Arthropods associated with commercial Proteaceae in the Western Cape Province, South Africa

by
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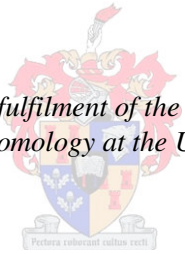

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Declaration

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Abstract

The commercial cultivation of Proteaceae is an important industry in the Western Cape, however, farmers are challenged with arthropod infestation which compels them to solely rely on chemical pesticides. Past studies in South Africa have shown that Proteaceae comprise a rich and diverse arthropod fauna. However, as most of these studies were conducted on wild Proteaceae, they may not be representative of cultivated proteas. Moreover, most of these species remained unidentified due to lack of identification expertise. These past studies, however, form a useful baseline for arthropod studies in proteas, e.g. the feeding guilds found in proteas. The aim of this research was to conduct an intensive and extensive survey of the arthropod-fauna associated with commercially-cultivated proteas across an entire year. Specifically, this survey was designed to document the composition of the arthropod fauna (creating a comprehensive reference collection for pest management purposes) and to assess whether the arthropod fauna differed between seasons and pesticide treatments.

Infructescences, inflorescences and foliage of mainly commercial Proteaceae were sampled for arthropods seasonally for a period of twelve months by collection of plant material and direct searching. Seven commercial protea blocks, and a wild protea block (remnant patch of fynbos vegetation), were used as the sampling sites, and two sprayed blocks were used for assessing pesticide efficacy. Individual arthropods were identified as far as possible, with 37% identified to species level. A species accumulation curve showed that rare (minor) arthropod species made up ≈ 70% of arthropods occurring in cultivated proteas.

More than 8 700 individuals from more than 140 species and about 80 families were collected and identified, revealing that cultivated proteas have a rich and diverse insect fauna. These arthropods represent the full range of plant-feeding guilds: leaf miners, leaf chewers,

flower bud borers, sap suckers and seed feeders. Flower visitors/free living guild was the most abundant (72%) and speciose (25%). In addition to phytophages, there was a large suite of insect predators and parasitoids. A large number of the arthropods were endemic to the Cape Floristic Region (CFR) and some (7.86%) have a pest status, in that they cause significant damage to the protea plants (for example, ≈ 60% of Safari sunset cultivar (*Leucadendron salignum* x *L. laureolum*) new flush stems and leaves were affected by *Epichoristodes acerbella* (Tortricidae). *Capys alphaeus* (Lycaenidae) and *Phyllocnistis* sp. (Phyllocnistidae) appear to be specialist pests, as they attack mainly *Protea cynaroides* and Susara cultivar (*Protea magnifica* x *P. susannae*) respectively.

Arthropod abundance did not differ significantly between seasons, although significant seasonal effects were observed in species richness when the protea cultivars were examined separately. Pesticide application did not affect arthropod abundance, but did decrease species richness in sprayed blocks. Pesticides appeared to negatively affect minor (rare) species disproportionately, probably due to their lack of prior exposure to pesticides and hence sensitivity. Due to this inefficacy of pesticides in cultivated proteas, an increasing emphasis on the importance of non-chemical control measures, and our improved knowledge of the predatory and parasitic species in this system, integrated pest management strategies deserve greater research attention.

Monitoring and use of threshold values for arthropod pests were suggested here, as well as the use of biological, cultural, physical and chemical (optimal use) control. For instance, in cultural control, polycropping and intercropping in proteas to increase plant diversity in the monocultures to promote a higher density of predators and parasitoids can be used. Certain flowering plants are known to provide greater temporal and spatial distribution of nectar and

pollen sources, which can increase parasitoid reproductive potential and abundance of alternative hosts/prey when the pest species are scarce or at an inappropriate stage.

Opsomming

Die kommersiële verbouing van Proteaceae (proteas) is ’n belangrike bedryf in die Wes-Kaap. Menige plantasie wemel egter van artropodes, wat boere noop om slegs van chemiese plaagdoders gebruik te maak. Vorige studies in Suid-Afrika toon dat proteas die gasheerplant vir ’n ryke en diverse artropodefauna is. Aangesien die meeste van hierdie studies egter op wilde proteas uitgevoer is, weerspieël dit moontlik nie die stand van sake met verboude proteas nie. Weens ’n gebrek aan kundigheid om die artropodes te eien word baie van die spesies boonop nooit uitgeken nie. Dié studies voorsien egter ’n nuttige grondlyn vir ’n ondersoek na die artropodes op proteas, veral vir die bestudering van die gilde wat van die protea leef (“the feeding guild”). Hierdie navorsing het ten doel om ’n intensiewe en omvattende opname te maak van die artropodefauna wat oor die tydperk van ’n jaar op kommersieel verboude proteas voorkom. Die opname is meer bepaald ontwerp om die samestelling van die artropodefauna te bestudeer (deur ’n omvattende verwysingsversameling vir plaagbestuurdoeleindes te skep), en om vas te stel of seisoene en plaagbehandelings enige beduidende uitwerking op die artropodefauna het.

Oor ’n tydperk van 12 maande is seisoenale monsters van die vrug- en bloeistadia, saadkoppe en blare van hoofsaaklik kommersiële proteas gesoek en ingesamel. Sewe kommersiële proteablokke sowel as ’n blok wilde proteas het as proefpersele gedien, en twee bespuite blokke is gebruik om die doeltreffendheid van plaagdoder te beoordeel. Individuele artropodes is so noukeurig moontlik uitgeken – 37% tot op spesievlak. Volgens ’n spesieakkumulasiekurwe maak seldsame (kleiner) artropodespesies sowat 70% van die artropodes uit wat op verboude proteas voorkom.

Die meer as 8 700 individue van meer as 140 spesies en sowat 80 families wat ingesamel en uitgeken is, toon die rykheid en diversiteit van die artropodefauna op verboude proteas.

Hierdie artropodes verteenwoordig die volle reeks plantvreterspesies – van blaardelwers en blaarkouers tot blomknopboorders, sapsuiers en saadvreters. Blombesoeker-/vrylewende spesies was die volopste (72%) en mees divers (25%). Buiten plantvreters was daar ook ’n groot aantal roofinsekte en parasitoïede. Baie van die artropodes was inheems, en sommige (7,86%) het boonop plaagstatus, aangesien hulle beduidende skade aan die proteaplant aanrig. [By ongeveer 60% van die Safari Sunset-kultivar (*Leucadendron salignum* x *L. laureolum*) is nuwe stamme en blare byvoorbeeld deur die *Epichoristodes acerbella* (Tortricidae) aangetas.] *Capys alphaeus* (Lycaenidae) en *Phyllocnistis* sp. (Phyllocnistidae) blyk spesialisplae te wees wat onderskeidelik hoofsaaklik die *Protea cynaroides* en die Susara-kultivar (*Protea magnifica* x *P. susannae*) in die visier het.

Artropodegetalle het nie juis tussen seisoene gewissel nie, hoewel ’n afsonderlike ondersoek van die proteakultivars ’n beduidende seisoenale uitwerking op spesierykheid aan die lig gebring het. Eweneens het die toediening van plaagdoder nie die artropodegetalle verminder nie, maar wel spesierykheid op die bespuite blokke verswak. Plaagdoders blyk ’n besonder negatiewe uitwerking op kleiner (seldsame) spesies te hê – waarskynlik omdat dié spesies nie voorheen aan plaagdoders blootgestel was nie, en dus gevoelig is daarvoor. Weens die oënskynlike ondoeltreffendheid van plaagdoders op verboude proteas, verg ’n toenemende klem op die belang van niechemiese beheermaatreëls, ’n behoefte aan meer kennis van die roof- en parasitiese spesies in die stelsel, en die vraag na geïntegreerde plaagbeheerstrategieë, meer navorsing.

