figure 3.3). *S. spinulosa* locations showed no significant difference in vegetation density where it was present or absent or between populations. However *S. quartzitica* showed significant differences between both populations ($F = 8.12$, $p = 0.007$) and present/absent locations ($F = 25.53$, $p = 0.000$).

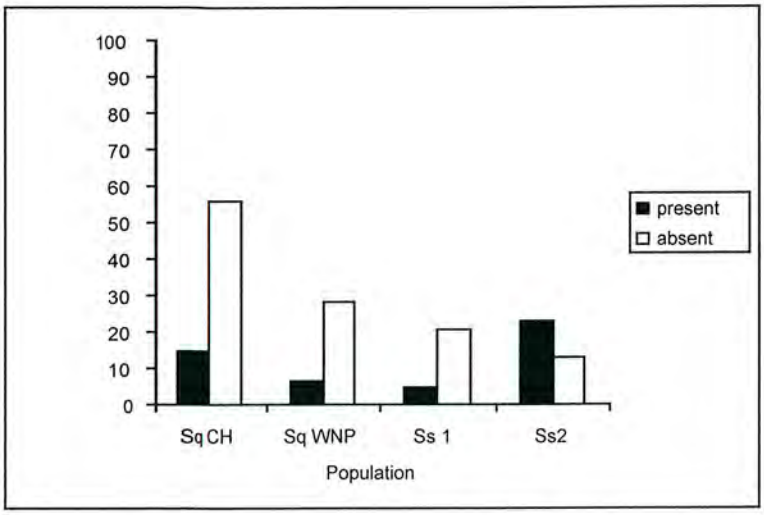

Figure 3.5. Vegetation density at populations where *Synaphea* is present and absent. Calculated using a spherical densiometer. (Sq CH = *S. quartzitica* Cairn Hill, Sq WNP = *S. quartzitica* Watheroo NP, Ss1 = *S. spinulosa* Population 1, Ss 2 = *S. spinulosa* Population 2).

There were present/absent differences observed in the mean amount of litter coverage at the *S. quartzitica* populations, but not at the *S. spinulosa* populations (Table 3.4.) Each population differed significantly from each other.

Table 3.4. Percentage litter coverage at the *Synaphea* populations.

Population	Present (+) absent (-)	% Litter (mean ± SD)	p + / -	p Pop.
S. quartzitica Cairn Hill	+	35 (29)	0.000	0.000
	-	95 (11)		
S.quartzitica Watheroo NP	+	0.1 (0.4)		
	-	32 (34)		
S. spinulosa 1	+	18 (23)	0.746	0.000
	-	14 (9)		
S.spinulosa 2	+	32 (32)		
	-	41 (27)		

The soils where *S. quartzitica* was absent differed in iron and pH at Cairn Hill and at Watheroo NP the soils from the present/absent locations differed in phosphorus organic carbon and iron. For *S. spinulosa* Population 1 all factors differed except for ammonium, sulphur, conductivity and pH. *S. spinulosa* Population 2 differed only in

iron where they were absent. The S. quartzitica populations where they were present had in common the levels of nitrates, phosphorus, organic carbon, iron and conductivity.

Table 3.5. Mean values of soil factors (± SD) where Synaphea is present and absent within populations. Sq = *Synaphea quartzitica*, Ss = *Synaphea spinulosa* (n = 10).

	NO_3 mg/kg	NH_4 mg/kg	P mg/kg	K mg/kg	S mg/kg	C %	Fe mg/kg	Cond mS	pH
Sq CH									
Present	2.9 (0.6)	4.0 (1.3)	4.1 (1.4)	93.3 (20.1)	3.90 (0.67)	1.53 (0.41)	233.1 (32.7)	2.320 (0.447)	4.71 (0.10)
Absent	2.6 (0.5)	4.8 (1.1)	3.9 (0.9)	93.7 (16.8)	4.04 (0.40)	1.544 (0.39)	194.3 (32.6)	2.330 (0.411)	4.47 (0.09)
Sq WNP									
Present	2.9 (0.6)	4.2 (1.6)	4.3 (1.5)	70.4 (17.3)	4.54 (2.20)	2.32 (0.69)	226.9 (22.48)	3.150 (1.339)	4.86 (0.38)
Absent	2.9 (0.6)	3.6 (1.4)	2.8 (1.7)	65.9 (21.4)	3.08 (1.38)	1.49 (0.37)	201.1 (20.7)	4.090 (5.640)	4.86 (0.18)
Ss 1									
Present	1.7 (0.5)	1.0 (0.0)	4.1 (1.3)	26.9 (7.4)	1.43 (0.30)	0.042 (0.141)	53.4 (7.6)	1.04 (0.280)	5.63 (0.36)
Absent	2.1 (0.3)	1.2 (0.6)	1.8 (0.9)	18 (4.4)	3.32 (5.73)	0.292 (0.089)	105.7 (19.0)	0.950 (0.350)	5.58 (0.29)
Ss 2									
Present	2.1 (0.3)	3.0 (1.3)	1.8 (0.8)	30.6 (9.1)	1.87 (0.71)	0.78 (0.55)	113.0 (38.1)	1.42 (0.579)	5.11 (0.29)
Absent	2.5 (0.5)	2.1 (1.4)	1.8 (1.0)	26.6 (18.9)	1.85 (0.90)	0.60 (0.21)	55.5 (11.4)	1.45 (0.740)	5.28 (0.34)

A Principal Component Analysis on the 9 factors was completed for each species. For both species 6 components adequately summarised the 9 original variables, representing approximately 90 percent of the variation. The soils in which *S. quartzitica* was present and absent formed 2 clusters with considerable overlap

(Figure3.6). High levels of the 9 variables characterised the absent sites, and low levels the present. PCA for *S. spinulosa* showed three clusters, with an overlap containing 20 percent of the data. *S. spinulosa* present sites tended to have low-moderate levels of nitrates, potassium, sulphur, carbon, conductivity and pH (Figure 3.7). *S. spinulosa* absent tended to have moderate-high levels of phosphorus and pH (cluster 1) or high levels of ammonium and iron (cluster 2).Vector analysis shows that soils where *S. quartzitica* is present are generally low in organic carbon, sulphur, ammonium, phosphorus and potassium, and higher in iron, nitrates and pH. *S. spinulosa* appears to occur in soil that are low in potassium, sulphur, organic carbon, nitrates and conductivity.

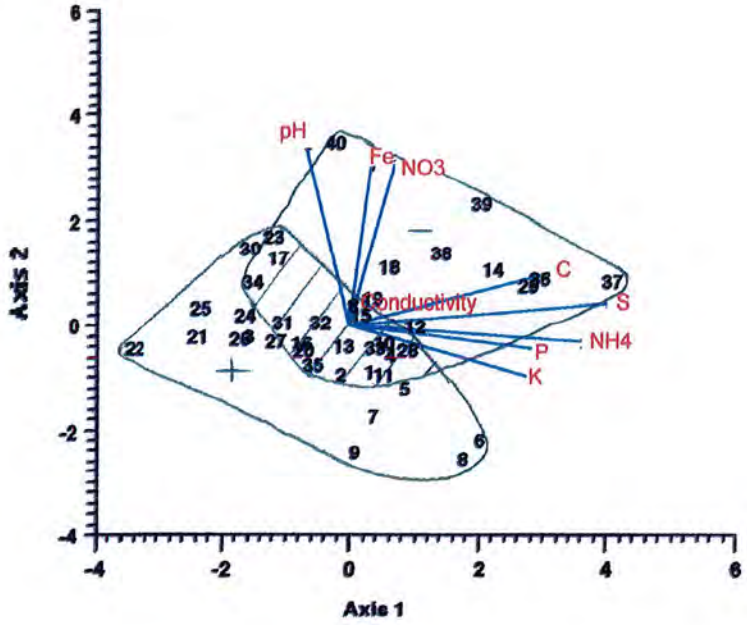

Figure 3.6. PCA plot on soil samples taken from location where *S. quartzitica* was present + (1-10, 21-30) and absent – (11-20, 31-40) within the population. 9 components used were N03, NH4, P, K, S C Fe conductivity and pH.

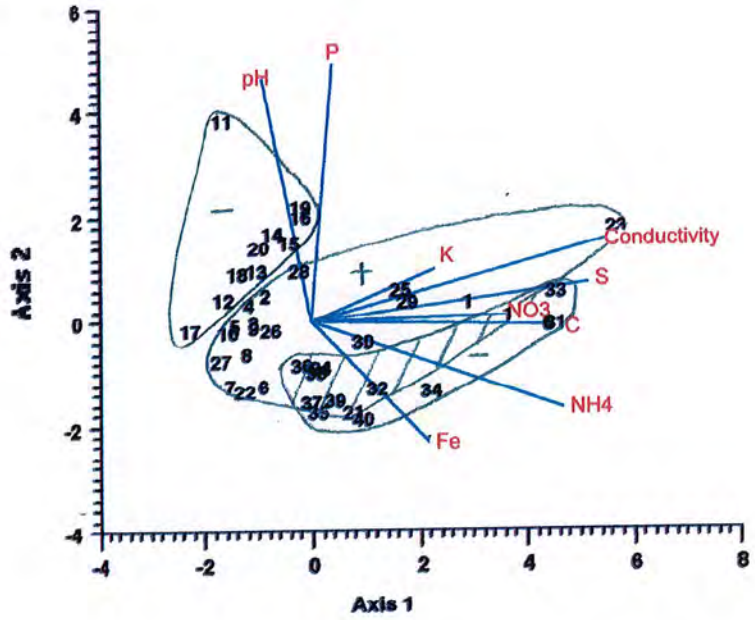

Figure 3.7. PCA plot on soil samples taken from locations where *S. spinulosa was* present + (1-10, 21-30) and absent – (11-20, 31-40) within the populations. 9 components used were N03, NH4, P, K, S C Fe conductivity and pH.

3.4 DISCUSSION

The number of *S. quartzitica* plants recorded at Cairn Hill and Watheroo NP (CALM Population 2a) are more than previously documented. A more extensive search for plants conducted during this study is the most likely explanation for the increase in the number of plants, rather than an increase in seedlings. There were very few seedlings and also very few dead plants recorded, which may suggest that the populations are stable.

The histograms show a few very large (old) plants, with escalating recruitment of small (young) ramets over time for *S. quartzitica*. This proliferation of ramets suggests that the species is fire-tolerant, like *Banksia elegans*, which regenerates after fire by resprouting and suckering from surface roots (Barrett 1985). Resprouting after fire might allow for rapid uptake of nutrients after a fire and to take advantage of increased light levels (Abrahamson 1980). Benwell (1998) recognizes resprouting as a stress-tolerant regeneration strategy that compensates for greater risks related to seed-based recruitment). *S. spinulosa* does not appear to produce root suckers. However, the rootstock is fire-tolerant (George 1995). The similar skewed shaped of the histograms of *S. spinulosa* indicate that there is also a few large (old) plants with many small (young) plants. This recent surge of recruitment is probably the result of a large recruitment event, most likely a fire, as many species from south-western Australia have seeds that germinate in response to fire (Bell *et al.* 1993). An explanation for the few very large plants observed may be that they are plants that have escaped damage due to a patchy fire.

Many resprouters have a poor capacity for seedling establishment, or have low seeds in the soil seed bank (Benwell 1998). Results of the seed bank investigation showed that there are very few seeds in the soil seed bank for *S. quartzitica*, with no seeds recorded at the Cairn Hill population. However, the smoke water investigation showed that this population does have some seeds stored in the soil, as a small number of *S. quartzitica* seedlings were recorded after treatments. Results of the

seed bank analysis for *S. spinulosa* recorded more seeds per sample, and a greater number of husks and damaged seeds. However, there was no significant difference between the species, mainly due to the large number of samples in both species lacking any seeds.

The very low numbers of seedlings in the smoke water investigation may not be because of a lack of seeds in the soil bank. The absence of any seedlings in the seed trial showed that while seeds may be present in the soil, they might not necessarily germinate or emerge. It can be concluded from these results the conditions for germination were not met. Seeds in a dormant state in the seed bank may need to await stimuli or suitable conditions before they can germinate, or they may have further dormancy imposed upon them by the conditions they meet on or in the soil (Harper 1977). It has been shown that smoke treatments can respond in the following year after application (Roche *et al.* 1998). Therefore, poor results in the smoke water application may reflect a delay in germination.

The clumping distribution of *S. quartzitica* can be attributed to the clonal nature of the plant. Ramet production is of benefit to the plant as it can increase the longevity of the genet, the area of habitat it occupies and the capture of resources (Hutchings & Mogie 1990). On the other hand, because no genetic recombination is involved, asexual reproduction leads to the production of genetically identical offspring, which is disadvantageous in an unpredictable environment (Abrahamson 1980). Thirty percent of plants at Cairn Hill and twenty two percent at Watheroo NP were recorded as ramets. The greater percentage of ramets, the less variation is likely in the populations. A fundamental fact in population genetics is that in closed populations the presence of only a small number of individuals, sustained over several generations, will lead to the depletion of genetic variation (Lande & Barrowclough 1987). Genetic variation must be maintained in order to prevent the deleterious effects of inbreeding and allow evolutionary change (Lande & Barrowclough 1987). Therefore, due to the small number of individuals, a

significant proportion of which is genetically identical, *S. quartzitica* perhaps possesses lower levels of genetic diversity than *S. spinulosa*.

Some of the most obvious causes of restricted range and low population numbers come from species inhabiting unusual landforms of limited area (Pate & Hopper 1993). Three vegetation subtypes occur in the heath community on the chert hills where *S. quartzitica* is present. These consist of dense heath dominated by *Regelia megecephala* or *Allocasuarina campestris* on the exposed chert ridges (sub-type 1); or dense heath or open woodland over dense to mid dense heath dominated by *Kunzea praestrans* (sub-type 2); or *Allocasuarina campestris* on shallow loamy rocky soil over chert on the slopes and ridges (sub-type 3) (Hamilton-Brown 2000). *S. quartzitica* occurs on the slopes of the chert hills where the vegetation density is less than 20 % cover and the litter is low. Population size in the rare bellflower, *Campanula cervicaria,* was negatively related to the amount of shade in habitats (Eisto *et al.* 2000). This may be the case with *S. quartzitica,* perhaps because it cannot obtain sufficient light in more dense patches due to its prostrate habit, or it may prefer areas of less intense competition.

Hamilton-Brown (2000a) states that the varying floristic composition of the heath is assumed to correspond to variations in soil/substrate types and depths. However, when comparing the soil from locations within the populations where *S. quartzitica* was present and absent, iron was the only variable at both populations that was significantly different. The value of iron was higher at locations where *S. quartzitica* was absent. This may suggest that *S. quartzitica* has a particular requirement for iron. Many rare species are adapted to marginal habitats such as alkaline or saline soils, high levels of toxic metals or droughty soils (Faulk 1990). Nearly all of the key nutrients (N, P, K) did not significantly differ between present and absent locations, therefore indicating that these variables are not limiting the distribution of *S. quartzitica*.

The PCA results showed that there were 4 variables that were shared by both species. These were sulphur, conductivity, iron and phosphorus. These may be factors that particularly characterise the soil properties for the genus *Synaphea*. As the soil/ substrate type is clearly different for each species, no comparisons were made for the soil properties between the species.

The habitat of rarity is expected to be sharply discontinuous with neighbouring habitats of contrasting attributes (Kruckeberg & Rabinowitz 1985). While the soil/substrate type may dictate the presence of the dominant species of this community, a combination of factors, rather than one, is likely to be responsible for the range limitation of this species. From the results it can be concluded that *S. quartzitica* occurs on the chert slopes, in a unique community with the surrounding vegetation and litter at low densities. It also appears that it may have a specific requirement for iron. This implies that habitat specificity is major factor explaining the rarity of *S. quartzitica.*

CHAPTER 4

REPRODUCTIVE BIOLOGY

4.1 INTRODUCTION

The reproductive biology of rare plant species may be a limiting factor in population growth (Lamont *et al.* 1993, Day *et al.* 1997). It is hypothesised here that a major limitation to population growth in *Synaphea quartzitica* is seed production. Pyke (1982) lists several factors that could limit seed set:

1. pollen limitation,
2. extent of predation of flowers (or flower parts),
3. availability of space for fruits, and
4. availability of necessary resources within the plant.