Die studie moniteer en gebruik drempelwaardes vir artropodeplae, sowel as biologiese, kulturele, fisiese én chemiese (‘optimalegebruik’-) plaagbeheer. Met kulturele beheer kan poli- en interverbouing van proteas byvoorbeeld gebruik word om plantdiversiteit in die monokulture te verbeter, ten einde só ’n hoër digtheid van roofspesies en parasitoïede in die

hand te werk. Sekere blomplante bied kenmerkend ’n wyer tyd- en ruimtelike verspreiding van nektar- en stuifmeelbronne, wat parasitoïede se voortplantingsvermoë en die getalle van alternatiewe gashere/prooi kan verbeter wanneer die plaagspesies skaars is of in ’n ontoepaslike stadium verkeer.

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Dedication

To the great future.

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Chapter 1

Introduction and aims of the study

1.1 Introduction

The family Proteaceae is an important component of the Cape Floristic Region (CFR) (Taylor 1978, Bond and Goldblatt 1984, Coetzee 1989, Goldblatt and Manning 2000). Out of about 400 Proteaceae species reported in Africa, more than 330 species (99% endemic) are in the CFR. The family is represented by 14 genera (out of about 15 genera reported in Africa) in the CFR, of which 10 are endemic (Bond and Goldblatt 1984, Rebelo 1995, Cowling and Lamont 1998). Members of this family are considered keystone species, being essential for continued functioning of plants and animals in the fynbos (Rourke 1998). Because of the beauty of their flowers and foliage, many species are universally utilized commercially (Coetzee 1989). Commercialisation of Proteaceae started in the 1940s (Parvin *et al*. 2003), when wild stands were harvested (Myburgh and Rust 1975, Parvin *et al*. 2003).

After realising that too much pressure was being exerted on the wild plants (van Wilgen and Lamb 1986) and, as a way to increase production to meet the demand, cultivation and management of Proteaceae began in the Western Cape, South Africa, and, since then, the industry has become more sophisticated. With the development of cultivars to improve quality, new markets developed, and the protea industry continued to grow. By 2000, the area under protea cultivation worldwide was estimated at 6000 hectares, with half in South Africa (Parvin *et al*. 2003). Other places where Proteaceae are grown commercially include, in Africa (Zimbabwe and Canary Islands), Oceania (Australia and New Zealand), USA (California and Hawaii), Europe (Portugal and Spain), South America (Chile and Colombia), Western Asia (Israel), Azores Islands and lately in Eastern Asia (China). Advantages of

growing proteas in South Africa are that climatic and soil conditions are highly suitable, but the great disadvantage is that indigenous insect pests are also present (Coetzee 1986), as well as mites (Myburgh *et al*. 1973, Wieczorek and Wright 2003), which cause problems for the cut flower industry (e.g., Myburgh and Rust 1975, Coetzee and Latsky 1986, Wright 2003, Wright unpubl.).

Ecological studies on cultivated Proteaceae-associated arthropods in South Africa are limited to a few studies by Gess (1968), Myburgh *et al*. (1973) and Myburgh and Rust (1975). There are also some fragmentary studies on pest control including those of Coetzee (1986), Wright and Saunderson (1995) and Wright (unpubl., 1995, 2003). Significant work on arthropod ecology and Proteaceae has been conducted on the wild protea species (Gess 1968, Myburgh *et al*. 1974, Coetzee and Giliomee 1985, 1987a, b, Coetzee *et al*. 1986, Coetzee 1989, Hattingh and Giliomee 1989, Wright and Giliomee 1990, Visser 1992, Wright and Giliomee 1992, Visser *et al*. 1996, Coetzee *et al*. 1997, Visser *et al*. 1999, Wright and Samways 1999, 2000, Fleming and Nicolson 2003, Roets *et al*. 2006).

Even though the arthropod species found on cultivated and wild protea species are similar, there is the issue of commercial cultivation of Proteaceae creating a change in local environment, favouring some arthropod species (Myburgh and Rust 1975). Hill (1983) pointed out that evolutionary changes are likely to be accelerated in agroecosystems. As most cultivated Proteaceae are cultivars (with some of these cultivars being derived from completely exotic protea species), new and existing arthropod pests are likely to be a challenge. For example, selection of new cultivars can result in a change in the flowering period, and this can adversely affect certain insects which attack the flowers but on the other hand can be advantageous to others. Coetzee (1986) noted that *Protea repens* cultivar

Guerna, which flowers in summer, was attacked by the larvae of protea butterfly *Capys alphaeus* (Cramer), which was not a problem on winter flowering *P. repens*. Thus, a comprehensive study, on a range of different Proteaceae species/cultivars and the associated arthropods is needed, (Coetzee 1986, Roets *et al*. 2006).

Gess (1968) and Myburgh *et al*. (1973) began to list some arthropods associated with cultivated Proteaceae. However, many species remained unidentified even in wild stands (Myburgh and Rust 1975). Another consideration is that the complement of major pests for any particular crop will change over a period of 10-50 years (Hill 1983). This means that it is possible that new pests might have arisen on proteas since the earlier surveys. From the above, it is clear that it is very timely that a new study is made of the status of protea pests, particularly those of cultivated proteas, especially as the industry continues to expand.

Proteaceae-arthropod interaction studies in South Africa over the past three decades indicate a rich and diverse arthropod fauna. This includes arthropods across a full range of plant-feeding guilds, including gall-formers, leaf miners, leaf chewers, flower bud borers, sap suckers and seed feeders. In addition to these arthropods that feed directly on the plant, there is a large suite of arthropod predators and parasitoids (Coetzee 1989). The large number of arthropods associated with Proteaceae partly arises from the structurally complex nature of the plants and can therefore provide a diversity of microhabitats for arthropods to exploit (Coetzee 1986, Coetzee and Latsky 1986).

It is the feeding habits of the arthropods that have ripple effects on the commercial aspect of Proteaceae. It is aesthetically unacceptable to market inflorescences with damaged inner involucral bracts or with damaged flower head stem leaves. However, not all arthropods associated with Proteaceae are pests, with some being beneficial to the plants (Coetzee and

Giliomee 1985, Coetzee 1986). For example, many beetles and hymenopterans are pollinators. Nevertheless, some of the beneficial arthropods to flowers tend to lead to phytosanitary problems (Coetzee 1986), which render the flowers unmarketable (Myburgh *et al*. 1973).

A commercial response to the arthropod pest problem is huge pesticide input into commercial protea fields, which is both expensive and not in keeping with integrated pest management, nor is it environmentally acceptable. Pests and their management on cultivated Proteaceae present a particular challenge, as a large percentage of the pest species are endemic to the Western Cape (Coetzee 1986). A plant growing outside its natural environment can be expected to have a narrower spectrum of pests of which only a few may be dominant (Coetzee 1986). It was as a result of this challenge that the Fynbos Unit of the ARC-Roodeplaat (Western Cape) developed a series of preliminary information sheets describing protea pests. These sheets provide information on the description of the arthropods (mostly insects), their host plant species, the damage they cause, and possible control measures. While information sheets from the Fynbos Unit form a useful baseline resource for the management of insect pests on Proteaceae, they are insufficient in that confirmation of arthropod identification still requires expert advice (E. Louw, M. Huysamer pers. com.). Furthermore, with increasing emphasis on the importance of non-chemical control measures, further research is required to realize effective, alternative management options to control the wide spectrum of pests.