Pollen limitation may result from any of three mechanisms: (1) there may be low numbers of pollinators, (2) there may be a suitable number of pollinators ordinarily, but due to profuse flowering, the pollinators become satiated, (3) pollinator visits may result in ineffective pollen transfer (Goldingay and Whelan 1990). Seed set per flower can increase with increases in the number of pollinator visits per flower, or in the amount of pollen deposited on the stigma (Pyke 1982). The number of flowers open at any one time on a plant is a major component of floral display in animal-pollinated angiosperms, and its variation may affect plant fitness through pollinator visitation (Ohashi & Yahara 1998). The floral displays by plants therefore, may be insufficient to attract suitable pollinators. Larger floral displays may result in a greater absolute number of pollinator visits, but this may translate to fewer visits per flower when pollinators are limited in number (Goldingay & Whelan 1990).

If pollinator visitation results in effective pollen transfer, ie successful contact with the stigma, certain processes must be completed before fertilization takes place.

Regardless of pollen size, form or mode of dispersal, the key factor is pollen viability (Dafni 1992). The pollen-stigma relationship depends on pollen viability, stigma receptivity, and genetic interaction of both partners as dictated by the incompatibility system, if any (Dafni 1992). After the arrival of pollen to the flower and contact with the stigma, rehydration of the pollen is needed to ensure pollen tube emergence (Dafni 1992). Before germination, the pollen grain must be accepted by stigmatic cells that recognise compatible pollen (Dafni 1992). After germination, pollen tube penetration will progress provided tissues of the stylar canal permit it. Successful tube growth results in fertilization of the ovule. Complete failure of pollen grains to germinate and later to result in the fertilization of an ovule means an unsuccessful result of a pollinator event.

Assessment of mating systems of Australian Proteaceae indicates almost complete outcrossing for most species (Goldingay and Carthew 1998). Self-incompatibility is assessed by examination of the development of pollen tubes, seeds or fruit following various hand pollination treatments. Typically, bags cover flowers for the duration of the flowering to test for automatic self-fertilization (spontaneous autogamy) (Goldingay & Carthew 1998).

The possibility that the availability of nutrients sets the upper limit to seed production in proteaceous species has been suggested by Pyke(1982). When plants have insufficient resources to develop all of the fertilized ovules, resources may be directed to the best zygotes (Paton & Turner 1985). In variable environments, outcrossed seeds should have greater fitness than selfed seeds (Carpenter & Recher 1979) and hence outcrossed zygotes should receive resources before selfed (Paton & Turner 1985). However, plants may be able to direct limited nutrients into various components of reproduction, for example a defined number of seeds per plant may be produced by few seeds on many inflorescences or many seeds on few inflorescences. Furthermore, plants may 'choose' between high quality and low quality pollen by aborting those ovules that were self-fertilized in favour of cross-fertilized (Goldingay and Whelan 1990, Paton and Turner 1985).

The aims of the research reported in this chapter were to investigate the flowering and pollination biology of both species and hence determine any limitations to population growth.

Hypotheses:

Ho5: The main limitation to population growth is of *S. quartzitica* is low seed set.

Ho6: Seed set in *S. quartzitica* is very low because it is limited by the availability of suitable pollinators.

4.2 MATERIALS AND METHODS

4.2.1 Floral display

For each plant tagged, the number of flower spikes produced per plant was recorded at each population in July-August, and an average number of spikes were calculated.100 flowers spikes (10 spikes from 10 plants) were measured for length and number of flowers per spike for each species. These results were used to calculate the mean number of flowers produced per plant.

4.2.2 Pollen viability and stigma receptivity

One flower spike from each of 10 plants was collected to test for pollen viability and stigma receptivity. Flowers were removed from the spike and classified into three categories: unopened, new, and old. Flowers that were taken from the bottom of the spike were regarded as old. The new flowers were taken directly below the unopened flowers located at the tip of the spike. It was also noted if the style had been triggered, and if the anthers were full, half-full or empty of pollen.

Flowers were placed under a dissecting microscope, where pollen (if present) was extracted from the anthers and placed onto a microscope slide containing a drop of Alexander's stain. The pollen was mixed into the stain and then a cover slip was placed onto the slide. The slides were left for two hours before examination under a compound microscope at 40x magnification. The grains were counted, noting the colour they stained. Purple grains were considered viable, blue and green were not viable. Percentage viability was calculated by dividing the number of viable grains by the total number of grains counted. A general linear model analysis of variance was performed to determine if there were any differences in percentage viability between flower types, populations and species.

The style was also removed during the dissection and dipped in deionised water. The stigma was gently pressed onto a piece of Peroxtesmo Ko test paper and observed under a dissecting microscope (Dafni & Maués 1998). A dark blue colour showed

the presence of peroxidase as an indicator of the stigma receptivity A chi-square analysis was performed for each species on the receptivity of the different flower types, and a comparison of receptivity between the species.

4.2.3 Fruit set and pollinator limitation

At all populaions10 flower spikes on each of ten plants were randomly chosen for covering with nylon bags 5 cm × 30 cm in size. Any open flowers were removed from the spike before the bag was sealed at the base of the spike with masking tape. After a period of 5 weeks, the spikes were cut from the plant, leaving the bags sealed. In the lab the bags were carefully removed and the numbers of flowers and fruit per spikes were counted. If flowers had fallen off the spike, the number of flowers could still be determined by counting the nodes. Percentage seed set was calculated by dividing the number of fruits by the total number of flowers produced. Another 10 spikes from each of 10 different plants were harvested at the same time to determine seed set of the species and to compare the results with the exclusion investigation. An additional investigation was made to determine if the application of the bags to the spike would trigger the flower. The number of flowers that had been already been triggered was counted before the spike was covered. The bag was then immediately removed and the condition of the flowers were counted again. For both species a two-way analysis of variance was completed for each treatment and population to determine any differences in seed set.

4.2.4 Pollen tube analysis

'Old' flowers which had their styles triggered were collected from each population for pollen tube analysis. One style per plant, from 10 plants per population was sampled. The styles were removed and fixed in FPA solution (formalin 40%, concentrated propionic acid, 50% ethanol, 5:5:90 by volume) for 24 hours and then stored in 70% ethanol. They were then rinsed in deionised water before softening in 8mol L^{-1} sodium hydroxide for 6 hours. The styles were rinsed again for 3 hours before staining in 0.1% aniline blue in potassium acetate for 4 hours (Dafni 1992). The styles were then gently squashed under a cover-slip and observed under a

fluorescence microscope (Olympus VANOX-S AHBS-513) at 100x magnification. One-way analysis of variance was performed to determine any differences between the species for the number of grains present on the stigma, and the number of pollen tubes.

4.2.5 Conditions for triggering flowers

An additional investigation was carried out to see if flowers required a pollinator to trigger the style. 10 flower spikes of *S. spinulosa* were placed 15 cm in front of a fan for one minute to see if wind could cause the style to trigger. The spikes were also held by the base and hit on a table fives times. The number of flowers per spike that were triggered before and after being placed near the fan was counted. The act of triggering the style was also performed using a dissecting needle to see if it was possible for self-pollen grains to reach the stigma. The number of grains present on the stigma after triggering was recorded. Twenty flowers of *S. spinulosa* were sampled for this investigation.

4.3 RESULTS

4.3.1 Floral display

The floral display of *Synaphea quartzitica* is larger, producing more flowers per plant than *S. spinulosa* (Table 4.1). Although the mean spike length of *S. quartzitica* is nearly five times longer it only produces twice as many flowers on average, as the flowers are less crowded on the spike. *S. spinulosa* however, produces more spikes per plant, which may make up for the smaller spike length and hence capacity for bearing flowers (Figure 1).

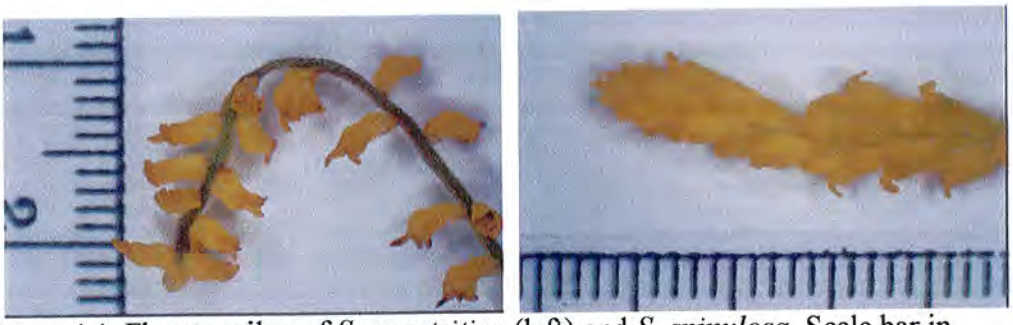

Figure 4.1. Flower spikes of *S. quartzitica* (left) and *S. spinulosa*. Scale bar in millimetres.

Table 4.1. Mean spike length (n = 100), flowers per spike, spikes per plant and flowers per plant for *S. quartzitica* and *Synaphea spinulosa.*

	S. quartzitica	*S. spinulosa*
Spike length (mm)	130	29
Flowers / spike	32	16
Spikes / plant	16	20
Flowers / plant	504	328

4.3.2 Stigma receptivity and pollen viability

Results of stigma receptivity for *S. quartzitica* showed that there was no significant difference between the three categories (unopened, open-not triggered, open-triggered) ($\chi^2 = 2.527$, $p = 0.283$). *S. spinulosa* also had no significant difference between categories ($\chi^2 = 2.542$, $p = 0.281$). Most flowers of *S. quartzitica* were non-receptive, while *S. spinulosa* had their majority receptive ($\chi^2 = 15.978$, $p = 0.000$) (Table 4.2).

Table 4.2. Number of receptive (R) and non-receptive (NR) stigmas of *Synaphea quartzitica* and *S. spinulosa* at each population for flowers at different developmental stages.

Population	Unopened		Opened – not triggered		Opened - triggered	
	R	NR	R	NR	R	NR
Sq CH	17	8	10	8	5	9
SqWNP	6	14	7	13	4	10
Total	**23**	**22**	**17**	**21**	**9**	**19**
Ss POP1	14	6	15	5	14	2
Ss POP2	14	6	15	3	9	12
Total	**28**	**12**	**30**	**8**	**23**	**14**

Small pollen grains stained blue, and were counted as non–viable. Nearly all the non-viable pollen grains for *S. quartzitica* were small. *S. spinulosa*, however had a mixture of small and large non-viable grains. There was no significant difference in viability between populations ($F = 0.04$ $p = 0.0.839$) and species ($F = 2.50$, $p = 0.116$), however there was a significant difference between flower type ($F = 9.18$, $p = 0.000$) (Figure 4.2). Fishers pairwise comparison showed that unopened and new flowers has similar viabilities, while old flowers were significantly lower in percentage viability.

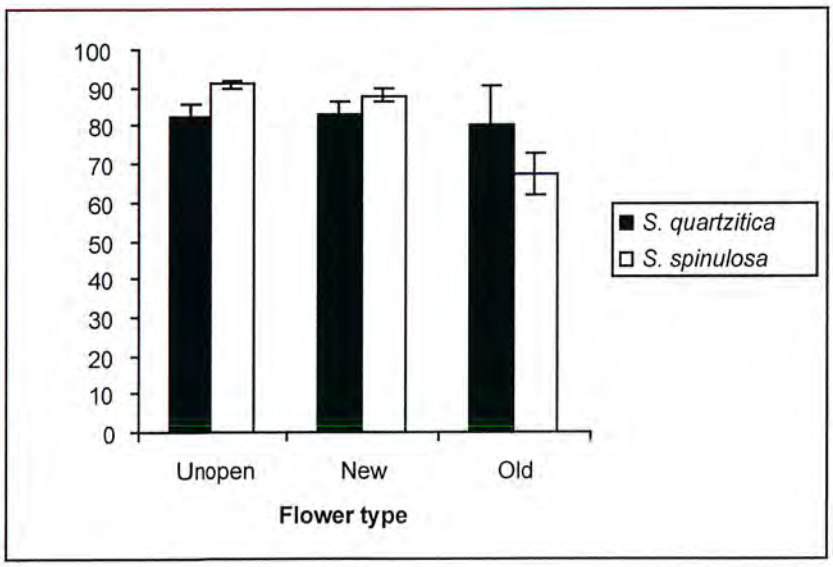

Figure 4.2. Mean percentage viability (±SE) of pollen taken from three flower types of two species of *Synaphea*.

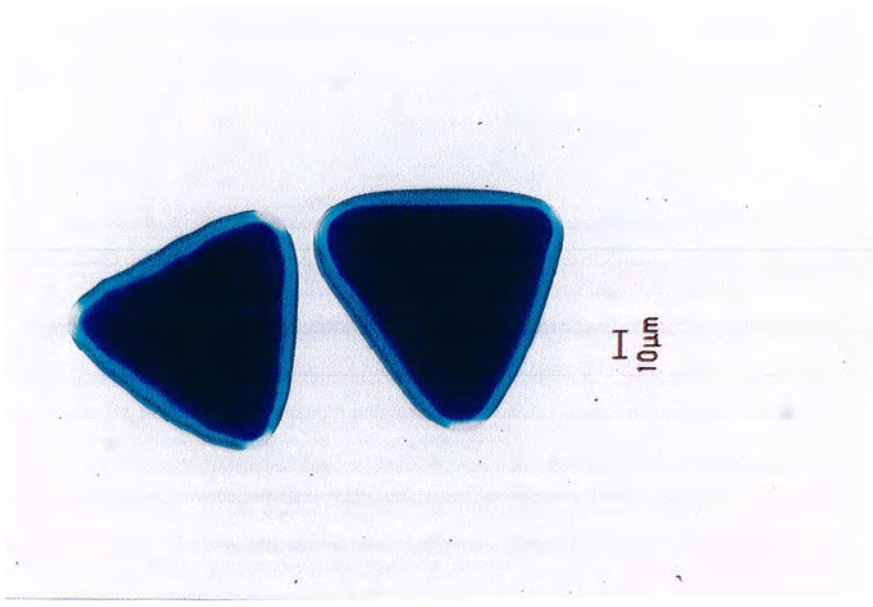

Figure 4.3. Stained *S. quartzitica* pollen grains.

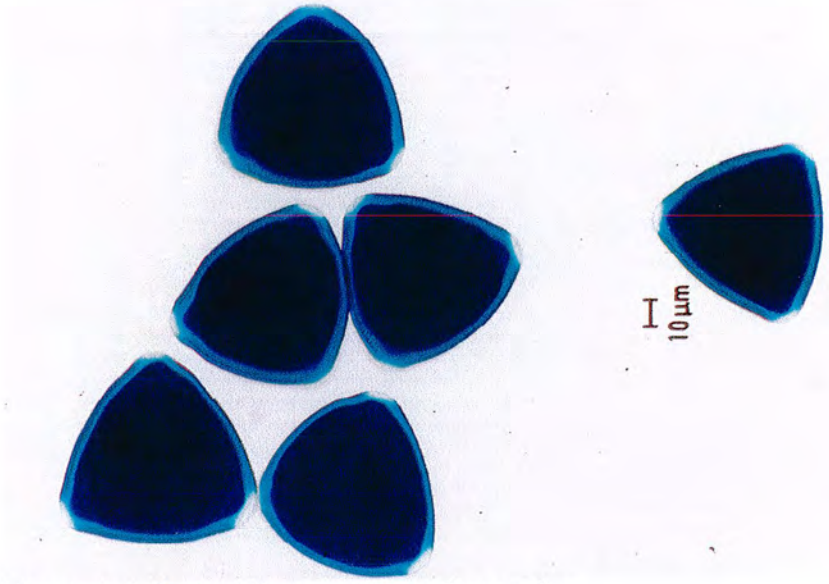

Figure 4.4. Stained *S. spinulosa* pollen grains.

4.3.3 Fruit set and pollinator limitation

A similar number of plants set seeds for both species. The number of spikes per plant that set fruit was also similar, with 2-3 spikes out of 10 producing fruit (Table 4.3). Mean seed set for *S. quartzitica* was calculated to be 4.0%, nearly half that of *S. spinulosa* (9.0%). These results were compared with those spikes that had

pollinators excluded (bagged). For *S. spinulosa* an ANOVA showed a significant difference in mean seed set per spike with seeds between the control and the bagged treatments ($F = 31.52$, $p = 0.000$), but no significant difference between populations ($F = 0.00$, $p = 1.000$). *S. quartzitica* showed no significant difference for both populations ($F = 0.82$, $p = 0.365$) and treatments ($F = 3.34$, $p = 0.068$)

Figure 4.5. *S. quartzitica* fruit on spike. Scale bar in millimetres.

Table 4.3. Summary of data collected from exclusion of pollinators investigation on *Synaphea quartzitica (Sq)* and *S. spinulosa (Ss)*.

CONTROL	Number of plants which set seeds (n = 10)	Mean number of spikes per plant which set seed (n = 10)	Mean seed set per spike with seeds (%)
Sq Cairn Hill	6	2	3
Sq Watheroo NP	9	3	5
Ss Population 1	7	3	10
Ss Population 2	9	3	7
BAGGED			
Sq Cairn hill	1	3	6
Sq Watheroo NP	3	3	6
Ss Population 1	3	1	7
Ss Population 2	2	2	8

4.3.4 Pollen tube analysis

Very few pollen grains were present on the stigmas of *S. quartzitica* (range 0-4 grains). Of the grains observed, only 3 produced any visible tubes. No tubes reached the ovary (the longest tube grew half way down the style). Samples from Watheroo National Park had only one stigma that had pollen visible (Table 4.4). The stigma had one pollen grain that had germinated, but it did not seem to penetrate the stigma, hence no tube growth. Cairn Hill samples had more stigmas containing pollen, but only two had tube growth. The first stigma had two tubes present, which both grew a quarter length of the style. The other stigma had one tube, which grew half a length of the style. *S. spinulosa* samples had more pollen grains present. However, only two stigmas in population 2 had tubes, all of which grew a quarter length of the style. In total only 3 tubes grew in the *S. spinulosa* samples. Results of the ANOVA showed that *S. spinulosa* had significantly higher numbers of pollen grains than *S. quartzitica* ($F = 10.20$, $p = 0.003$). However, there was no significant difference between the number of pollen tubes between species ($F = 0.27$, $p = 0.609$).

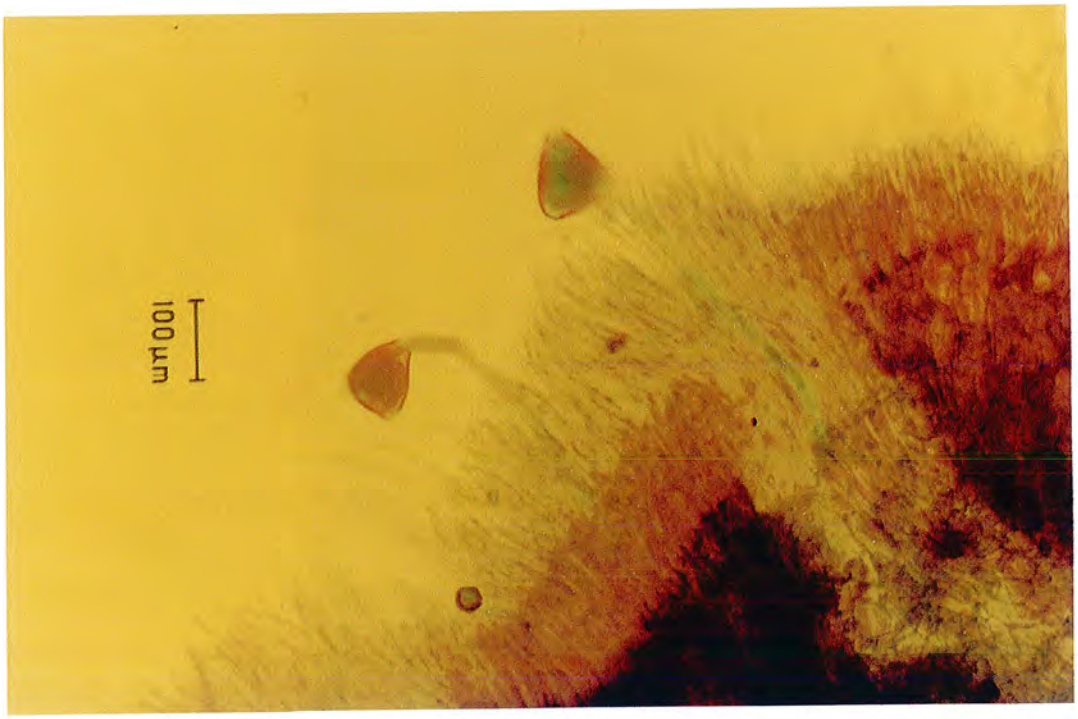

Figure 4.6. Pollen tube growth on stigma of *Synaphea quartzitica.*

Table 4.4. Number of pollen grains and percentage germination of those grains on stigmas taken from *Synaphea quartzitica* and *S. spinulosa* populations.

Population	No. stigmas that had pollen (n = 10)	Mean no. grains per stigma	Mean no. tubes per stigma
S. quartzitica Cairn hill	3	0.6	0.2
S. quartzitica Watheroo NP	1	0.1	0
S. spinulosa 1	7	4.2	0.1
S. spinulosa 2	5	1.9	0.2

4.3.5 Conditions for triggering flowers

The action of bagging or beating flower spikes did not cause any styles to trigger. Wind also had no effect. However, it was possible for self-pollen to reach the stigma on triggering. The act of triggering resulted in self-pollen adhering to the stigma 80% of the time (mean number of grains 7, range 0-25, n = 20)

4.4 DISCUSSION

Most genera of the Proteaceae possess hermaphroditic flowers which in general have low fruit-to-flower ratios, with fruit set often less than 10 % (Goldingay & Whelan 1990, Trueman & Wallace 1999). My results showed that both *Synaphea quartzitica* and *S. spinulosa* follow this trend, with fruit set averaging 4% for *S. quartzitica*, and 8.5 % for *S. spinulosa*. A study on fruit-flower ratios in *Grevillea* (Proteaceae) concluded that low fruit-flower ratios resulted from a combination of pollen limitation and high levels of flower and fruit predation (Hermanutz *et al.* 1998). My initial observations in the field showed that there was no predation of flowers so only pollen limitation was investigated. Pollinators of *Synaphea* are currently unknown. During 90 hours of fieldwork (including two people at any time) conducted at the four populations, only once was a possible pollinator (a honeybee, *Apis mellifera*) observed on a spike. This general lack of pollinators could be a major contributing factor to these low values. However, no formal investigation into pollinators was performed.

Jennersten (1988) states that plants in smaller populations or less dense patches generally receive fewer visits from pollinators. This may explain the low numbers for *S. quartzitica*, but does not for the common and widespread *S. spinulosa*. Results from a study conducted by Collins *et al.* (1984) showed that a decline in the number of pollinator visits was not because small populations are too isolated, as the nearest population distance was similar for small and large populations. It was concluded that total nectar supply (and other food) were too low. In most cases in the Proteaceae abundant nectar is offered and structural features favour the visitor carrying rather than ingesting pollen (Ladd & Bowen 1997). *Synaphea* has no nectaries (Venakta Rao 1971) but has explosive anthers that limit the ability of the visitor to obtain all the pollen (Ladd & Bowen 1997). Another possible reason could be the displacement of native pollinators by the introduced honeybee.

Pollen limitation may also be the result of ineffective pollen transfer (Goldingay & Whelan 1990) or receival of unsuitable pollen. Results of the pollen tube analysis

showed that very few grains were present on the stigma of both species, with none reaching the ovary. For example, only one *S. quartzitica* stigma out of 10 sampled at Watheroo NP had pollen present. It is assumed the flowers had been visited by pollinators as the styles had been triggered, and there is no evidence that the style triggers itself (Douglas 1997).

Of the pollen grains present, most had germinated but failed to penetrate the stigma. Studies on *Grevillea linearifolia* and *Telopea speciosissima* demonstrated the rejection of self pollen at the level of the stigma (Hermanutz *et al.* 1997, Whelan & Goldingay 1989). It is possible that selection against self-pollen is also occurring in both species of *Synaphea.* Since pollinators make frequent within-plant movements, transfer of self-pollen to receptive stigmas is common and self-pollination is inevitable (Goldingay & Carthew 1998). However, the results of the bagging experiments showed that both species are possibly partially self-compatible and capable of producing some seeds in the absence of pollinators by spontaneous autogamy. While the bagged treatments did have plants that produced fruits, the number of plants was considerably fewer than the untreated (control) plants. This may indicate a mixed breeding system as seen in *Dryandra querifolia* and *D. formosa*, where self-pollen is less favoured, and often results in post–zygotic abortion of seeds (Mathews & Sedgley 1998). The results of fruit set in the bagged treatment raises the question of how the pollen arrived onto the stigma. *Synaphea* requires a pollinator to release the pollen from the explosive anthers and physical factors that might have caused triggering of the flower (such as the application of a bag and wind) were ineffective. This question remains unanswered.

It is possible that germinated pollen grains may not have been able to penetrate the stigma due to it not being receptive. Stigma receptivity is a crucial stage in the maturation of the flowers, which may greatly influence the rate of self-pollination. The receptivity of the stigma varies from a few hours up to 10 days in some species (Dafni 1992). Results from the receptivity tests showed that there was a difference in receptivity between the species; however, they both produced the same number of

pollen tubes. It is interesting to note that there was no significant difference between the three categories (unopened, open-triggered, open- not triggered). Whether stigma receptivity is triggered by pollen removal or anthesis is unknown for most species (Goldingay & Carthew 1998). However, the age of the flower, the time of day and the presence or absence of stigmatic exudate are known to influence receptivity (Dafni 1992). This could explain the lack of any pattern noticed between the categories.

The number of pollen tubes observed was also very low for both species. Robertson *et al.* (1999) established that a lack of pollen tubes in the style was one cause of low fruit production in an endemic New Zealand mistletoe. By artificially supplementing pollen to the mistletoe flowers, fruit production increased up to 5 times. This contrasts with Pyke's (1982) results for *Lambertia formo*sa, which produced no increase in seed set after artificial supplementation compared with untreated flowers. Ineffective pollination was stated to be the limiting factor for fruit set in *Telopea speciossima* (Whelan & Goldingay 1989). However, it was concluded that ineffective pollen transfer did not sufficiently explain the low fruit to flower ratio when artificial pollination experiments resulted in extremely low fruit set. A low sample size could have affected the results of the pollen tube analysis, as only 10 per population were examined. Other studies had larger samples sizes that ranged from 15 to 100 pistils, with 20-25 the most common.

In a study on *Banksia goodii*, Lamont *et al.* (1993) determined that pollen quality is more important in explaining difference in fertility between populations than the number of pollinator visits. The authors suggested that pollen quality may be poorer in small populations because pollen transfer will increasingly be between related neighbours. As a result smaller populations can be expected to produce disproportionately fewer seeds until a critical population size is reached, beyond which seed production may be negligible. Pollen viability did not appear to be a limiting factor in seed set in this investigation. Viability was above 80% in unopened and 'new' flowers, but was significantly lower in 'old' flowers. In *Banksia menziesii*

over 90% of pollen grains were viable when flowers first opened, but viability decreased rapidly, with most pollen non-viable within 24 hours (Ramsey & Vaughton 1991). In contrast Vaughton & Ramsey (1991) discovered that over 50% of pollen in *Banksia spinulosa* was viable 8 days after flowers first opened. This difference in pollen longevity is believed to be related to efficiency of pollen removal (Ramsey and Vaughton 1991).

Pollen transfer appears to be the major limiting factor for seed set in *Synaphea quartzitica* and *S. spinulosa*. However, availability of necessary resources cannot be ruled out as an accompanying factor as no investigation into this subject was made.

CHAPTER 5

GENERAL DISCUSSION

Effective conservation of biological diversity requires a sound basis for scientific understanding of the species involved (Faulk 1990). Rare and endangered species often represent a special problem for conservation, reflecting characteristic differences from common species in their biology, patterns of threat and resources available for conservation (Faulk 1990). To assess the status of rare plant species and to prioritise among conservation approaches, the factors affecting the numbers of individuals within a species must be understood (Schemske *et al* 1994). This study investigated key aspects of conservation biology, concentrating on the population and reproductive biology of the rare and critically endangered *S. quartzitica* compared with the common *S. spinulosa*. The specific aims of the study were:

1. To determine the population structure of *S. quartzitica* and compare it with *S. spinulosa* to gain insights into any difference between a rare and a common species.

2. To determine the number of seeds of *S. quartzitica* in the soil seed bank and compare it with *S. spinulosa* to gain insights into any difference between a rare and common species.

3. To determine if habitat specificity is constraining population growth of S. quartzitica.

4. To investigate the flowering and pollination biology of both species and hence determine any limitations to population growth, and

5. To rank the threats and constraints to population growth of *S. quartzitica* so that better informed decisions can be made in terms of its management.

Coates and Atkins (1997) state that the continual decline of small populations of threatened flora indicate the their long term survival is unlikely without significant intervention in the form of population enhancement and habitat rehabilitation programs. Population structure was determined by using a size classification system. The results from the population biology studies suggest that the *S. quartzitica* populations are stable or increasing, as deaths recorded were insignificant and the populations comprised many small ramets. However, the results are based upon a study confined to one year. To determine this precisely, surveys should continue over several years. The comparison of the population structure of *S. quartzitica* and *S. spinulosa* showed that most plants were small, except for a few very large (old) plants for both species.

Separate and usually mutually exclusive suites of adaptations are found in fire-adapted trees and shrubs that have evolved in habitats prone to fire (Carpenter & Recher 1979). Two basic categories of life history strategy in relation to fire may be recognised as non-sprouters (obligate seeders) and resprouters (Pate & Hopper 1993). As *S. quartzitica* is capable of resprouting, by root suckering, fire should not destroy the plant. Fire could be a threat, however, if fires are too frequent. If seeds germinate in response to fire, stores of seeds could be rapidly depleted if fires recurred before regenerating or juvenile plants reached maturity to replenish the soil seed bank.

An investigation was made into the number of seeds stored in the soil seed bank. This was achieved by the physical search for seeds and the application of smoke water to the soil. Low numbers of seed were found for both species in the soil seed bank. The numbers of seedlings in the smoke water investigation were also not significantly different between treatments, populations or species. These results may reflect the bad climatic conditions experienced during the year of study. During the

eight-month period from March to October, south-western Australia had serious to severe deficiencies in rainfall (Bureau of Meteorology 2001). The very poor recruitment is of concern if population growth is to occur without intervention. The criterion for success of the Interim Recovery Plan is that the number of individuals within populations and/or the number of populations have increased (Stack & English 1999). For a clonal species this needs to be interpreted as an increase in genets rather than ramets.

To increase the number of individuals seed may be collected and germinated off site and later planted at existing populations, or at sites where they could possibly occur but do not. For example, the populations of *S. quartzitica* are part of the scrub-heath community growing on the chert hills of the Coomberdale floristic region. There are eight known occurrences of this type of community (Hamilton-Brown 2000a), which leaves six possible sites for translocation to be explored. Also the collection and storage of germplasm can be performed to enable the effective re-establishment of plants in the future, to counter the possible loss of genetic diversity and ultimately prevent the extinction of the species (Coates & Atkins 1997).