1.2 Aims and objectives

1.2.1 Aim

The main aim of the study is to determine the major arthropod species associated with cultivated Proteaceae. This will give rise to the establishment of a comprehensive reference collection for ease of identification of arthropod pest species.

1.2.2 Objectives

- To identify which component of the arthropod assemblage associated with Proteaceae are key species, pests on other crops, and which species are specific to Proteaceae (which species are commercially damaging - key pests) and additionally, to note the feeding guilds (this has implications for the application, and development of new pest management techniques).
- To identify which arthropod species have pest status across a broad range of Proteaceae species/cultivars/blocks, and which are specific to particular Proteaceae species/cultivar/block (generalists and specialists).
- To compare the arthropod species found on the cultivated species and those in the remnants of natural fynbos vegetation which borders the protea fields (the "Wild" block). This is to determine whether there are any introduced pests in commercial plantings.
- To determine the seasonal population trends (abundance and species richness) of the arthropods in Proteaceae and to elucidate the biology of key arthropod pest species to facilitate the development of improved control measures.
- To determine the effectiveness of the spraying programme and to ascertain whether it is controlling both the beneficial arthropods and pests.

- To make some preliminary suggestions for an integrated pest management (IPM) programme.

A long term objective is to introduce an IPM programme to avoid continual dependence on pesticides which are not environmentally friendly.

As emphasized by Myburgh *et al*. (1973), Myburgh and Rust (1975), Coetzee (1986) and Roets *et al*. (2006), answers to the questions in this study are of both ecological and economic importance.

In this study, Proteaceae inflorescence refers to flower heads, infructescence to fruiting stage of inflorescence and seed heads. Proteaceae refers to protea (common collective name for all Proteaceae), while *Protea* refers to members of the genus *Protea*. The presence of *P. eximia* and *Leucospermum patersonii*, species which do not occur naturally in the sampling area region raises some questions as to whether they were planted or grew by chance in the remnant fynbos vegetation. This somehow disqualified the remnant vegetation from being referred to as wild but "Wild" block throughout this study.

1.3 Thesis structure

Chapter 1: provides a general introduction to the Proteaceae commercial industry in the Western Cape, Proteaceae - arthropod associations and aims of the study.

The results of this study are then presented in the following three chapters which will be submitted as papers to recognised scientific journals. Finally, the thesis has a general discussion as the final chapter.

Chapter 2: Arthropod species in cultivated and wild Proteaceae in the remnant vegetation of fynbos and their levels of host specificity. In this chapter arthropod pest community associated with other crops will be identified as well.

Chapter 3: Seasonal pattern of absence and presence of arthropod species in Proteaceae and the biology of key arthropod pest species. This chapter involves assessment of the trends of arthropods throughout the year. General life cycles of key arthropod pest species will be presented.

Chapter 4: Efficacy of the spray programme, and preliminary suggestions for an Integrated Pest Management (IPM) programme in Proteaceae.

Chapter 5: This general discussion provides linkages between chapters 2, 3 and 4, and a general synthesis.

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Chapter 2

Arthropod species associated with cultivated and wild Proteaceae and their levels of host specificity

Abstract

Arthropod species were collected from commercial Proteaceae blocks (King protea, Sylvia, Sheila, Safari sunset, Susara, Susara (S), Seedling) and "Wild" block (a remnant of wild protea) for a year. Active searching (spot check) and collection of plant material were the methods used for arthropod sampling from the plants. A diverse array of arthropods (95.9% being insects) were collected from mainly commercial proteas, covering the whole range of feeding guilds, from flower visitors/free living, sap suckers, ectophagous, thrips, spiders, mites to ants and parasitoids. Coleoptera, Lepidoptera, Hymenoptera and Diptera were the most abundant and speciose groups, and 37% of all the specimens collected were identified to species level. 30% of the arthropod species were classified as major (abundant) species, with the rest falling under minor (rare) species. The particular host plant species or cultivar was found to play a major role in determining the presence of particular arthropod species, with more structurally complex plants harboring more arthropod species. It was mostly the feeding and phytosanitary issues of these arthropod species which affects commercial Proteaceae growing in the Western Cape. 7.26% of the arthropods were classified as key pest species of commercial Proteaceae. A large number (≈ 93 %) of the species are endemic to the Western Cape, South Africa, with only 5.6% of the total arthropod species being associated with other crops in South Africa. Most species were generalist species, occurring on most of the protea species and cultivars studied, with very few classified as specialists.

2.1 Introduction

2.1.1 Arthropods associated with Proteaceae in South Africa

South Africa is home to a number of internationally cultivated Proteaceae species and cultivars (Wright and Saunderson 1995). While soil and climatic conditions are suitable for protea growth, arthropod pests are among the main limiting factors for the production of high quality protea flowers (Coetzee 1986, Wieczorek and Wright 2003).

Cultivated Proteaceae-arthropod interactions in South Africa have been limited to just a few studies, Gess (1968), Myburgh *et al*. (1973), Myburgh and Rust (1975), Coetzee (1986), Wright and Saunderson (1995), Wright (1995, 2003 and unpubl.). Gess (1968) was the first to list the large number of insects found on proteas. Further recognizing the arthropod pest problem in the South African protea industry, Myburgh *et al*. (1973) and Myburgh and Rust (1975) carried out arthropod surveys and obtained quantitative and qualitative data on commercial proteas. Even though these studies were incomplete (Myburgh and Rust 1975, Coetzee 1986, Roets *et al*. 2006), with most arthropods being unidentified, today these publications are regarded as the foundations of arthropod studies in cultivated proteas. Coetzee (1986), Wright and Saunderson (1995), Wright (1995, 2003) were all fragmentary review studies on pest control in commercial proteas.

However, in contrast the situation with cultivated proteas, the diversity and ecology of wild protea-associated arthropods have been relatively well studied (Gess 1968, Myburgh *et al*. 1973, Myburgh and Rust 1975, Coetzee and Giliomee 1985, 1987a, b, Coetzee 1986, 1989, Hattingh and Giliomee 1989, Wright and Giliomee 1990, Visser 1992, Wright and Giliomee 1992, Visser *et al*. 1996, Coetzee *et al*. 1997, Visser *et al*. 1999, Wright and Samways 1999, 2000, Fleming and Nicolson 2003, Roets *et al*. 2006).

From the early cultivated and wild Proteaceae-arthropod studies, a diverse array of arthropod (mainly insects) groups were found in cultivated proteas and ranged from flower visitors, borers (affecting the stem, inflorescence and infructescence), leaf miners, leaf chewers to sap suckers (e.g. Myburgh *et al*. 1973). However, the poor quality of proteas as a source of insect nutrition may limit these and other species (Wright and Giliomee 1992). Several hypotheses have been formulated to provisionally explain this diverse array of arthropods on Proteaceae. The structural complexity of most protea plants provides a diversity of favourable niches and enemy free areas which favour various arthropod groups (Lawton 1983, Coetzee and Latsky 1986). There is also the assumption that a crop which is grown in its natural habitat is attacked by a wide spectrum of arthropods (Coetzee 1986). It is also assumed that different arthropods could have a chance of adapting to the plant for a long period of time (evolutionary time). Since Proteaceae plants are grown in their natural environment in South Africa, it is also believed that heavy infestations in natural stands lead to great pressure on adjacent cultivated stands and encourage a diverse array of arthropods into the fields.

Most of these hypotheses were, however, questioned, except for the structural complexity hypothesis (Lawton 1983, Coetzee and Latsky 1986) after a wide range of arthropod species were recorded in a non-native protea region, Portugal (just after a few years of protea introduction in that region) (Leandro *et al*. 2003). Therefore, it can be suggested that in areas where Proteaceae do not occur naturally, arthropods from the local natural fauna and crops surrounding the protea fields can quickly adapt to the "foreign" plant, (most probably making use of the numerous and usually enemy free microhabitats provided by the Proteaceae plants) with some becoming a nuisance.

The diverse array of plant-feeding arthropods associated with proteas was found to present a problem for the commercial cultivation of Proteaceae, as most of the arthropods were found to inhibit production of the cut-flowers (Myburgh *et al*. 1973, Myburgh *et al*. 1974, Myburgh and Rust 1975, Coetzee 1986, Wright and Saunderson 1995, Wright 2003). Even though beneficial in pollination (as generalist flower visitors) (Coetzee and Giliomee 1985, Hattingh and Giliomee 1989, Wright *et al*. 1991), most flower visitors were found to cause serious phytosanitary problems, while leaf feeders and leaf miners caused unsightly leaf damage which is unacceptable on cut flowers. Inflorescence and infructescence borers destroy the flower heads (also creating phytosanitary problems) and the seed bank (otherwise not important economically) (Coetzee 1986, Coetzee and Latsky 1986). Some of the damage can be tolerated by the plants but this is unacceptable commercially. For example, numerous phytophagous species were found to remove between 2% - 14% of leaf area on protea species (Wright and Giliomee 1992, Coetzee *et al*. 1997), a damage level which can be tolerated by a plant but presents an aesthetic problem for the sale of cut flowers and foliage.

Generally, highest abundance of arthropod species was recorded in Coleoptera, and relatively low numbers in Diptera and Lepidoptera (e.g. Wright and Giliomee 1990). Various beetles were free living, and up to 2 000 beetles may occur in a single flower (Rebelo 1995). Surprisingly, some of the groups which were recorded in lower abundances were found to be the most destructive ones, for example, lepidopterous borers (Wright and Giliomee 1990). Another feature of proteas is the occurrence of thousands of mites mostly in mature *Protea* species inflorescences. As many as 6 000 mites may occur in a single protea inflorescence (Myburgh *et al*. 1973, Rebelo 1995). Mites are of phytosanitary importance (and itch mites were also found to cause skin irritation to human beings). Apparently, there is very little research on arachnids associated with Proteaceae. Coetzee *et al*. (1990) analyzed the spider

assemblages on five Proteaceae species and Visser *et al*. (1999) assessed species richness of arachnids associated with *Protea nitida*. From these studies, Araneae (spiders) were the most abundant of all arachnids in Proteaceae and unlike the case in mites, tended to favor non *Protea* genera, i.e. *Leucospermum* and *Leucadendron*. Furthermore, unlike mites, the spiders prefer habiting in the foliage rather than in the inflorescence (Coetzee 1989).

Most arthropod studies have been done on wild Proteaceae. However, the change in environment in the case of cultivated proteas and planting of exotic derived cultivars may play a role in bringing new and promoting certain arthropod groups in the Proteaceae fields. In support, Whitehouse (2005) and Samways (2007) stated that crop fields (usually being monocultures) are considered beneficial for pestiferous species and some rare insect species which require such disturbed conditions which simulate early successional habitats. Since plants of the same kind are grown in a dense monoculture in cultivated Proteaceae, it is expected that the number of arthropod pests increase to higher levels as no energy will be spent on searches for food or oviposition sites but all channeled into reproduction (Coetzee 1986).

The ability of exotic pests to exploit Proteaceae in South Africa, and elsewhere where there are no indigenous Proteaceae may be limited (Wright and Saunderson 1995). However, Leandro *et al*. (2003) and Wright (2003) later revealed that Proteaceae grown outside South Africa are almost entirely affected by different, non-South African arthropods.

Arthropods affecting commercial proteas are indistinct and there is need to identify arthropod populations both in the field and surrounding areas. In other words, there is a need for intensive and extensive studies in cultivated Proteaceae. Furthermore, with the growing of proteas increasing worldwide, there is a need to recognize arthropods from one growing

region to another for easy control of pests (and for quarantine purposes). To produce high quality flowers, it is important to control the arthropod pests of these plants.

It is therefore necessary to have an in-depth knowledge of the natural arthropod fauna surrounding the Proteaceae fields as well (Coetzee and Latsky 1986).

This part of the study concentrated on identifying the arthropod populations associated with cultivated Proteaceae and identifying pest populations (key arthropod species) in the field.

2.1.2 Arthropods associated with cultivated Proteaceae outside South Africa

In other countries where Proteaceae is grown commercially, a number of arthropods have become pests. Studies on arthropod-protea interactions outside South Africa (for example, Leandro *et al*. 2003, Wright 2003) revealed that arthropod species associated with commercial proteas elsewhere are different from the South African species. In Portugal, Lepidoptera (3 species, i.e. *Helicoverpa armigera* (Noctuidae), *Cacoecimorpha pronubana* (Tortricidae) and *Sesamia nonagrioides* (Noctuidae)), mealybugs (*Paracoccus* sp.) and scale insects (*Saissetia coffeae*) and one species from the Diaspididae family were found as key arthropod species in cultivated Proteaceae (Leandro *et al*. 2003). Bugs (some Miridae and Cicadelidae members), weevils, aphids and thrips were also found but in very low numbers, as well as some beneficial beetles and parasitoids (Leandro *et al*. 2006). In the USA, Hawaii recorded sap sucking insects (mealybugs, aphids and scale insects) as problematic, but no borers, whereas in California, beetles, ants and thrips were recorded (Wright 2003).

In Australia and New Zealand, leaf miners, borers, scale insects, weevils and general flower visiting arthropods were reported to be a problem (Wright 2003). In Zimbabwe not much has been done on identifying arthropods associated with proteas, with Wright (pers. obs. and unpubl.) suggesting that *Argyroploce* sp. and *Epichoristodes* sp. might be infesting proteas

grown there. Israel, Spain, South America (e.g. Chile, Colombia), China, Canary and Azores Islands are the other areas known to grow Proteaceae commercially and actually no literature has been found on protea-arthropod interactions from any of these areas.

2.1.3 Exotic and other arthropods associated with other crops

The occurrence of arthropods regarded as major pests from other crops and countries in South Africa is limited to carnation worm (*Epichoristodes acerbella*), bollworm (*H. armigera*) and lucerne butterfly (*Colias electo*) (Viljoen and Wright 1991, Wright and Saunderson 1995) and the less important species being *Machiademus diplopterus* (Lygaeidae), *Frankliniella schultzei* (Thripidae), *Eremnus setulosus* (Curculionidae) and *E. atratus* (Curculionidae). This is a surprisingly short list considering that numerous exotic arthropod pests occur in various crops in South Africa (Annecke and Moran 1982). According to Wright and Giliomee (1992) and Wright and Saunderson (1995), this may be due to the defense mechanisms and poor nutritional quality of Proteaceae for arthropods, which may have excluded those plants from becoming exploited by arthropod pests from other crops.