In south-western Australia, unusually high proportions of rare flora are encountered among taxa which require open habitats for recruitment or persistence, or occur on unusual landforms such as granite outcrops and other rocky types (Pate & Hopper 1993). *S. quartzitica* is present on a highly restricted chert substrate which supports a unique ecological community. It appears that limited suitable habitat is a major factor contributing to its rarity. An investigation into the physical properties and nutrient status of the soils where the species does and does not occur within its community was completed. It revealed that there are some differences in terms of nutrient levels. However, a Principal Component Analysis showed considerable overlapping of properties. This indicates that it is possible for *S. quartzitica* to occur in some areas where it currently does not, but may be restricted due to other factors such as light and competition.

Ineffective pollen transfer appears to be the major limiting factor for seed set in the rare and common species. All flowers examined for the pollen tube analysis were triggered, but for *S. quartzitica* the number of stigmas that actually contained pollen was less than 30 %. The number of grains observed was significantly different between the species. However, the number of tubes was not. This may be due to rejection of self-pollen as seen in *Grevillea linearifolia* (Hermanutz *et al.* 1997) and *Telopea speciosissima* (Goldingay & Whelan 1993). Both *S. quartzitica* and *S. spinulosa* probably possess a mixed breeding system as partial self-compatibility and spontaneous autogamy were observed. This may be of advantage to *S. quartzitica* as species that are self-incompatible are particularly vulnerable to the effects of habitat fragmentation (Renner 1988).

The low numbers of seed in the soil seed bank reflects the low reproductive output of both species. Results of the reproductive biology of *S. quartzitica* and *S. quartzitica* confirm the hypothesis that the main limitation to population growth is low seed set. Low seed set is characteristic of the genus (George 1995), with both *S. quartzitica* and *S. spinulosa* producing similarly low numbers of seeds. The low seed set is comparable with most genera of the Proteaceae, which generally have fruit set less than 10 % (Goldingay & Whelan 1990, Trueman & Wallace 1999). Low seed-set does not appear to limit population growth in *S. spinulosa*, as it is a widespread, common species to South-western Australia (George 1995). Therefore it is unlikely that it should limit *S. quartzitica.*

Of the four known populations, three occur in Watheroo National Park and the remaining population is privately owned. However, CALM is negotiating to acquire this land (Hamilton-Brown 2000b). The scrub-heath community it belongs to is also threatened. This is because the community is present on the restricted, discontinuous outcrops of Noondine chert in the Moora-Watheroo area (Hamilton-Brown 2000). Much of this area has been extensively cleared for agriculture, and therefore loss of suitable habitat has occurred.

South-western Australia has a remarkable level of plant species richness and a large number of rare, locally endemic plants (Hopper 1992). A significant proportion of this flora consists of relictual species that often have naturally geographically restricted and fragmented or disjunct distributions (Hopper 1979). Fiedler & Ahouse (1992) suggest that rarity describes three situations in terms of distribution and abundance of a particular species. *S. quartzitica* fits the third situation which are those taxa whose distribution is clumped and whose individual abundance is low where known.

Small population size, often the result of a recent and rapid decline in numbers of individuals within populations due to habitat destruction, is currently considered to be one of the greatest threats to rare flora (Coates & Atkins 1997). Associated with habitat loss and degradation are a range of threatening processes of which inappropriate fire regimes, track maintenance, grazing, and mining and gravel extraction have been identified in order of most to least threatening for the *S. quartzitica* populations (Satck & English 1999). The threat of inappropriate fire regimes has been discussed earlier in this chapter. Track maintenance is of most significance to the populations in Watheroo National Park. These populations occur adjacent to the roads within the Park, with some individuals very close to the edge of the tracks. Therefore road graders and other machinery may destroy plants during maintenance. Grazing by kangaroos and rabbits is considered a small threat to the populations, as severe grazing was not observed during this study. Mining and gravel extraction is a threat only at Cairn Hill. Until recently the Moora Shire has been extracting gravel and quartzite from the base of the hill, and a mining tenement occurs on part of the land (Stack & English 1999). This has been considered the least threat as this site has recently been identified as a Threatened Ecological Community, and steps have been taken to acquire the land. It is unlikely that mining and gravel extraction will be allowed to occur at this site from this time.

Conserving the remaining area of suitable habitat appears to be the most important in terms of the survival of *S. quartzitica.* Due to the small numbers of populations and individuals remaining, conservation and management of rare species often has little margin for error (Faulk 1990). The conservation of Western Australia's flora has been achieved through a variety of approaches involving the acquisition of land for private reserves, improved management of reserves and other government land and privately owned remnant vegetation, as well as the protection of flora through legislation (Coates & Atkins 1997).

5.1 Conclusion

Habitat loss is considered to be one of the most important factors leading to the decline of many of the worlds threatened species (Recher &Lim 1990). *S. quartzitica* is part of a unique ecological community, which is also threatened due to the restricted nature of the chert substrate in the area, and the extensive clearing of this habitat for agriculture. Investigations into the population and reproductive biology of *S. quartzitica* and *S. spinulosa* showed no apparent differences that could explain the rarity of *S. quartzitica*, except for its restricted habitat. Therefore, I conclude that growing in a specialised habitat over a restricted range is the major cause of rarity for *S. quartzitica.*

5.2 Recommendations

The *S. quartzitica* populations appear to be stable. If numbers of populations and/or individuals (genets) are to be increased then some intervention will be required as recruitment of this species is low. The following recommendation are made:

- Regular monitoring of the populations should occur to ensure that the aforementioned threats are not threatening populations.

- Support is given to the acquisition of Cairn Hill, and any other land that contains suitable habitat that could be used as possible translocation sites.

- The promotion of genet not ramet recruitment should occur where possible to allow for greater genetic diversity within the populations.

- Fire may be of use in promoting new growth via suckering and the germination of soil stored seed, however the frequency and intensity of fires must be considered. It is suggested here that a fire interval of 20 years be considered at a sufficient intensity to remove overstorey vegetation, and allow for recruits to become fire tolerant. The effects of fire on other species growing in association with *S. quartzitica* and post fireweed invasion must also be considered.

- Sexual reproduction results in viable seeds that may be collected to be used for increasing numbers of individuals at existing populations, and/or for translocations. However, seed set is low, and seeds may have to be collected over a number of years before an adequate collection is made.

- Further research to increase the understanding of the biology of *S. quartzitica*. As pollen transfer appears to be the major factor limiting seed set in S. quartzitica, studies on hand pollination treatments should be undertaken to see if the artificial addition of pollen onto the stigma increases seed set of the species. This research should also include studies that help to understand how to increase the opportunities for outcrossing. Other areas for investigations may focus on germination studies that determine optimum conditions for germination and survival of seed, and research into population genetic structure and levels of genetic diversity.

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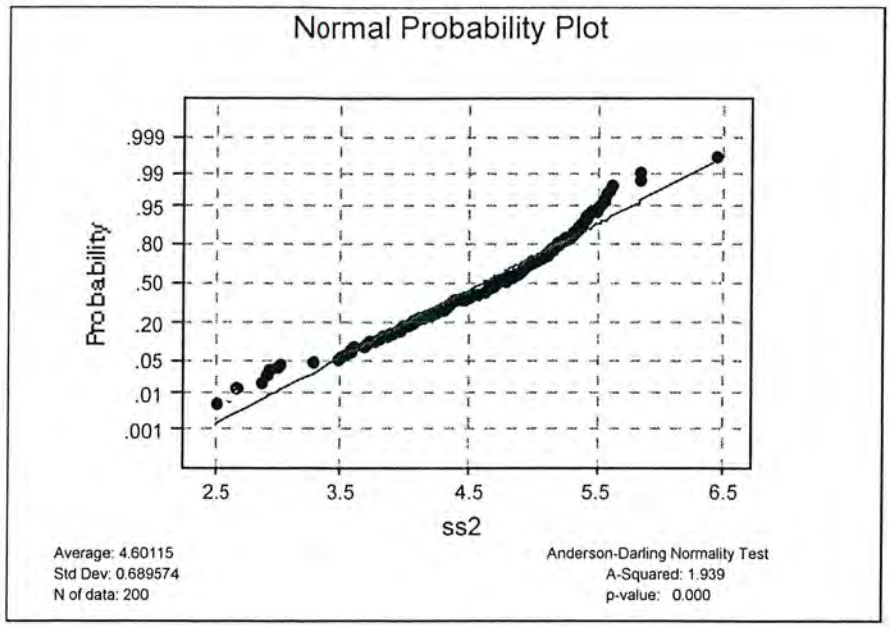
APPENDIX 1

Statistics

Levene's Test on plant size data (log transformed)

```
Test Statistic: 2.067
p value       : 0.152
```



Two Sample T-Test and Confidence Interval

```
Twosample T for sqch vs sqwnp
          N      Mean     StDev   SE Mean
sqch     94     4.332     0.625     0.065
sqwnp   100     3.772     0.672     0.067

95% C.I. for mu sqch - mu sqwnp: ( 0.377,  0.744)
T-Test mu sqch = mu sqwnp (vs not =): T= 6.02  P=0.0000  DF=  191
```

Two Sample T-Test and Confidence Interval

```
Twosample T for ss1 vs ss2
        N      Mean     StDev   SE Mean
ss1   100     4.775     0.759     0.076
ss2   100     4.428     0.565     0.056

95% C.I. for mu ss1 - mu ss2: ( 0.160,  0.534)
T-Test mu ss1 = mu ss2 (vs not =): T= 3.67  P=0.0003  DF=  182
```

Analysis of Variance for soil seed bank

Source	DF	Seq SS	Adj SS	Adj MS	F	P
pop	1	36.55	34.35	34.35	1.55	0.221
sp	1	48.06	48.06	48.06	2.17	0.150
Error	36	798.83	798.83	22.19		
Total	38	883.44				

Analysis of Variance for seedlings – smoke water investigation

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	1	0.2912	0.3162	0.3162	1.24	0.270
population	1	0.6342	0.6343	0.6343	2.48	0.120
species	1	0.0158	0.0158	0.0158	0.06	0.804
Error	76	19.4463	19.4463	0.2559		
Total	79	20.3875				

Analysis of Variance for canopy cover - Synaphea quartzitica

Source	DF	Seq SS	Adj SS	Adj MS	F	P
pres/abs	1	10017.2	10017.2	10017.2	25.53	0.000
pop	1	3186.2	3186.2	3186.2	8.12	0.007
Error	37	14518.5	14518.5	392.4		
Total	39	27722.0				

Analysis of Variance for canopy cover – Synaphea spinulosa

Source	DF	Seq SS	Adj SS	Adj MS	F	P
pres/abs	1	84.1	84.1	84.1	0.43	0.517
pop	1	291.6	291.6	291.6	1.49	0.230
Error	37	7255.9	7255.9	196.1		
Total	39	7631.6				

Analysis of Variance for % litter – Synaphea quartzitica

Source	DF	Seq SS	Adj SS	Adj MS	F	P
pres/abs	1	42090	42090	42090	72.76	0.000
populat	1	48069	48069	48069	83.10	0.000
Error	77	44543	44543	578		
Total	79	134702				

Analysis of Variance for % litter – Synaphea spinulosa

Source	DF	Seq SS	Adj SS	Adj MS	F	P
p/a	1	63.0	63.0	63.0	0.11	0.746
pop	1	8590.5	8590.5	8590.5	14.35	0.000
Error	77	46085.0	46085.0	598.5		
Total	79	54738.5				

Descriptive Statistics – Synaphea quartzitica soil samples

Variable	Sites	N	Mean	Median	TrMean	StDev	SEMean
NO3	1	10	2.600	3.000	2.625	0.516	0.163
	2	10	2.900	3.000	2.875	0.568	0.180
	3	10	2.900	3.000	2.875	0.568	0.180
	4	10	2.900	3.000	2.875	0.568	0.180
NH4	1	10	4.800	5.000	4.750	1.135	0.359
	2	10	4.000	4.000	3.875	1.333	0.422
	3	10	3.600	3.000	3.375	1.350	0.427
	4	10	4.200	4.000	4.125	1.619	0.512
P	1	10	3.900	4.000	4.000	0.876	0.277
	2	10	4.100	4.000	3.875	1.370	0.433
	3	10	2.800	2.000	2.625	1.687	0.533
	4	10	4.300	4.000	4.000	1.494	0.473
K	1	10	93.70	91.00	93.37	16.84	5.33
	2	10	93.30	90.00	90.25	20.13	6.37
	3	10	65.90	59.50	62.25	21.45	6.78
	4	10	70.40	65.00	67.87	17.26	5.46
S	1	10	4.040	4.050	4.038	0.395	0.125
	2	10	3.900	3.800	3.888	0.667	0.211
	3	10	3.080	2.750	2.825	1.384	0.438
	4	10	4.540	3.750	4.313	2.199	0.695
C	1	10	1.544	1.550	1.514	0.393	0.124
	2	10	1.531	1.335	1.521	0.413	0.131
	3	10	1.493	1.430	1.444	0.371	0.117
	4	10	2.325	2.105	2.204	0.690	0.218
Fe	1	10	194.3	193.0	190.9	32.6	10.3
	2	10	233.1	227.5	232.6	32.7	10.3
	3	10	201.10	204.00	200.13	20.66	6.53
	4	10	226.90	229.00	229.38	22.48	7.11
Conductivity	1	10	0.02330	0.02250	0.02275	0.00411	0.00130
	2	10	0.02320	0.02400	0.02337	0.00447	0.00141
	3	10	0.0409	0.0230	0.0241	0.0564	0.0179
	4	10	0.03150	0.02700	0.02975	0.01339	0.00424
pH	1	10	4.4700	4.5000	4.4750	0.0949	0.0300
	2	10	4.7100	4.7000	4.7000	0.0994	0.0314
	3	10	4.8600	4.8000	4.8625	0.1838	0.0581
	4	10	4.860	4.750	4.838	0.381	0.120

Sites - Synaphea quartzitica
1 = present Cairn Hill
2 = absent Cairn Hill
3 = present Watheroo NP
4 = absent Watheroo NP

Descriptive Statistics – Synaphea spinulosa soil samples

Variable	Sites	N	Mean	Median	TrMean	StDev	SEMean
NO3	1	10	2.100	2.000	2.000	0.316	0.100
	2	10	1.700	2.000	1.750	0.483	0.153
	3	10	2.500	2.500	2.500	0.527	0.167
	4	10	2.100	2.000	2.000	0.316	0.100
NH4	1	10	1.200	1.000	1.000	0.632	0.200
	2	10	1.0000	1.0000	1.0000	0.0000	0.0000
	3	10	2.100	1.500	1.875	1.370	0.433
	4	10	3.000	2.500	2.750	1.333	0.422
P	1	10	1.800	2.000	1.625	0.919	0.291
	2	10	4.100	4.000	4.000	1.287	0.407
	3	10	1.800	1.500	1.625	1.033	0.327
	4	10	1.800	2.000	1.750	0.789	0.249
K	1	10	18.00	18.00	17.88	4.42	1.40
	2	10	26.90	26.00	26.75	7.40	2.34
	3	10	26.60	20.00	22.12	18.93	5.99
	4	10	30.60	27.50	28.75	9.11	2.88
S	1	10	1.570	1.350	1.400	0.729	0.230
	2	10	1.4300	1.4000	1.4250	0.3057	0.0967
	3	10	1.850	1.700	1.650	0.902	0.285
	4	10	1.870	1.550	1.725	0.717	0.227
C	1	10	0.2920	0.2850	0.2875	0.0890	0.0282
	2	10	0.4210	0.4500	0.4263	0.1414	0.0447
	3	10	0.5980	0.5400	0.5975	0.2135	0.0675
	4	10	0.781	0.635	0.649	0.549	0.174
Fe	1	10	105.70	105.50	105.37	19.01	6.01
	2	10	53.40	56.00	54.37	7.60	2.40
	3	10	55.50	55.50	55.50	11.36	3.59
	4	10	113.0	106.5	106.2	38.1	12.0
Conductivity	1	10	0.00950	0.00900	0.00887	0.00350	0.00111
	2	10	0.01040	0.01050	0.01050	0.00280	0.00088
	3	10	0.01450	0.01250	0.01313	0.00740	0.00234
	4	10	0.01420	0.01200	0.01313	0.00579	0.00183
pH	1	10	5.5800	5.5500	5.5500	0.2898	0.0917
	2	10	5.6300	5.6500	5.6125	0.3057	0.0967
	3	10	5.280	5.350	5.300	0.343	0.108
	4	10	5.1100	5.0000	5.0375	0.2923	0.0924