2.1.4 Arthropod specificity

Proteaceae arthropods can be classified simply as generalists, i.e. one species can be found to affect a range of Proteaceae species and can be also found affecting other plant species. However, mites appeared to favor members of *Protea* genus (Myburgh *et al*. 1973, Coetzee *et al*. 1986) and spiders appear to specialize on non *Protea* genera, i.e. *Leucadendron* and *Leucospermum* species (Coetzee *et al*. 1990, Visser *et al*. 1999).

2.1.5 Objectives

- To identify which component of the arthropod community associated with Proteaceae are the major species, specific to Proteaceae (which species are of economic importance) and which ones are also pests on other crops, and, additionally to note their feeding guilds (this has implications for the application, and development of new pest management techniques).
- To identify which arthropod species have pest status across a broad range of Proteaceae species and cultivars, and which are specific to particular Proteaceae species/cultivar (generalists and specialists).
- To compare the arthropod species found on the cultivated Proteaceae species and those in the remnants of natural fynbos vegetation which borders the protea fields. This is to determine whether there are any introduced arthropod pests in commercial plantings.

In this study, protea is a common collective name for all Proteaceae, while *Protea* refers to members of the genus *Protea*. "Wild" block refers to remnant fynbos vegetation surrounding the cultivated protea fields.

2.2 Materials and methods

2.2.1 Study site

Proteaceae inflorescences (flower heads), infructescences (fruiting stages of inflorescences and seed heads) and leaves (including <15 cm stems) were collected from commercial and wild Proteaceae at Molteno Brothers Estate (34° 08 S, 19° 02 E) (Elgin), Western Cape Province, South Africa. The specific sampling sites were designed as Sheila (34° 08.278´ S 19° 03.029´ E), Seedling (34° 07.672´ S 19° 04.134´ E), Sylvia (34° 07.729´ S 19° 04.129´ E), "Wild" (34° 07.364´ S 19° 03.602´ E), Susara (34° 07.031´ S 19° 03.441´ E), Susara (S) (34° 06.978´ S 19° 03.451´ E), Safari sunset (34° 07.981´ S 19° 02.649´ E) and King protea (34° 07.777´ S 19° 04.277´ E) (Figure 2.1).

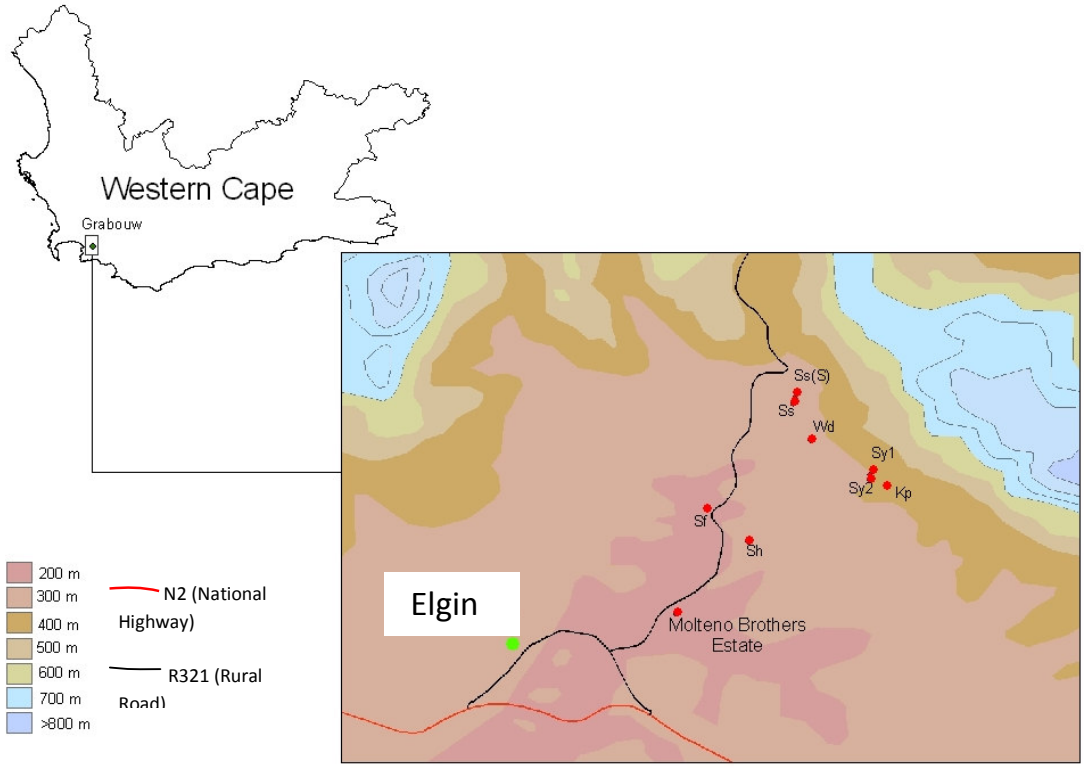

Figure 2.1. Map showing the position of Molteno Brothers Estate, Elgin in the Western Cape, South Africa and specific sampling sites. (Sh = Sheila, Sf = Safari sunset, Ss = Susara, Ss(S) = Susara (sprayed), Wd = "Wild", Sy1 = Seedling, Sy2 = Sylvia, Kp = King protea).

Each specific sampling site represented a block of cultivated Proteaceae species/cultivar (Table 2.1), except for Seedling and "Wild" blocks. The Seedling block is a field with several Proteaceae species/cultivars (Table 2.2) used for breeding new protea cultivars. The "Wild" block referred to the area with wild protea species (Table 2.3) growing in a remnant vegetation patch of the natural fynbos in the upper, eastern side of the estate. However, the presence of *P. eximia* and *Leucospermum patersonii*, species which do not occur naturally in the sampling area region raises some questions as to whether they were planted or grew by chance in the remnant fynbos vegetation. This somehow disqualified the remnant vegetation from being referred to as wild but "Wild" block throughout this study. Sylvia and Susara (S) (sprayed Susara block) represented blocks treated with pesticides.

Table 2.1. Proteaceae cultivars used in the study and their parent species.

Cultivar	Parent species
Susara	*Protea magnifica* x *P. susannae*
Sheila	*P. magnifica* x *P. burchellii*
Sylvia	*P. eximia* x *P. susannae*
Safari sunset	*Leucadendron salignum* x *L. laureolum*
King protea	*P. cynaroides*

Table 2.2. Proteaceae species/cultivars in the Seedling block at Molteno Brothers Estate, Elgin, South Africa.

Species
**Protea neriifolia*
**Protea eximia*
Protea lacticolor
Protea repens
Protea neriifolia x *Protea laurifolia*
Protea mundii x *Protea aurea*
**Protea susannae*

***** Parent Proteaceae species of the cultivars or common protea species in other sampling blocks.

Table 2.3. Proteaceae species in the "Wild" block at Molteno Brothers Estate, Elgin, South Africa.

Species
Leucandendron tinctum
**Leucandendron laureolum*
Leucospermum conocarpodendron
#Leucospermum patersonii
**#Protea eximia*
**Protea neriifolia*

***** Parent Proteaceae species of the cultivars or common protea species in other sampling blocks.
# Protea species which do not occur naturally in the Elgin area.