Sites - Synaphea spinulosa
1 = present population 1
2 = absent population 1
3 = present population 2
4 = absent population 2

Principal Component Analysis for soil variable – S. quartzitica

Eigenanalysis of the Correlation Matrix

Eigenvalue	2.5020	1.4811	1.2494	1.1293	0.8512	0.7451
Proportion	0.278	0.165	0.139	0.125	0.095	0.083
Cumulative	0.278	0.443	0.581	0.707	0.801	0.884

Eigenvalue	0.4803	0.3051	0.2564
Proportion	0.053	0.034	0.028
Cumulative	0.938	0.972	1.000

Variable	PC1	PC2	PC3	PC4	PC5	PC6
NO3	0.092	-0.531	0.304	-0.328	-0.244	-0.499
NH4	0.482	0.055	-0.132	-0.311	-0.346	-0.142
P	0.383	0.079	0.226	-0.297	0.063	0.685
K	0.376	0.168	0.169	0.499	-0.486	0.010
S	0.535	-0.068	-0.132	0.220	0.069	-0.097
C	0.417	-0.169	-0.188	-0.121	0.659	-0.146
Fe	0.041	-0.528	0.231	0.587	0.193	0.127
Conduct	-0.002	-0.064	-0.801	0.160	-0.139	-0.029
pH	-0.095	-0.603	-0.252	-0.162	-0.291	0.463

Variable	PC7	PC8	PC9
NO3	0.397	-0.193	0.084
NH4	-0.246	0.667	-0.073
P	0.461	-0.012	0.149
K	0.096	-0.287	-0.475
S	-0.310	-0.333	0.649
C	-0.010	-0.131	-0.523
Fe	0.101	0.504	0.064
Conduct	0.547	0.055	0.078
pH	-0.393	-0.224	-0.184

Principal Component Analysis for soil variable – S. spinulosa

Eigenanalysis of the Correlation Matrix

Eigenvalue	3.3614	1.6504	1.2072	0.9206	0.7905	0.5131
Proportion	0.373	0.183	0.134	0.102	0.088	0.057
Cumulative	0.373	0.557	0.691	0.793	0.881	0.938

Eigenvalue	0.3799	0.1332	0.0437
Proportion	0.042	0.015	0.005
Cumulative	0.980	0.995	1.000

Variable	PC1	PC2	PC3	PC4	PC5	PC6
NO3	-0.322	-0.011	-0.354	0.223	0.700	-0.078
NH4	-0.427	0.219	0.413	-0.092	-0.091	0.132
P	-0.040	-0.650	0.216	-0.204	-0.263	-0.241
K	-0.216	-0.132	-0.124	0.814	-0.443	0.237
S	-0.467	-0.095	0.282	-0.170	0.078	0.309
C	-0.388	0.011	-0.354	-0.078	-0.263	-0.703
Fe	-0.195	0.295	-0.536	-0.420	-0.369	0.372
conducti	-0.503	-0.202	0.070	-0.042	0.129	0.024
pH	0.080	-0.612	-0.380	-0.159	0.092	0.364

Variable	PC7	PC8	PC9
NO3	-0.381	-0.252	0.129
NH4	0.248	-0.626	0.335
P	-0.534	-0.272	-0.037
K	-0.074	-0.003	0.024
S	-0.200	0.645	0.326
C	0.245	0.170	0.256
Fe	-0.312	-0.128	-0.150
conducti	0.299	0.018	-0.769
pH	0.465	-0.094	0.288

Descriptive Statistics – S. spinulosa floral display

Variable	N	Mean	Median	TrMean	StDev	SEMean
Spiek length	100	28.830	27.000	28.733	7.758	0.776
flowers/spike	100	16.47	15.00	15.42	11.06	1.11
sikes/plant	100	19.93	6.00	15.30	31.85	3.18

Variable	Min	Max	Q1	Q3
length	11.000	47.000	23.000	35.000
flowers/spike	5.00	117.00	12.25	18.00
spikes/plant	0.00	200.00	0.00	30.75

Descriptive Statistics – S. quartzitica floral display

Variable	N	Mean	Median	TrMean	StDev	SEMean
length	100	128.20	122.50	128.22	38.82	3.88
flowers/spike	100	32.01	32.50	31.73	11.64	1.16
spikes/plant	100	15.76	10.00	14.66	14.73	1.47

Variable	Min	Max	Q1	Q3
length	25.00	210.00	100.00	160.00
flowers/spike	10.00	67.00	23.00	39.00
spikes/plant	0.00	58.00	4.00	26.75

One-Way Analysis of Variance on spike length

Analysis of Variance

Source	DF	SS	MS	F	p
Factor	1	493720	493720	629.94	0.000
Error	198	155184	784		
Total	199	648904			

Level	N	Mean	StDev
length	100	128.20	38.82
l	100	28.83	7.76

Pooled StDev = 28.00

Individual 95% CIs For Mean
Based on Pooled StDev

```
---+---------+---------+---------+---
                                  (-*-)
   (-*)
---+---------+---------+---------+---
  30        60        90       120
```

One-Way Analysis of Variance on spikes per plant

```
Analysis of Variance
Source     DF        SS        MS        F        p
Factor      1       869       869     1.41    0.236
Error     198    121907       616
Total     199    122776

                                      Individual 95% CIs For Mean
                                      Based on Pooled StDev
 Level      N      Mean     StDev  ---+---------+---------+---------+---
Sq        100     15.76     14.73  (-----------*-----------)
Ss        100     19.93     31.85              (-----------*-----------)
                                      ---+---------+---------+---------+---
Pooled StDev =    24.81              12.0      16.0      20.0      24.0
```

One-Way Analysis of Variance on flowers per spike

```
Analysis of Variance
Source     DF        SS        MS        F        p
Factor      1     12075     12075    93.61    0.000
Error     198     25540       129
Total     199     37614

                                      Individual 95% CIs For Mean
                                      Based on Pooled StDev
 Level      N      Mean     StDev  -------+---------+---------+---------
Sq        100     32.01     11.64                              (--*---)
Ss        100     16.47     11.06  (--*---)
                                      -------+---------+---------+---------
Pooled StDev =    11.36              18.0      24.0      30.0
```

Chi-Square Test S. quartzitica stigma receptivity of flower types

```
Expected counts are printed below observed counts

             R        NR    Total
    1       23        22       45
         19.86     25.14

    2       17        21       38
         16.77     21.23

    3        9        19       28
         12.36     15.64

Total       49        62      111

ChiSq =  0.495 +  0.391 +
         0.003 +  0.002 +
         0.914 +  0.722 = 2.527
df = 2, p = 0.283
```

Chi-Square Test S. spinulosa stigma receptivity of flower types

```
Expected counts are printed below observed counts

             R       NR    Total
    1       28       12       40
         28.17    11.83

    2       30        8       38
         26.77    11.23

    3       23       14       37
         26.06    10.94

Total       81       34      115

ChiSq =  0.001 +  0.003 +
         0.391 +  0.931 +
         0.360 +  0.856 = 2.542
df = 2, p = 0.281
```

Chi-Square Test comparison of species stigma receptivity

```
Expected counts are printed below observed counts

             R       NR    Total
    Sq      49       62      111
         63.85    47.15

    Ss      81       34      115
         66.15    48.85

Total      130       96      226

ChiSq =  3.454 +  4.677 +
         3.333 +  4.514 = 15.978
df = 1, p = 0.000
```

Analysis of Variance for viability

Source	DF	Seq SS	Adj SS	Adj MS	F	P
flr type	2	5062.7	5606.3	2803.1	9.18	0.000
popn	1	9.5	12.6	12.6	0.04	0.839
species	1	763.2	763.2	763.2	2.50	0.116
Error	160	48857.6	48857.6	305.4		
Total	164	54692.9				

One-Way Analysis of Variance

```
Analysis of Variance on viability
Source      DF        SS        MS        F        p
flower type  2      5063      2531     8.26    0.000
Error      162     49630       306
Total      164     54693

                                      Individual 95% CIs For Mean
                                      Based on Pooled StDev
 Level       N      Mean     StDev  -------+---------+---------+---------
 Unopened   78     86.72     15.04                            (-----*----)
 New        57     85.35     15.49                         (------*-----)
 Old        30     71.87     25.45   (--------*--------)
                                     -------+---------+---------+---------
Pooled StDev =    17.50               70.0      77.0      84.0

Fisher's pairwise comparisons

    Family error rate = 0.122
Individual error rate = 0.0500

Critical value = 1.975

Intervals for (column level mean) - (row level mean)

             Unopened    New

     New    -4.66
             7.39

     Old     7.42       5.69
            22.28      21.28
```

Analysis of Variance for seed set – S. quartzitica

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	1	12.896	12.832	12.832	3.34	0.068
population	1	3.160	3.160	3.160	0.82	0.365
Error	399	1531.128	1531.128	3.837		
Total	401	1547.184				

Analysis of Variance for seed set – S. spinulosa

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	1	353.44	353.44	353.44	31.52	0.000
population	1	0.00	0.00	0.00	0.00	1.000
Error	397	4452.32	4452.32	11.21		
Total	499	4805.76				

One-Way Analysis of Variance

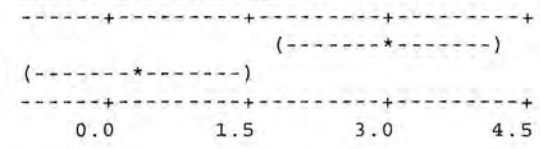
Analysis of Variance on number of pollen grains

Source	DF	SS	MS	F	p
species	1	72.90	72.90	10.20	0.003
Error	38	271.50	7.14		
Total	39	344.40			

Level	N	Mean	StDev
Ss	20	3.050	3.663
Sq	20	0.350	0.933

Pooled StDev = 2.673

Individual 95% CIs For Mean Based on Pooled StDev



One-Way Analysis of Variance

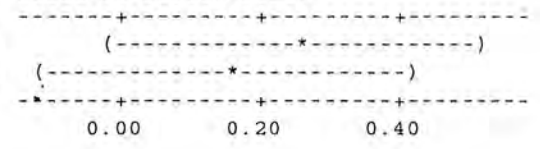
Analysis of Variance on number of pollen tubes

Source	DF	SS	MS	F	p
species	1	0.100	0.100	0.27	0.609
Error	38	14.300	0.376		
Total	39	14.400			

Level	N	Mean	StDev
Ss	20	0.2500	0.7164
Sq	20	0.1500	0.4894

Pooled StDev = 0.6134

Individual 95% CIs For Mean Based on Pooled StDev



APPENDIX 2

Raw data

DATE	22-5-2001	LOCATION	CH	*Synaphea*	*quartzitica*			
plant #	w1 (cm)	w2	h	# leaves	# old spikes	ramets / genet	genet	nearest plant (cm)
1	26	19	32	12	8	1	1	
2	43	36	34	51	7	1	1	
3	34	37	31	35	3	1	1	
4	43	35	29	120	17	1	1	
5	40	38	42	13	7	1	1	7
6	73	51	33	73	12	1	1	4.5
7	33	29	41	14	4	1	1	2.8
8	34	27	18	5	6	1	1	2.8
9	31	26	36	14	9	1	1	3.35
10	5	9	35	8	2	1	1	0.6
11	31	26	27	31	4	1	1	0.93
12	16	11	21	14	1	2	0	0.55
13	53	33	32	27	11	2	1	2.91
14	38	37	38	56	24	1	1	4
15	38	40	19	31	1	2	1	0.83
16	5	5	9	3	0	2	0	1.4
17	26	44	32	66	23	2	0	0.2
18	77	69	48	68	22	2	1	0.55
19	42	45	36	53	10	2	1	0.33
20	13	21	21	11	2	2	0	2.7
21	174	63	36	106	26	1	1	0.78
22	18	14	21	4	0	1	1	2.96
23	26	24	29	22	3	1	1	1.43
24	32	27	34	15	4	1	1	1.25
25	dead							
26	28	37	33	18	7	1	1	1.45
27	29	37	26	55	18	3	0	0.61
28	24	36	23	42	14	3	0	0.21
29	39	23	16	12	4	3	1	0.12
30	dead							0.82
31	43	51	36	31	3	1	1	0.33
32	13	9	31	11	5	1	1	1.39
33	21	13	16	8	5	1	1	1.74
34	15	22	19	6	0	1	1	4.73
35	3	9	21	9	3	1	1	0.87

DATE		LOCATION	CH	*Synaphea*	*quartzitica* /			
plant #	w1 (cm)	w2	h	# leaves	# old spikes	ramets / genet		nearest plant (cm)
36	20	8	17	7	2	1	1	
37	80	52	29	63	12	1	1	6.8
38	47	62	32	78	11	1	1	4.2
39	52	57	28	45	13	3	1	1.36
40	31	28	38	18	4	3	0	0.58
41	33	24	27	17	9	3	0	0.44
42	42	46	37	33	25	1	1	0.57
43	89	85	56	94	38	1	1	2.6
44	82	76	64	72	38	1	1	2.25
45	28	39	41	25	19	1	1	1.2
46	13	9	23	5	2	2	0	2.45
47	48	43	32	40	33	2	1	0.3
48	40	25	28	47	6	1	1	1.9
49	77	64	39	125	25	2	1	2.1
50	29	46	28	29	8	2	0	0.29
51	78	89	47	186	100+	1	1	0.58
52	8	28	24	24	0	2	0	0.81
53	23	23	28	16	4	2	1	0.25
54	84	71	44	62	19	2	1	0.7
55	46	30	36	29	11	2	0	0.69
56	37	25	28	24	14	1	1	1.7
57	54	40	29	28	3	1	1	3.9
58	59	52	32	36	21	1	1	
59	41	39	33	31	10	1	1	1.23
60	39	52	25	34	17	1	1	2.08
61	11	7	17	4	0	1	1	2.1
62	100	74	48	190	100+	1	1	1.45
63	149	258	336	42	19	1	1	3.2
64	37	35	37	30	22	1	1	3.5
65	113	223	27	5	0	1	1	2.6
66	33	49	32	21	10	1	1	2.2
67	46	49	37	46	11	1	1	1.5
68	33	25	36	24	12	3	0	1.1
69	31	33	51	28	15	3	0	0.12
70	23	20	17	14	11	3	1	10

DATE		LOCATION	CH	*Synaphea*	*quartzitica* /			
plant #	w1 (cm)	w2	h	# leaves	# old spikes	ramets / genet		nearest plant (cm)
71	51	41	34	70	21	1	1	2
72	60	33	20	30	9	1	1	2
73	62	36	33	40	5	1	1	2.9
74	58	37	26	14	12	1	1	0.9
75	24	30	32	13	4	2	1	4
76	26	15	27	9	3	2	0	0.31
77	23	8	33	6	2	2	1	1.2
78	35	37	39	23	14	2	0	0.3
79	18	21	26	14	2	1	1	
80	53	34	36	30	21	1	1	
81	42	37	20	38	12	1	1	1.7
82								
83	69	55	46	72	100+	1	1	
84	27	33	31	34	15	1	1	1.8
85	40	43	27	32	11	1	1	5.1
86	12	21	19	9	3	2	1	4.3
87	43	31	26	21	2	2	0	0.29
88	52	40	17	23	14	1	1	0.9
89								
90								
91	48	62	35	34	17			
92	17	24	18	13	0			
93	58	47	32	52	32			
94	15	14	28	5	6			
95	39	42	24	64	45			
96	13	14	16	12	0			
97	37	68	34	44	50			
98	25	36	35	15	4			
99	24	37	16	8	9			
100								

DATE	23-5-2001	LOCATION	WNP	*Synaphea*	*quartzitica*			
plant #	w1 (cm)	w2	h	# leaves	# old spikes	ramets / genet	genet	nearest plant (cm)
1	23	17	22	18	7	1	1	
2	35	27	26	45	5	1	1	
3	48	51	29	88	29	1	1	1.54
4	29	23	26	18	12	1	1	2.6
5	19	24	18	33	4	5	0	2.3
6	2	5	8	4	0	5	0	3.3
7	9	11	17	13	3	5	0	0.33
8	36	55	25	53	21	5	1	0.1
9	8	6	10	3	0	5	0	0.45
10	31	43	29	60	45	4	1	0.81
11	40	28	25	45	45	4	0	0.1
12	16	26	18	16	6	4	0	0.15
13	28	32	17	25	12	4	0	0.31
14	7	11	12	5	0	4	0	1
15	26	14	18	18	20	4	1	0.2
16	7	10	18	5	4	4	0	0.1
17	4	3	14	2	1	4	0	0.14
18	30	42	20	46	22	1	1	1.2
19	26	33	29	44	21	1	1	2.1
20	35	26	19	32	7	1	1	0.72
21	22	30	23	33	22	2	0	2.4
22	16	7	15	12	9	2	1	0.17
23	2	4	12	1	0	2	0	1.4
24	37	26	22	40	4	2	1	0.23
25	8	13	21	8	0	3	0	1.5
26	30	37	28	63	10	3	1	0.77
27	13	23	26	14	1	3	0	0.25
28	38	34	29	63	24	1	1	3.8
29	18	9	14	14	4	1	1	5.6
30	7	5	13	5	1	1	1	0.8
31	24	23	23	18	3	1	1	1.9
32	36	42	17	44	41	1	1	2.2
33	10	12	17	7	5	1	1	0.3
34	15	20	18	21	1	2	1	0.4
35	3	6	11	4	0	2	0	0.07

DATE	23-5-2001	LOCATION	WNP	*Synaphea*	*quartzitica*			
plant #	w1 (cm)	w2	h	# leaves	# old spikes	ramets / genet	genet	nearest plant (cm)
36	25	28	25	20	10	1	1	0.22
37	21	33	19	33	8	3	1	1
38	13	11	20	15	0	3	0	0.07
39	18	20	24	32	7	3	0	0.12
40	19	14	20	30	11	2	0	5.9
41	67	72	33	134	100+	2	1	0.3
42	22	26	22	32	13	1	1	4.4
43	26	23	18	23	12	1	1	5.4
44	25	22	22	21	11	1	1	0.25
45	20	18	12	16	20	1	1	1.3
46	18	20	20	17	2	2	1	1.1
47	9	8	16	12	0	2	0	0.16
48	16	17	20	14	6	2	0	1.46
49	32	26	23	33	12	2	1	0.1
50	28	23	22	29	6	1	1	3.2
51	44	44	29	80	55	1	1	0.6
52	40	55	34	65	18	1	1	0.3
53	34	29	32	43	12	1	1	0.35
54	34	34	25	41	24	1	1	2.6
55	23	15	36	16	1	1	1	1.3
56	17	19	20	12	8	1	1	0.7
57	9	8	11	7	1	1	1	0.25
58	24	18	22	15	6	1	1	1.2
59	17	20	24	43	28	2	1	1.87
60	33	18	24	65	38	2	0	0.1
61	34	22	25	28	17	1	1	0.7
62	25	20	24	34	14	1	1	0.75
63	38	27	31	24	9	1	1	0.2
64	35	37	29	33	22	1	1	0.85
65	37	61	28	72	45	1	1	1.75
66	35	35	22	42	18	1	1	1.4
67	40	45	26	56	15	1	1	1.3
68	327	49	26	88	53	1	1	2.4
69	27	18	26	32	5	1	1	3.8
70	8	10	2	6	2	1	1	1.4

DATE	23-5-2001	LOCATION	WNP	*Synaphea*	*quartzitica*			
plant #	w1 (cm)	w2	h	# leaves	# old spikes	ramets / genet	genet	nearest plant (cm)
71	37	34	26	47	26	1	1	1.55
72	52	46	9	67	32	1	1	1
73	18	11	17	8	1	1	1	1.2
74	35	59	19	57	10	1	1	1.2
75	37	22	25	28	10	1	1	1.2
76	50	55	20	67	34	1	1	0.3
77	28	22	19	22	8	1	1	1.1
78	22	28	25	17	5	1	1	3.6
79	21	13	23	10	2	1	1	1.4
80	45	40	25	34	7	1	1	0.7
81	4	8	16	4	0	1	1	2.2
82	29	57	32	42	18	1	1	3.1
83	3	2	9	1	0	1	1	1.55
84	24	22	26	18	9	1	1	1.32
85	18	16	15	17	4	1	1	0.75
86	54	47	28	56	23	1	1	1
87	52	57	30	47	43	1	1	1.85
88	40	42	26	39	26	1	1	1.1
89	45	39	22	38	16	1	1	4.2
90	16	26	15	11	5	1	1	2.7
91	11	14	16	8	9	1	1	2.5
92	46	66	33	70	37	1	1	3.2
93	19	23	27	13	13	2	1	1.5
94	5	4	12	4	0	2	0	0.1
95	13	12	9	6	0	3	0	0.85
96	14	9	14	9	0	3	1	0.9
97	15	8	18	4	0	3	0	0.1
98	51	33	24	50	36	1	1	1.1
99	18	19	23	9	4	2	1	0.55
100	6	8	12	2	0	2	0	0.05
101	19	16	21	16	7	1	1	2.7
102	44	39	21	38	26	1	1	1.6
103	41	28	21	46	18	1	1	4.2
104	12	11	12	9	1	1	1	0.97
105	23	24	18	33	5	1	1	0.2

DATE	23-5-2001	LOCATION	WNP	*Synaphea*	*quartzitica*			
plant #	w1 (cm)	w2	h	# leaves	# old spikes	ramets / genet	genet	nearest plant (cm)
106	34	40	21	54	22	1	1	0.4
107	25	39	28	26	9	1	1	0.05
108	54	47	42	61	100+	1	1	6.5
109	29	14	21	17	6	1	1	5.3
110	27	18	24	14	5	3	1	2.3
111	15	18	24	16	9	3	0	0.11
112	10	14	21	12	4	3	0	0.15
113	43	48	29	48	14	1	1	7
114	44	39	22	63	27	1	1	4.2
115	26	45	23	33	15	1	1	1.4
116	24	26	37	27	10	1	1	8
117	15	22	24	13	0	1	1	11
118	36	42	35	23	16	1	1	5
119	33	17	19	7	4	1	1	1.4
120	37	33	28	27	9	1	1	5.5
121	20	16	12	9	0	1	1	2.4
122	16	15	20	21	3	1	1	2.4
123	33	65	34	34	20	1	1	10
124	30	24	25	23	13	1	1	8
125	37	34	37	20	5	1	1	3.1

Synaphea spinulosa		LOCATION	WNP1	
plant #	w1 (cm)	w2	h	# old spikes
1	64	51	58	27
2	26	42	40	32
3	25	41	43	25
4	13	13	33	0
5	9	11	16	0
6	8	9	16	0
7	14	18	16	0
8	6	14	43	8
9	39	45	52	19
10	17	23	21	0
11	75	64	46	103
12	58	49	45	94
13	54	59	65	68
14	6	6	10	0
15	22	25	29	0
16	13	21	24	1
17	64	52	49	70
18	43	44	47	37
19	37	27	52	54
20	16	26	22	0
21	15	19	23	0
22	14	16	16	0
23	44	49	53	90
24	120	102	54	100+
25	21	27	39	0
26	44	26	38	12
27	12	16	19	0
28	83	74	39	46
29	72	67	56	98
30	465	81	46	88
31	84	65	48	76
32	83	68	42	100+
33	18	26	46	14
34	17	20	36	10
35	50	54	45	64
36	67	47	44	40
37	135	120	55	100+
38	50	55	45	74
39	56	58	51	62
40	84	56	51	100+
41	55	74	35	78
42	94	77	52	100+
43	47	82	49	100+
44	82	75	54	100+
45	88	62	45	76
46	40	45	47	50
47	40	32	46	40
48	30	23	29	0
49	34	25	42	14
50	40	54	43	25
51	55	48	52	66
52	48	51	40	36
53	96	88	51	100+
54	89	96	57	100+
55	65	88	54	100+
56	77	69	52	70

Synaphea spinulosa		LOCATION	WNP1	
plant #	w1 (cm)	w2	h	# old spikes
57	50	62	50	46
58	77	82	46	94
59	62	59	45	76
60	19	23	15	0
61	65	85	48	78
62	51	75	56	66
63	74	86	45	100+
64	82	77	58	100+
65	62	39	73	76
66	18	79	40	30
67	62	49	32	70
68	56	78	60	100+
69	70	43	38	80
70	31	68	51	20
71	75	85	26	100+
72	62	73	46	50
73	94	59	66	80
74	36	39	47	26
75	82	55	62	60
76	33	64	66	26
77	83	73	45	100+
78	42	49	43	10
79	39	46	43	48
80	83	85	56	52
81	61	75	57	50
82	66	67	57	46
83	74	69	64	100+
84	17	15	14	0
85	33	26	25	0
86	89	62	44	100+
87	29	35	38	20
88	36	47	42	46
89	46	35	39	40
90	28	44	34	30
91	47	52	31	36
92	57	45	44	70
93	48	49	34	26
94	22	27	21	18
95	13	7	16	0
96	54	66	46	42
97	35	42	44	10
98	83	81	36	98
99	43	54	33	50
100	74	120	55	100+

Synaphea spinulosa		LOCATION	WNP2	
plant #	w1 (cm)	w2	h	# old spikes
1	43	42	36	8
2	43	56	35	12
3	16	14	17	0
4	26	22	25	0
5	27	33	39	16
6	24	27	42	4
7	46	37	52	16
8	27	22	32	0
9	27	22	38	0
10	25	32	41	2
11	8	12	48	0
12	13	22	39	0
13	9	11	15	0
14	27	23	34	0
15	16	24	27	0
16	12	9	29	0
17	26	16	15	0
18	32	24	39	0
19	51	40	47	50
20	18	22	63	6
21	23	28	36	0
22	60	62	58	8
23	37	57	47	28
24	15	25	20	0
25	62	29	32	16
26	17	32	44	20
27	47	56	46	62
28	18	36	40	8
29	27	26	48	30
30	21	24	43	3
31	23	25	33	0
32	18	21	22	0
33	14	25	19	0
34	26	29	52	6
35	57	56	54	90
36	34	29	42	18
37	75	55	43	60
38	46	59	42	60
39	16	21	14	0
40	46	38	52	80
41	62	49	35	50
42	36	32	33	4
43	25	34	41	0
44	59	48	61	20
45	22	33	48	12
46	27	49	71	24
47	49	63	73	30
48	32	48	68	26
49	29	42	52	36
50	50	32	54	70
51	46	56	65	30
52	45	59	37	32
53	44	66	44	46
54	22	15	26	0
55	34	41	64	8
56	25	47	66	14

Synaphea spinulosa		LOCATION	WNP2	
plant #	w1 (cm)	w2	h	# old spikes
56	25	47	66	14
57	21	53	59	16
58	23	25	18	0
59	45	44	59	50
60	27	14	44	20
61	92	94	67	70
62	36	26	24	0
63	41	35	59	6
64	41	29	47	0
65	27	22	25	0
66	64	62	57	56
67	62	54	49	40
68	13	16	46	12
69	25	36	51	4
70	57	74	59	30
71	36	35	69	36
72	25	29	58	14
73	12	11	16	0
74	13	14	15	0
75	17	21	46	10
76	8	5	10	0
77	54	59	32	60
78	19	16	37	0
79	29	40	46	28
80	39	16	26	4
81	25	19	48	14
82	57	13	26	0
83	53	57	52	48
84	32	29	53	26
85	64	33	58	30
86	20	14	29	3
87	14	15	21	0
88	51	24	47	28
89	9	14	18	0
90	14	13	21	0
91	52	27	18	36
92	64	53	45	38
93	17	21	23	0
94	2	4	5	0
95	41	57	49	60
96	65	82	55	100+
97	54	62	44	50
98	97	66	49	80
99	5	8	39	0
100	37	27	52	0

Smokewater Investigation

S. quartzitica

No. seedlings	Treatment	Population
0	1	Cairn Hill
0	0	Cairn Hill
0	1	Cairn Hill
0	0	Cairn Hill
0	1	Cairn Hill
0	0	Cairn Hill
2	1	Cairn Hill
0	1	Cairn Hill
0	0	Cairn Hill
0	1	Cairn Hill
0	0	Cairn Hill
0	0	Cairn Hill
0	1	Cairn Hill
0	0	Cairn Hill
1	0	Cairn Hill
0	1	Cairn Hill
0	1	Cairn Hill
0	0	Cairn Hill
0	0	Cairn Hill
0	1	Watheroo NP
0	0	Watheroo NP
0	1	Watheroo NP
0	0	Watheroo NP
0	0	Watheroo NP
0	1	Watheroo NP
0	1	Watheroo NP
0	0	Watheroo NP
0	1	Watheroo NP
0	1	Watheroo NP
0	0	Watheroo NP
0	0	Watheroo NP
0	0	Watheroo NP
0	1	Watheroo NP
0	0	Watheroo NP
0	0	Watheroo NP
0	0	Watheroo NP
0	1	Watheroo NP
0	0	Watheroo NP
0	1	Watheroo NP
0	1	Watheroo NP

S. spinulosa

No. seedlings	Treatment	Population
0	0	1
0	1	1
0	0	1
0	0	1
0	1	1
0	0	1
0	1	1
0	0	1
0	1	1
0	0	1
0	1	1
0	0	1
0	1	1
4	0	1
0	1	1
0	0	1
0	0	1
0	1	1
0	1	1
0	1	1
0	1	2
0	0	2
0	1	2
0	0	2
0	1	2
0	1	2
0	0	2
0	0	2
0	1	2
0	0	2
0	1	2
0	0	2
0	1	2
0	0	2
0	1	2
0	0	2
0	1	2
0	0	2
0	1	2
0	0	2

treatment: 0 = control, 1 = smokewater

Soil Seed Bank

No. Seeds	No. husks	No. holes	Population	Species
0	0	0	Cairn Hill	*S. quartzitica*
0	0	0	Cairn Hill	*S. quartzitica*
0	0	0	Cairn Hill	*S. quartzitica*
0	0	0	Cairn Hill	*S. quartzitica*
0	0	0	Cairn Hill	*S. quartzitica*
0	0	0	Cairn Hill	*S. quartzitica*
0	0	0	Cairn Hill	*S. quartzitica*
0	0	0	Cairn Hill	*S. quartzitica*
0	0	0	Cairn Hill	*S. quartzitica*
0	0	0	Cairn Hill	*S. quartzitica*
2	0	0	Watheroo NP	*S. quartzitica*
0	0	0	Watheroo NP	*S. quartzitica*
0	0	0	Watheroo NP	*S. quartzitica*
0	0	0	Watheroo NP	*S. quartzitica*
0	0	0	Watheroo NP	*S. quartzitica*
1	0	0	Watheroo NP	*S. quartzitica*
0	0	0	Watheroo NP	*S. quartzitica*
0	0	0	Watheroo NP	*S. quartzitica*
0	0	0	Watheroo NP	*S. quartzitica*
0	0	0	Watheroo NP	*S. quartzitica*