2.2.2 Sampling periods

There were eight sampling periods, from September 2007 – July 2008 which covered the all four seasons of the year (i.e. spring, summer, autumn and winter) as shown in Table 2.4. Two sampling visits were conducted per season.

Table 2.4. Arthropod sampling periods (September 2007 – July 2008) from Proteaceae at Molteno Brothers Estate, Elgin, Western Cape, South Africa.

Season	Months	Sampling period (T)
Spring	September	1
	October	2
Summer	December	3
	January	4
Autumn	March	5
	April	6
Winter	June	7
	July	8

2.2.3 Sampling protocol for plants

Each focal site was sub-divided into four quadrants. Within each quadrant, twelve protea plants were selected at random in a way that covers the full expanse of the quadrant (see Figure 2.2). This was done to make sure that the sampling universe was covered. 48 samples were collected per sampling period from each site. The sampled plants were separated by at least 5 m distance. Care was taken not to sample the same plant during successive sampling periods. The reason for this was that inflorescences and infructescences were removed, as

well as some leaves. To ensure this, the sampled plant was marked with small red colored tag on the stem. A herbarium collection of all the Proteaceae plant species/cultivars was made.

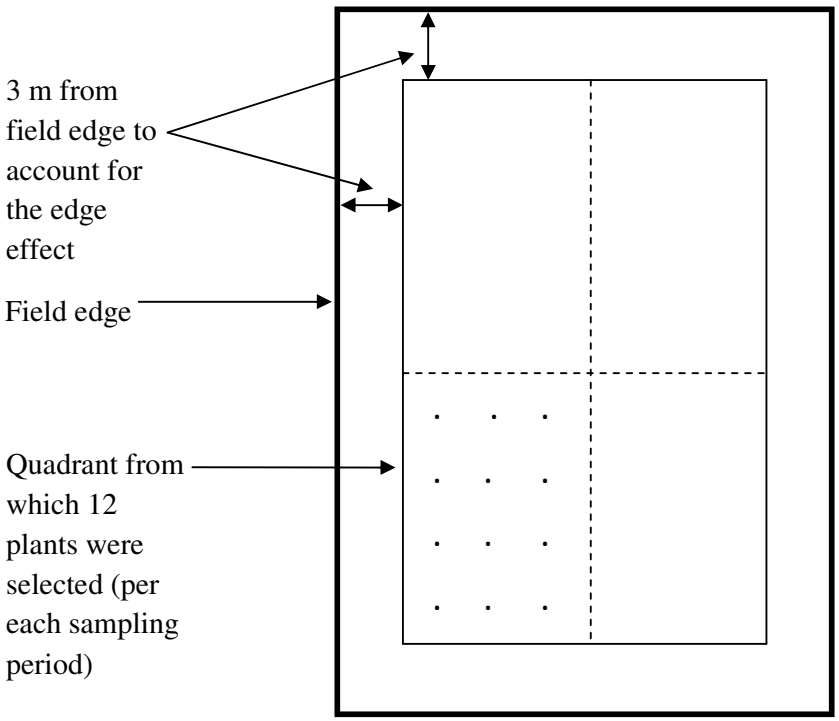

Figure 2.2. Layout of the sampling plan per sampling site.

2.2.4 Sampling and collecting methods for arthropods

Each plant sampled for arthropods was conceptually divided into four quadrants (i.e. N, E, S and W) and samples were picked from each side. The edge effect was avoided by sampling >3 m from the field edges.

Active collection of plant parts and active searching (spot check) were the methods employed on sampling for arthropods. Active collection was employed on systematic sampling in the quadrants and involved collection of three of each, i.e. inflorescences (flower heads), infructescences (fruiting inflorescences and seed heads) and leaves (including <15 cm long tip end stems) per each plant. However, inflorescences and infructescences samples depended

on availability, otherwise when absent, they were replaced by stems. The plant parts were cut using pruning shears and placed in transparent polythene plastic bags (240 mm x 330 mm) and then dissected in the laboratory to procure all the arthropods inhabiting them. Plant parts of different seasons were sampled. Active searching was conducted after active collection, and involved sampling on visibly-damaged plants, and was standardized as five minutes per quadrant. Microhabitat preferences of arthropods on the plant and type of feeding were also noted and used in compiling the feeding guilds. Caution was taken during sampling, to minimize disturbance on the plants as many arthropods could be dislodged as the samples were taken (Satchel and Mountford 1962). A special attention was given to small arthropods as these are often overlooked during sampling (Condrashoff 1967). 70% ethanol in 70 ml vacutainers were used as the preservation medium.

2.2.5 Specimen identification

The specimens were identified to species level where possible by use of identification keys, literature and by sending specimens to taxonomists/specialist entomologists to obtain reliable identifications. A Leica MZ75 stereomicroscope (Meyer Instruments, Inc., USA) was used in the identification of some arthropod specimens and a Canon PowerShot A710 IS camera (Canon, USA) was used for photographic records. There were identification problems with mainly immature specimens such as pupae, larvae and eggs. In such cases, Roets *et al*. (2006) method was used where the specimens were morphotyped and linked to whatever level it has been identified to and here after referred to as species, except when they could be associated with adult taxa. In some cases, rearing of larva was undertaken to try and raise it until it develop into an adult specimen for easy identification. Representative specimens were mounted and dried or stored in 70% ethanol (depending on size and nature of their

exoskeleton) for a reference collection, and are stored in the Entomology Museum, Stellenbosch University, South Africa.

2.2.6 Insect rearing/Identification of immature specimens

Larvae were exposed to cold temperatures (cold room <5°C) until they pupated. The pupae were then taken to room temperature and pressure where the adults emerged under a fine mesh fabric "organza" closed clear plastic jars and identified. Success of this method was marked at 45% and only worked for lepidopterans. However, the problems of the effect of microbial pathogens and prolonged development time of specimens were encountered.

2.2.7 Key arthropod species and feeding guilds determination

To determine key arthropod species, rank-abundance curve described by Gaston (1994) was used. To determine if collected species were also associated with other crops, information was obtained by searching literature available (e.g. Annecke and Moran 1982). To determine key Proteaceae pests, information on feeding guilds was required and was acquired from literature as well as from field observations.

The arthropod specimens were put into the following guilds: free living/flower visitors (FL/FV), endophagous (EN), ectophagous (EC), sap suckers (SS), ants (AN), parasitoids (PR), spiders (SP), mites (MT) and thrips (TH). The guilds were allocated based on consulting literature; Moran and Southwood (1982), Coetzee (1989) and Wright and Giliomee (1990) and personal observations. All arthropods collected from inflorescences were put under the flower visitors/free living guild, species which bore into plant structures and mined in leaves were grouped as endophagous. Species which fed on the leaf and/or chewed other outward plant structures were labelled as ectophagous. All sap sucking arthropods were classified as sap suckers. Due to the unique feeding and general behaviour of

ants, parasitoids, spiders, mites and thrips, these were classified as separate, independent guilds.