No. Seeds	N.o husks	No. holes	Population	Species
1	0	0	1	*S. spinulosa*
0	0	0	1	*S. spinulosa*
0	0	0	1	*S. spinulosa*
0	0	0	1	*S. spinulosa*
0	0	0	1	*S. spinulosa*
2	0	0	1	*S. spinulosa*
2	0	0	1	*S. spinulosa*
0	0	0	1	*S. spinulosa*
0	0	2	1	*S. spinulosa*
0	0	0	1	*S. spinulosa*
30	17	9	2	*S. spinulosa*
3	10	2	2	*S. spinulosa*
0	0	0	2	*S. spinulosa*
2	0.5	2	2	*S. spinulosa*
0	0	0	2	*S. spinulosa*
0	0	0	2	*S. spinulosa*
0	0	0	2	*S. spinulosa*
3	4.5	2	2	*S. spinulosa*
0	0	0	2	*S. spinulosa*
3	0	1	2	*S. spinulosa*

Canopy Cover

sspop1+										
n	4	7	9	3	0	1	0	0	5	17
s	0	4	9	2	0	2	0	0	0	28
e	4	10	11	7	0	6	2	0	0	21
w	0	5	3	2	0	12	4	2	0	12
mean	2	7	8	4	0	5	2	1	1	20
%	2	6	8	3	0	5	1	0	1	19
sspop1-										
n	0	22	20	18	42	30	62	0	66	0
s	0	6	22	7	81	32	74	0	33	0
e	3	30	30	20	82	4	0	0	32	0
w	0	0	12	14	38	19	24	0	28	0
mean	1	15	21	15	61	21	40	0	40	0
%	1	14	20	14	58	20	38	0	38	0

sspop2+	*2m*	*4m*	*6m*	*8m*	*10m*	*2m*	*4m*	*6m*	*8m*	*10m*
north	17	9	2	19	36	26	10	36	8	34
south	14	0	4	20	25	45	15	44	14	64
east	16	28	7	26	25	36	24	45	16	56
west	23	20	2	13	39	42	5	14	18	52
mean	18	14	4	20	31	37	14	35	14	52
% cover	17	14	4	19	30	36	13	33	13	49
sspop2-										
n	26	2	6	13	48	16	17	7	5	10
s	16	12	8	13	24	17	23	4	8	16
e	32	22	10	4	19	8	8	22	16	11
w	8	9	11	10	14	13	10	5	6	6
mean	21	11	9	10	26	14	15	10	9	11
%	20	11	8	10	25	13	14	9	8	10

*note: ss = Synaphea spinulosa, pop= population
+ = present, - = absent

Canopy Cover

sqch+										
n	24	11	17	11	9	18	13	0	32	16
s	9	8	34	12	10	5	14	8	25	15
e	18	3	20	3	3	23	33	13	21	13
w	7	6	26	18	43	2	15	5	30	13
m	15	7	24	11	16	12	19	7	27	14
%	14	7	23	11	16	12	18	6	26	14
sqch-										
n	39	36	34	40	28	96	96	96	81	45
s	17	48	22	30	31	91	96	96	90	39
e	37	24	36	52	22	88	96	96	84	42
w	26	40	21	32	17	93	96	96	93	92
m	30	37	28	39	25	92	96	96	87	55
%	29	36	27	37	24	88	92	92	84	52
sqwnp+										
n	6	0	0	6	0	0	7	1	52	26
s	0	2	0	5	0	0	0	0	16	14
e	0	2	0	8	0	0	8	0	38	11
w	2	0	0	0	0	0	0	0	42	22
m	2	1	0	5	0	0	4	0	37	18
%	2	1	0	5	0	0	4	0	36	18
sqwnp-										
n	21	15	12	18	24	5	9	96	32	41
s	30	24	27	6	33	3	38	96	42	9
e	27	36	16	14	21	10	29	67	52	5
w	23	32	23	4	32	32	16	96	44	29
m	25	27	20	11	28	13	23	89	43	21
%	24	26	19	10	26	12	22	85	41	20

* note: sq = Synaphea quartzitica, ch = Cairn Hill, wnp = Watheroo NP
+ = present, - + absent

S. spinulosa Litter (%)	P/A	Population
100	present	2
95	present	2
45	present	2
20	present	2
50	present	2
5	present	2
5	present	2
15	present	2
20	present	2
95	absent	2
80	absent	2
50	absent	2
75	absent	2
40	absent	2
50	absent	2
30	absent	2
15	absent	2
40	absent	2
30	absent	2
5	absent	2
50	absent	2
15	absent	2
15	absent	2
5	absent	2
20	absent	2
20	absent	2
45	absent	2
90	absent	2
50	absent	2

S. quartzitica Litter (%)	P/A	Population
0	present	Watheroo NP
0	present	Watheroo NP
2	present	Watheroo NP
0	present	Watheroo NP
0	present	Watheroo NP
0	present	Watheroo NP
0	present	Watheroo NP
0	present	Watheroo NP
0	present	Watheroo NP
25	absent	Watheroo NP
5	absent	Watheroo NP
10	absent	Watheroo NP
5	absent	Watheroo NP
15	absent	Watheroo NP
5	absent	Watheroo NP
5	absent	Watheroo NP
15	absent	Watheroo NP
25	absent	Watheroo NP
30	absent	Watheroo NP
2	absent	Watheroo NP
5	absent	Watheroo NP
5	absent	Watheroo NP
45	absent	Watheroo NP
80	absent	Watheroo NP
100	absent	Watheroo NP
75	absent	Watheroo NP
70	absent	Watheroo NP
100	absent	Watheroo NP
10	absent	Watheroo NP

S. spinulosa			*S. quartzitica*		
Litter (%)	P/A	Population	Litter (%)	P/A	Population
5	present	1	15	present	Cairn Hill
20	present	1	10	present	Cairn Hill
25	present	1	20	present	Cairn Hill
2	present	1	10	present	Cairn Hill
10	present	1	25	present	Cairn Hill
80	present	1	25	present	Cairn Hill
25	present	1	20	present	Cairn Hill
75	present	1	100	present	Cairn Hill
20	present	1	100	present	Cairn Hill
5	present	1	50	present	Cairn Hill
45	present	1	25	present	Cairn Hill
10	present	1	50	present	Cairn Hill
15	present	1	80	present	Cairn Hill
15	present	1	20	present	Cairn Hill
5	present	1	20	present	Cairn Hill
2	present	1	60	present	Cairn Hill
2	present	1	15	present	Cairn Hill
2	present	1	20	present	Cairn Hill
2	present	1	5	present	Cairn Hill
5	present	1	25	present	Cairn Hill
5	absent	1	90	absent	Cairn Hill
10	absent	1	100	absent	Cairn Hill
2	absent	1	100	absent	Cairn Hill
1	absent	1	100	absent	Cairn Hill
30	absent	1	100	absent	Cairn Hill
10	absent	1	100	absent	Cairn Hill
15	absent	1	100	absent	Cairn Hill
10	absent	1	100	absent	Cairn Hill
20	absent	1	100	absent	Cairn Hill
10	absent	1	100	absent	Cairn Hill
15	absent	1	75	absent	Cairn Hill
10	absent	1	100	absent	Cairn Hill
15	absent	1	100	absent	Cairn Hill
5	absent	1	100	absent	Cairn Hill
25	absent	1	100	absent	Cairn Hill
20	absent	1	75	absent	Cairn Hill
30	absent	1	60	absent	Cairn Hill
25	absent	1	100	absent	Cairn Hill
10	absent	1	100	absent	Cairn Hill
2	absent	1	100	absent	Cairn Hill
20	present	2	0	present	Watheroo NP
25	present	2	0	present	Watheroo NP
30	present	2	0	present	Watheroo NP
10	present	2	0	present	Watheroo NP
55	present	2	0	present	Watheroo NP
2	present	2	0	present	Watheroo NP
2	present	2	0	present	Watheroo NP
10	present	2	0	present	Watheroo NP
20	present	2	0	present	Watheroo NP
20	present	2	0	present	Watheroo NP
100	present	2	0	present	Watheroo NP

SQWNP+	Texture	Gravel%	Colour	NO3	NH4	P	K	S	C	Fe	conductivity	pH
1	2.5	5-10	GRBR	3	5	5	78	3.90	1.12	198	0.0210	4.5
2	2.5	15-20	GRBR	3	4	3	91	4.20	1.21	203	0.0200	4.4
3	2.5	15-20	GRBR	2	3	2	73	3.70	1.00	268	0.0190	4.6
4	2.5	25-30	GRBR	3	5	4	92	4.30	1.39	213	0.0190	4.5
5	2.5	25-30	GRBR	3	4	4	116	4.20	1.78	176	0.0260	4.5
6	2.5	25-30	GRBR	2	6	4	117	4.80	2.33	169	0.0260	4.5
7	2.5	25-30	GRBR	3	5	4	78	4.00	1.59	148	0.0240	4.4
8	2.5	25-30	GRBR	2	7	4	116	4.10	1.83	174	0.0320	4.4
9	2.5	25-30	GRBR	2	4	5	91	3.30	1.51	188	0.0210	4.3
10	2.5	25-30	GRBR	3	5	4	85	3.90	1.68	206	0.0250	4.6
MEAN	**2.5**	**25-30**	**GRBR**	**3**	**5**	**4**	**94**	**4.04**	**1.54**	**194**	**0.0233**	**4.5**

SQWNP-	Texture	Gravel%	Colour	NO3	NH4	P	K	S	C	Fe	conductivity	pH
1	2.5	25-30	BRGR	2	4	6	89	3.20	1.97	218	0.0290	4.7
2	2.5	25-30	BRGR	3	5	4	80	4.80	1.99	214	0.0240	4.6
3	2.5	25-30	BRGR	3	4	4	94	3.90	1.22	185	0.0210	4.8
4	2.5	25-30	BRGR	4	7	7	78	3.70	1.95	237	0.0270	4.6
5	2.5	25-30	BRGR	3	4	3	69	4.60	2.08	204	0.0240	4.7
6	2.5	25-30	BRGR	3	3	3	85	3.70	1.35	206	0.0190	4.6
7	2.5	25-30	BRGR	3	2	4	91	3.10	1.06	285	0.0160	4.8
8	1.5	25-30	BRGR	3	3	3	142	4.80	1.32	271	0.0270	4.9
9	1.5	25-30	BRGR	3	4	4	105	4.10	1.28	255	0.0270	4.7
10	1.5	25-30	BRGR	2	4	3	100	3.10	1.09	256	0.0180	4.7
MEAN	**2.2**	**25-30**	**BRGR**	**3**	**4**	**4**	**93**	**3.90**	**1.53**	**233**	**0.0232**	**4.7**

SQCH+	Texture	Gravel%	Colour	NO3	NH4	P	K	S	C	Fe	conductivity	pH
1	1.5	25-30	BRGR	2	3	1	61	2.70	1.34	191	0.2000	4.9
2	1.5	25-30	BRGR	2	3	1	41	1.70	0.97	190	0.0160	5.0
3	1.5	25-30	BRGR	4	4	2	77	2.40	1.43	210	0.0250	5.0
4	1.5	25-30	BRGR	3	3	3	68	2.20	1.43	205	0.0220	4.8
5	1.5	25-30	BRGR	3	2	2	54	2.80	1.28	204	0.0160	4.8
6	1.5	25-30	BRGR	3	3	2	53	2.80	1.55	204	0.0180	4.5
7	1.5	25-30	BRGR	3	3	5	58	2.30	1.60	176	0.0190	4.8
8	1.5	25-30	BRGR	3	7	4	69	4.30	1.58	170	0.0260	4.8
9	1.5	15-20	GRBR	3	4	6	120	6.50	2.41	240	0.0430	4.8
10	2.5	25-30	GRBR	3	4	2	58	3.10	1.34	221	0.0240	5.2
MEAN	**1.6**	**25-30**	**BRGR**	**3**	**4**	**3**	**66**	**3.08**	**1.49**	**201**	**0.0409**	**4.9**

SQCH-	Texture	Gravel%	Colour	NO3	NH4	P	K	S	C	Fe	conductivity	pH
1	2.5	15-20	GRBR	3	3	3	65	2.70	1.99	198	0.0210	4.7
2	2.0	15-20	GR	3	3	4	73	3.20	1.84	233	0.0220	4.5
3	2.0	15-20	GR	2	3	4	62	6.30	1.97	217	0.0200	4.7
4	2.0	15-20	GR	3	2	3	53	2.20	2.22	247	0.0180	4.6
5	2.0	15-20	GR	2	3	8	52	2.40	1.72	183	0.0220	5.0
6	2.0	15-20	GR	3	5	4	65	6.70	3.90	246	0.0410	4.4
7	2.0	15-20	GR	3	7	5	109	8.70	2.33	225	0.0590	4.9
8	2.0	15-20	GR	3	5	3	85	4.30	3.07	251	0.0320	4.8
9	2.0	15-20	GR	3	6	5	80	5.70	2.49	225	0.0430	5.5
10	2.0	15-20	GR	4	5	4	60	3.20	1.72	244	0.0370	5.5
MEAN	**2.1**	**15-20**	**GR**	**3**	**4**	**4**	**70**	**4.54**	**2.33**	**227**	**0.0315**	**4.9**

SSPOP2+	Texture	Gravel%	Colour	NO3	NH4	P	K	S	C	Fe	conductivity	pH
1	1.5	0	GR	2	3	2	19	1.80	0.89	74	0.0110	4.6
2	1.5	0	GR	2	1	1	12	1.40	0.44	63	0.0080	5.0
3	1.5	0	GR	3	5	4	35	4.20	0.91	54	0.0320	5.5
4	1.5	0	GR	2	3	1	28	1.70	0.43	51	0.0120	5.2
5	1.5	0	GR	3	1	1	77	1.70	0.66	61	0.0160	5.5
6	1.5	0	GR	3	1	3	16	1.10	0.46	37	0.0080	5.0
7	1.5	0	GR	2	1	1	15	1.10	0.29	54	0.0080	5.3
8	1.5	0	GR	3	1	2	21	1.30	0.52	39	0.0130	5.8
9	1.5	0	GR	3	2	2	19	2.10	0.82	65	0.0200	5.5
10	1.5	0	GR	2	3	1	24	2.10	0.56	57	0.0170	5.4
MEAN	**1.5**	**0**	**GR**	**3**	**2**	**2**	**27**	**1.85**	**0.60**	**56**	**0.0145**	**5.3**

SSPOP2-	Texture	Gravel%	Colour	NO3	NH4	P	K	S	C	Fe	conductivity	pH
1	1.5	0	GR	2	6	3	24	3.60	0.90	90	0.0270	5.2
2	1.5	0	GRBR	2	3	1	53	1.50	0.66	111	0.0130	5.1
3	1.5	5-10	GR	3	2	3	36	2.00	2.28	204	0.0220	5.9
4	1.5	5	BRGR	2	4	2	35	2.50	0.72	113	0.0150	4.9
5	1.5	0	BRGR	2	4	1	25	1.30	0.34	76	0.0100	5.0
6	1.5	5	BRGR	2	2	2	30	1.40	0.43	76	0.0110	5.0
7	1.5	5	BRGR	2	2	1	25	1.40	0.72	92	0.0100	5.0
8	1.5	5-10	BRGR	2	2	2	25	1.60	0.60	102	0.0100	5.1
9	1.5	5-10	BRGR	2	3	2	23	1.40	0.55	125	0.0110	5.0
10	1.5	5-10	BRGR	2	2	1	30	2.00	0.61	141	0.0130	4.9
MEAN	**1.5**		**BRGR**	**2**	**3**	**2**	**31**	**1.87**	**0.78**	**113**	**0.0142**	**5.1**

*note: + = present, - = absent

SSPOP1+	Texture	Gravel	Colour	NO3	NH4	P	K	S	C	Fe	conductivity	pH
1	1.5	0	BRGR	3	3	4	22	3.50	0.35	137	0.0180	5.3
2	1.5	0	BRGR	2	1	2	24	1.40	0.28	107	0.0110	5.9
3	1.5	0	BRGR	2	1	2	24	1.20	0.25	105	0.0100	5.6
4	1.5	0	BRGR	2	1	1	14	1.20	0.41	96	0.0110	6.1
5	1.5	0	BRGR	2	1	2	14	1.00	0.29	125	0.0080	5.8
6	1.5	0	BRGR	2	1	1	19	19.50	0.20	125	0.0060	5.3
7	1.5	0	BRGR	2	1	1	13	1.20	0.23	106	0.0070	5.3
8	1.5	0	BRGR	2	1	2	17	1.50	0.29	96	0.0070	5.3
9	1.5	0	BRGR	2	1	2	13	1.30	0.45	83	0.0100	5.5
10	1.5	0	BRGR	2	1	1	20	1.40	0.17	77	0.0070	5.7
MEAN	**1.5**	**0**	**BRGR**	**2**	**1**	**2**	**18**	**3.32**	**0.29**	**106**	**0.0095**	**5.6**

SSPOP1-	Texture	Gravel%	Colour	NO3	NH4	P	K	S	C	Fe	conductivity	pH
1	1.0	0	BRGR	1	1	7	30	1.50	0.19	51	0.0110	6.2
2	1.0	0	BRGR	1	1	4	19	1.40	0.61	58	0.0070	5.2
3	1.0	0	BRGR	2	1	4	25	1.30	0.39	41	0.0100	5.3
4	1.0	0	BRGR	2	1	4	15	1.40	0.47	56	0.0140	5.8
5	1.0	0	BRGR	2	1	4	29	1.40	0.49	56	0.0140	5.6
6	1.0	0	BRGR	2	1	4	26	1.90	0.57	60	0.0130	5.9
7	1.0	0	BRGR	1	1	2	26	1.00	0.43	39	0.0060	5.3
8	1.0	0	BRGR	2	1	3	23	1.00	0.32	60	0.0100	5.7
9	1.0	0	BRGR	2	1	5	36	1.90	0.52	54	0.0110	5.7
10	1.0	0	BRGR	2	1	4	40	1.50	0.22	59	0.0080	5.6
MEAN	**1.0**	**0**	**BRGR**	**2**	**1**	**4**	**27**	**1.43**	**0.42**	**53**	**0.0104**	**5.6**

Stigma Receptivity

1= receptive, 0= nonreceptive

S. quartzitica

	unopened	open trig	open not-trig
Watheroo NP	0	1	0
	0	1	0
	1	0	1
	0	1	1
	0	0	0
	0	1	0
	1	0	0
	1	0	0
	0	0	0
	0	0	0
	1	0	1
	1	1	0
	0	0	0
	0	0	1
	0	0	
	0	1	
	1	0	
	0	0	
	0	1	
	0	0	
Cairn Hill	1	1	0
	0	1	1
	1	1	1
	1	1	0
	0	1	1
	1	1	1
	0	1	0
	1	1	0
	1	0	1
	0	1	0
	1	0	0
	0	0	0
	0	0	0
	0	0	0
	0	1	
	0	0	
	1	0	
	0	0	

S. spinulosa

	unopened	open trig	open not-trig
ss 1	1	1	1
	1	1	0
	1	1	1
	1	1	1
	0	1	1
	0	0	1
	0	1	1
	1	1	1
	1	1	1
	1	0	1
	0	0	1
	1	0	1
	1	0	0
	0	1	1
	1	1	1
	1	1	1
	1	1	
	1	1	
	1	1	
	0	1	
ss2	1	0	0
	0	0	0
	1	1	1
	0	1	1
	1	1	1
	1	1	1
	1	1	1
	1	1	1
	1	1	1
	1	1	0
	1	1	1
	0	0	1
	1	1	
	0	1	
	1	1	
	1	1	
	1	1	
	1	0	
	0	1	
	0	0	

16 open 1	n	full	30	4	0	34	88
17 open 1	n	full	86	9	0	95	91
18 open 1	y	empty				0	
19 open 1	n	full	73	51	0	124	59
20 open 1	n	full	74	37	3	114	65
1 open 2	n	half	14	0	45		
2 open 2	n	half	24	0	18	42	57
3 open 2	y	empty				0	
4 open 2	n	half	17	0	12	29	59
5 open 2	y	empty				0	
6 open 2	n	half	53	0	12	65	82
7 open 2	n	half	4	0	61	65	6
8 open 2	n	half	32	0	20	52	62
9 open 2						0	
10 open 2						0	
11 open 2	y	empty				0	
12 open 2	y	empty				0	
13 open 2	y	empty				0	
14 open 2	n	half	34	0	4	38	89
15 open 2						0	
16 open 2						0	
17 open 2	n	half	39	0	8	47	83
18 open 2	n	half	2	31	0	33	6
19 open 2	n	half	46	66	0	112	41
20 open 2	n	half	23	26	0	49	47

2 open 2	y	empty	74	8	0	82	90
3 open 2	y	empty				0	
4 open 2	y	empty				0	
5 open 2	n	half	53	3	0	56	95
6 open 2	n	half	96	2	5	103	93
7 open 2	n	half	34	0	10	44	77
8 open 2	n	half	67	5	10	82	82
9 open 2	n	half	129	4	5	138	93
10 open 2	n	half	93	0	22	115	81
11 open 2	n	half	39	9	3	51	76
12 open 2	n	half	22	13	2	37	59
13 open 2	n	half	29	0	11	40	73
14 open 2	n	half	47	0	22	69	68
15 open 2	n	empty				0	
16 open 2	n	half				0	
17 open 2	n	full	48	0	14	62	77
18 open 2	n	half					
19 open 2	y	empty					
20 open 2	y	empty					

S. spinulosa Populaiton 3

				Viability Stain				
Number	Flower type	Triggered	Anthers	Purple	Blue	Green	Total	%Viability
1	unopen	n	full	225	0	12	237	95
2	unopen	n	full	146	0	15	161	91
3	unopen	n	full	143	0	43	186	77
4	unopen	n	full	117	0	14	131	89
5	unopen	n	full	172	0	10	182	95
6	unopen	n	full	70	0	7	77	91
7	unopen	n	full	225	0	14	239	94
8	unopen	n	full	170	4	0	174	98
9	unopen	n	full	158	0	12	170	93
10	unopen	n	full	91	0	4	95	96
11	unopen	n	full	88	5	0	93	95
12	unopen	n	full	130	0	74	204	64
13	unopen	n	full	171	7	0	178	96
14	unopen	n	full	130	8	0	138	94
15	unopen	n	full	146	10	0	156	94
16	unopen	n	full	199	35	0	234	85
17	unopen	n	full	113	0	48	161	70
18	unopen	n	full	178	28	0	206	86
19	unopen	n	full	165	47	0	212	78
20	unopen	n	full	232	50	0	282	82
1	open 1	n	full	139	0	11	150	93
2	open 1	n	full	157	0	14	171	92
3	open 1	n	full	65	0	5	70	93
4	open 1	n	full	81	0	11	92	88
5	open 1	y	empty				0	
6	open 1	y	empty				0	
7	open 1	n	full	128	0	9	137	93
8	open 1	n	full	145	0	12	157	92
9	open 1	n	full	68	0	3	71	96
10	open 1	n	full				0	
11	open 1	y	empty				0	
12	open 1	n	full	10	1	0	11	91
13	open 1	n	full				0	
14	open 1	y	empty				0	
15	open 1	y	empty				0	

9 open 2	yes	empty					
10 open 2	yes	empty					
11 open 2	yes	empty					
12 open 2	yes	empty					
13 open 2	yes	empty					
14 open 2	yes	empty					
15 open 2	yes	empty					
16 open 2	yes	empty					
17 open 2	no	full	86	2		88	98
18 open 2	no	full	80	3		83	96
19 open 2	yes	empty				0	
20 open 2	yes	empty				0	

S. spinulosa Populaiton 2

				Viability Stain				
Number	Flower type	Triggered	Anthers	Purple	Blue	Green	Total	%Viability
1	unopen	no	full	91	2	0	93	98
2	unopen	no	full	188	3	0	191	98
3	unopen	no	full	130	5	1	136	96
4	unopen	no	full	239	15	0	254	94
5	unopen	no	full	174	9	1	184	95
6	unopen	no	full	130	2	0	132	98
7	unopen	no	full	72	3	6	81	89
8	unopen	no	full	143	2	0	145	99
9	unopen	no	full	157	3	1	161	98
10	unopen	no	full	228	6	13	247	92
11	unopen	no	full	72	6	17	95	76
12	unopen	no	full	129	14	0	143	90
13	unopen	no	full	171	0	11	182	94
14	unopen	no	full	137	3	0	140	98
15	unopen	no	full	162	2	0	164	99
16	unopen	no	full	142	5	12	159	89
17	unopen	no	full					
18	unopen	no	full	245	0	21	266	92
19	unopen	no	full	176	8	1	185	95
20	unopen	no	full	117	0	11	128	91
1	open 1	no	full	146	3	0	149	98
2	open 1	no	full				0	
3	open 1	no	full	125	15	0	140	89
4	open 1	no	full	199	12	14	225	88
5	open 1	no	full	163	8	0	171	95
6	open 1	no	full	80	8	0	88	91
7	open 1	no	full				0	
8	open 1	no	full				0	
9	open 1	no	full	123	0	31	154	80
10	open 1	no	full	92	3	0	95	97
11	open 1	no	full	12	2	0	14	86
12	open 1	no	full	6	1	1	8	75
13	open 1	no	full				0	
14	open 1	no	full	95	8	0	103	92
15	open 1	y	empty				0	
16	open 1	y	empty				0	
17	open 1	no	full	190	0	21	211	90
18	open 1	no	full	50	2	0	52	96
19	open 1	no	full					
20	open 1	no	full					
1	open 2	no	half	67	2	0	69	

15	open 2	yes	empty				0	
16	open 2	no	half	25	19	0	44	57
17	open 2	yes	empty				0	
18	open 2	yes	empty				0	
19	open 2	no	full	106	19	0	125	85
20	open 2	yes	empty				0	

S. quartzitica Cairn Hill

				Viability Stain				
Number	Flower type	Triggered	Anthers	Purple	Blue	Green	Total	%Viability
1	unopen	no	full	169	36		205	82
2	unopen	no	full	114	25		139	82
3	unopen	no	full	108	4		112	96
4	unopen	no	full	86	0		86	100
5	unopen	no	full	82	16		98	84
6	unopen	no	full	96	11		107	90
7	unopen	no	full	187	45		232	81
8	unopen	no	full	135	41		176	77
9	unopen	no	full	68	6		74	92
10	unopen	no	full	57	8		65	88
11	unopen	no	full	108	10		118	92
12	unopen	no	full	112	6		118	95
13	unopen	no	full	117	16		133	88
14	unopen	no	full	164	11		175	94
15	unopen	no	full	137	53		190	72
16	unopen	no	full	122	44		166	73
17	unopen	no	full	91	6		97	94
18	unopen	no	full	125	8		133	94
19	unopen	no	full	99	0	1	100	99
20	unopen	no	full	160	5		165	97
1	open 1	no	full	119	30		149	80
2	open 1	no	full	32	5		37	86
3	open 1	no	full	21	0		21	100
4	open 1	no	full	40	5		45	89
5	open 1	no	full	53	4		57	93
6	open 1	no	full	48	4		52	92
7	open 1	no	full	142	63		205	69
8	open 1	no	full	190	46		236	81
9	open 1	no	full	39	1		40	98
10	open 1	no	full	39	3		42	93
11	open 1	no	full	29	2		31	94
12	open 1	no	full	137	12		149	92
13	open 1	no	full	125	4		129	97
14	open 1	no	full	12	0		12	100
15	open 1	no	full	40	21		61	66
16	open 1	no	full	94	37		131	72
17	open 1	no	full	118	1		119	99
18	open 1	no	full	144	2		146	99
19	open 1	no	full	75	3		78	96
20	open 1	no	full	38	6		44	86
1	open 2	yes	empty					
2	open 2	yes	empty					
3	open 2	yes	empty					
4	open 2	yes	empty					
5	open 2	no	full	17	3		20	85
6	open 2	no	full	22	3		25	88
7	open 2	no stigma			6		6	
8	open 2	yes	empty					

Pollen viability

S. quartzitica Watheroo NP

Number	Flower type	Triggered	Anthers	Viability Stain Purple	Blue	Green	Total	%Viability
1	unopen	no	full	84	2	0	86	98
2	unopen	no	full	50	2	0	52	96
3	unopen	no	full	63	2	0	65	97
4	unopen	no	full	81	1	0	82	99
5	unopen	no	full	204	7	0	211	97
6	unopen	no	full	148	4	0	152	97
7	unopen	no	full	12	21	0	33	36
8	unopen	no	full	21	20	0	41	51
9	unopen	no	full	33	41	0	74	45
10	unopen	no	full	29	75	0	104	28
11	unopen	no	full	157	19	0	176	89
12	unopen	no	full	107	8	0	115	93
13	unopen	no	full	80	5	0	85	94
14	unopen	no	full	63	12	0	75	84
15	unopen	no	full	65	41	0	106	61
16	unopen	no	full	40	42	0	82	49
17	unopen	no	full	22	5	2	27	81
18	unopen	no	full	46	32	0	78	59
19	unopen	no	full	47	2	0	49	96
20	unopen	no	full				0	
1	open 1	no	full	43	2	0	45	96
2	open 1	no	full	78	9	0	87	90
3	open 1	no	full	40	2	1	43	93
4	open 1	yes	empty					
5	open 1	yes	half	43	1	0	44	98
6	open 1	no	full	63	2	0	65	97
7	open 1	yes	half	16	37	0	53	30
8	open 1	yes	empty				0	
9	open 1	yes	empty				0	
10	open 1	no	full	13	15	0	28	46
11	open 1	no	full	133	21	0	154	86
12	open 1	no	full				0	
13	open 1	no	full	81	17	0	98	83
14	open 1	no	full				0	
15	open 1	no	full	47	32	0	79	59
16	open 1	no	full	65	41	0	106	61
17	open 1	no	full	22	37	0	59	37
18	open 1	no	full				0	
19	open 1	no	full	71	9	0	80	89
20	open 1	no	full				0	
1	open 2	yes	empty				0	
2	open 2	yes	empty				0	
3	open 2	no	full	85	0	0	85	100
4	open 2	no	full	160	7	0	167	96
5	open 2	yes	empty				0	
6	open 2	yes	empty				0	
7	open 2	yes	empty				0	
8	open 2	no	half	15	34	0	49	31
9	open 2	yes	empty				0	
10	open 2	yes	empty				0	
11	open 2	yes	empty				0	
12	open 2	yes	empty				0	
13	open 2	yes	empty				0	
14	open 2	yes	empty				0	

Pollen tubes

Species	Population	No. grains	No. germin	No. tubes	Tube length	No. diff pollen
S. spinulosa						
	2	6	4	3	0.25	1
	2	1	1	0	0	0
	2	1	1	1	0.25	0
	2	0	0	0	0	0
	2	0	0	0	0	0
	2	6	4	0	0	1
	2	5	4	0	0	3
	2	0	0	0	0	0
	2	0	0	0	0	0
	2	0	0	0	0	0
	1	0	0	0	0	0
	1	6	3	1	0.25	0
	1	1	1	0	0	0
	1	6	6	0	0	0
	1	4	4	0	0	0
	1	0	0	0	0	0
	1	10	10	0	0	4
	1	3	3	0	0	2
	1	0	0	0	0	0
	1	12	12	0	0	2
S. quartzitica						
	WNP	0	0	0	0	0
	WNP	0	0	0	0	0
	WNP	0	0	0	0	0
	WNP	0	0	0	0	0
	WNP	0	0	0	0	0
	WNP	1	1	0	0	0
	WNP	0	0	0	0	0
	WNP	0	0	0	0	0
	WNP	0	0	0	0	0
	WNP	0	0	0	0	0
	CH	0	0	0	0	0
	CH	0	0	0	0	0
	CH	4	4	2	0.25	0
	CH	1	1	0	0	0
	CH	0	0	0	0	0
	CH	0	0	0	0	0
	CH	0	0	0	0	0
	CH	1	1	1	0.5	0
	CH	0	0	0	0	0
	CH	0	0	0	0	0