For determining the key Proteaceae pests, mainly literature (including grey literature form), crop loss surveys (Mulaa 1995) and personal observations from the field and laboratory analysis of plant material were used. Personal interviews were conducted with a group of protea farmers (South African Protea Producers and Exporters - SAPPEX) for the crop loss surveys. The surveys were undertaken simply to determine the types of losses occurring and their main causes (Walker 1987). The plant material (inflorescences, infructescences and <15 cm long stems) collected from the field were closely analysed for any arthropod damage. The damage on the plants was then associated with an arthropod. The numbers of damaged plant material by an arthropod per block were tallied (Appendix 4). The arthropods that affected most plant materials collected from the field were considered key pests. Those that damage the essential plant parts (harvestable product) to the extent that renders them completely unmarketable were designated as "most devastating" pests. Those arthropod species that had instead their numbers (abundant) being a problem and usually not directly affecting the essential plant materials (of phytosanitary importance) were labelled as "less devastating" pests.

2.2.8 Statistical analyses

Arthropod data collected from the field was analyzed by factorial ANOVA using Statistica 8 statistical package (StatSoft Inc, USA). Post hoc Bonferroni tests (Statistica 8, StatSoft Inc, USA) were used to determine any significant differences between arthropods associated with various Proteaceae blocks. Canonical correspondence analysis (CCA) was used in CANOCO

4.5 (Biometris, The Netherlands) to show associations between arthropod species and Proteaceae blocks.

2.3 Results

2.3.1 Arthropod assemblage structure

A total of 8 745 arthropod specimens was collected, mainly from commercial and "Wild" Proteaceae blocks covering the whole range of feeding guilds. Insects made up 95. 9% of the overall arthropod abundance whilst other arthropods (millipedes, spiders, *mites, centipedes and springtails) made up only 4.1%. Coleoptera was the most abundant order making up 72% of the total abundance, followed by Lepidoptera 9%, Diptera 5%, with "Others" (Diplopoda, Collembola, Isopoda, Orthoptera, Thysanoptera, Psocoptera, Blattodea, Mantodea, Chilopoda and Dermaptera) contributing only 2% (Figure 2.3).

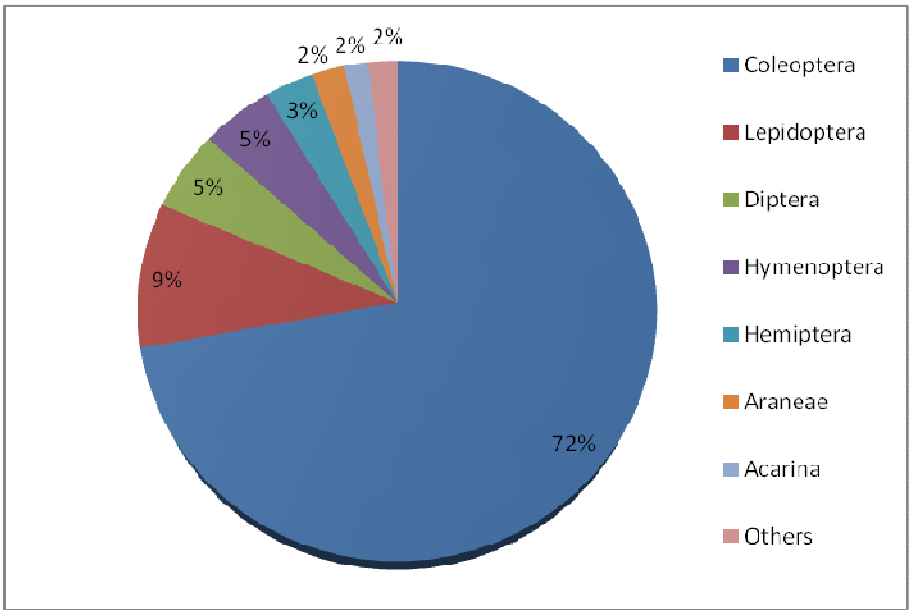

Figure 2.3 Arthropod abundance (per order) percentages from Proteaceae sampled from September 2007 – July 2008 at Molteno Brothers Estate, Elgin, South Africa.

Coleoptera was the most speciose order contributing 25% of all the species collected from Proteaceae, followed by Araneae with 19% and Others (Chilopoda, Dermaptera, Diplopoda, Isopoda, Collembola and Psocoptera) with 4% (Figure 2.4). However, the species

*excluding *Proctolaelaps vandenbergi* mites which were too numerous to count

accumulation curve for the arthropod species from Proteaceae over the sampling period did not approach an asymptote, indicating that the total species richness of the arthropod assemblages had not been sampled.

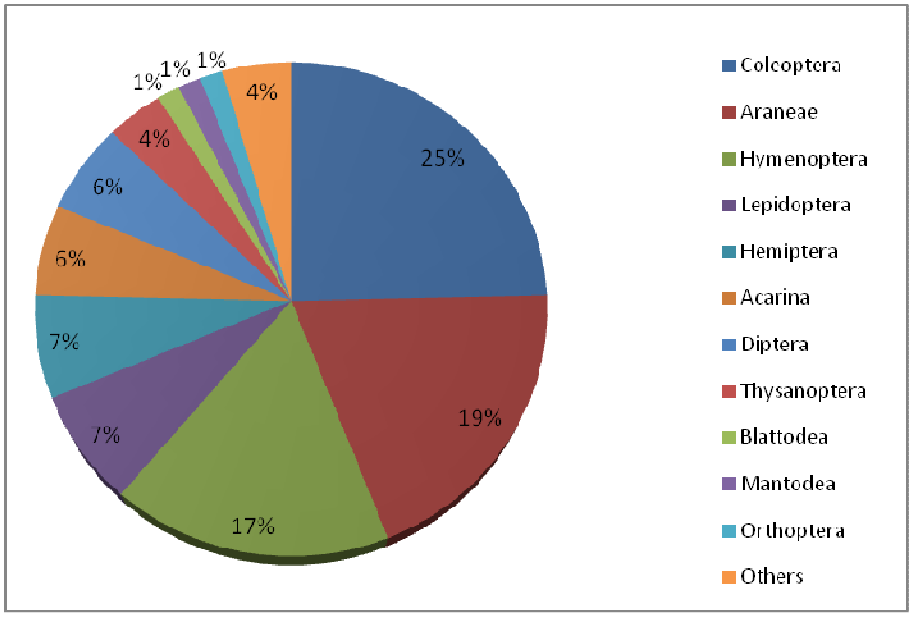

Figure 2.4. Arthropod species richness (per order) percentages from Proteaceae sampled from September 2007 – July 2008 at Molteno Brothers Estate, Elgin, South Africa.

Overall identifications yielded about 142 species, with about 37% identified to species level, 36% only to genus, 19% only to family level with 4% and 1% only to order and class level respectively. A rank-(log) abundance curve (Figure 2.5) (described by Gaston 1994) was used to distinguish major species (most abundant) from minor species or what Gaston (1994) referred to as rare species (least abundant). The species were ranked (see Appendix 1) and a lower quartile definition was used to categorize the least abundant (rare) species.

According to the rank-log abundance curve quartile definition (Q3 = 31.5), 43 out of 142 species fell under the major (abundant) species category with the rest being regarded as minor

(rare) species (see Appendix 1). The first 8 highest ranking species had much higher abundances than the rest of the other species (Figure 2.5 and Appendix 1).

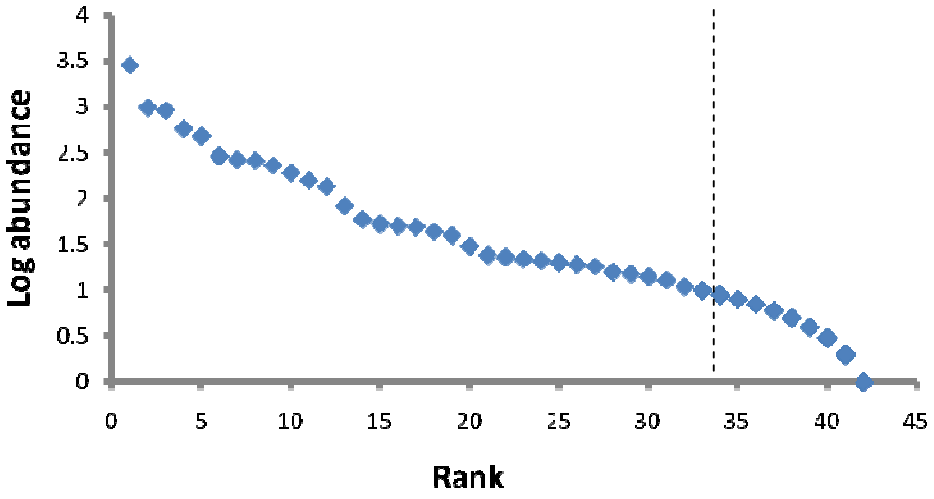

Figure 2.5. Rank-log abundance (log of number of individuals) relationship for arthropod species collected from Proteaceae at Molteno Brothers Estate, Elgin (Western Cape, South Africa). The dashed line demarcates those species categorized as minor (rare) species under quartile definition.

2.3.2 Arthropods per Proteaceae block

Overall, the Seedling block had the highest arthropod abundance and Safari sunset block had the least. There were significant differences in arthropod abundances between blocks ($F = 6.3314$, $df = 7$, $p<0.05$). The Seedling block was significantly different from the rest except from the King protea block ($p>0.05$). The "Wild" block was not significantly different from the rest of the protea blocks except with the Seedling block ($p<0.05$) (Figure 2.6 and Table 2.5) (N.B: a fire broke out in the "Wild" block in July 2007, two months before systematic sampling began).

Table 2.5. Test for significant differences between the abundances of arthropods associated with the various Proteaceae blocks (post hoc Bonferroni tests) on Molteno Brothers Estate, Elgin (n = 8).

	Bonferroni test, variable log (A) Probabilities for Post Hoc Tests							
Block	SH	SD	SY	WD	SS	SS(S)	SF	KP
SH		0.000001	1.000000	1.000000	0.464544	1.000000	1.000000	0.056055
SD	0.000001		0.000053	0.000008	0.011766	0.000466	0.000000	0.063262
SY	1.000000	0.000053		1.000000	1.000000	1.000000	1.000000	0.699911
WD	1.000000	0.000008	1.000000		1.000000	1.000000	1.000000	0.298861
SS	0.464544	0.011766	1.000000	1.000000		1.000000	0.043714	1.000000
SS(S)	1.000000	0.000466	1.000000	1.000000	1.000000		1.000000	1.000000
SF	1.000000	0.000000	1.000000	1.000000	0.043714	1.000000		0.002998
KP	0.056059	0.063262	0.699911	0.298861	1.000000	1.000000	0.002998	

log (A) = log Abundance, SH = Sheila, SD = Seedling, SY = Sylvia, WD = "Wild", SS = Susara, SS(S) = Susara (S), SF = Safari sunset, KP = King protea.

The Proteaceae blocks had an effect on species richness ($F = 40.76$, $df = 7$, $p<0.05$). However, Proteaceae block effect had a significant interaction with the season effect ($F = 15.63$, $df = 21$, $p<0.05$) (significant interaction results between Proteaceae block and season were presented in detail in Chapter 3 - Seasonal pattern of arthropod species associated with Proteaceae). On plotting species richness per Proteaceae block data, the King Protea block had a relatively high number of species while the Susara (S) block had the least (Figure 2.7). The "Wild" block was not notably different from the rest of the blocks in terms of species richness. However, the "Wild" block had intermediate species richness in relation to other blocks (Figure 2.7), as well as intermediate species abundance (Figure 2.6).

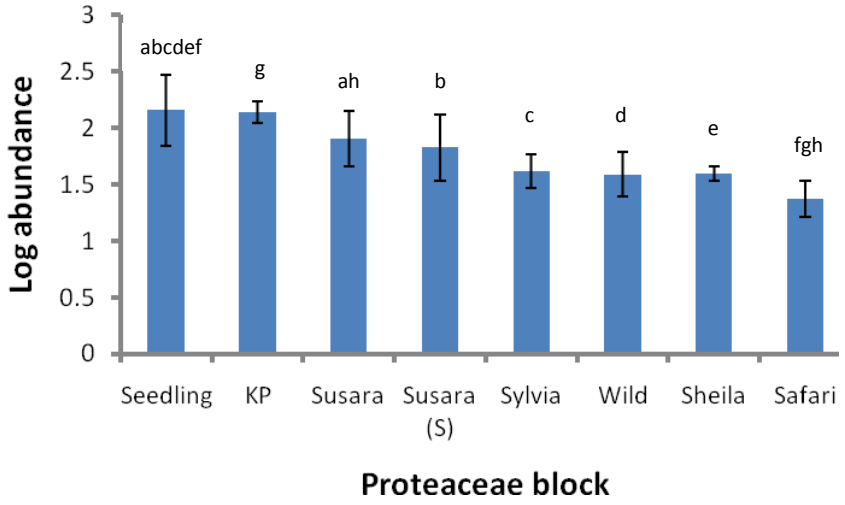

Figure 2.6. Total arthropod abundance per Proteaceae blocks over the sampling period, September 2007 – July 2008 at Molteno Brothers Estate, Elgin, South Africa. Wild here represents the "Wild" block. a, b, c, d, e, f, g, h indicate significant differences. Error bars indicate Standard Error.

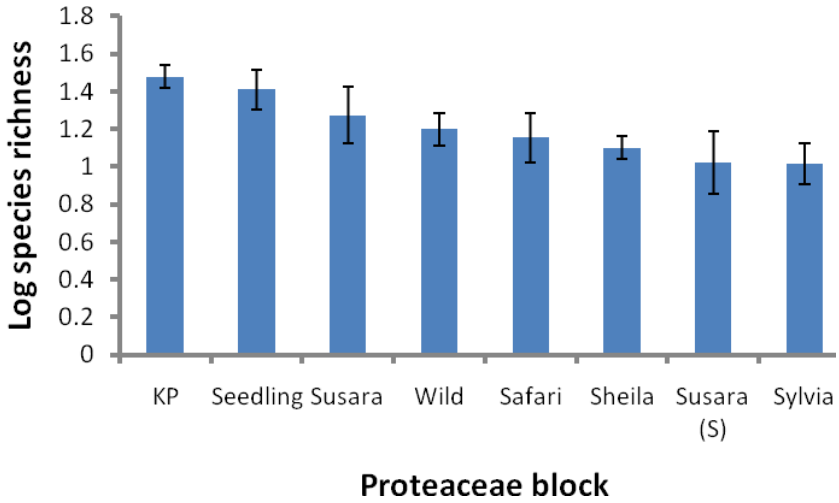

Figure 2.7. Total species richness per Proteaceae blocks over the sampling period, September 2007 – July 2008 at Molteno Brothers Estate, Elgin, South Africa. Wild here represents the "Wild" block. Error bars indicate Standard Error.

Arthropod specificity in Proteaceae and similarities among the blocks

Ho: all the arthropod species have identical (probability) patterns in all Proteaceae.

Hi: all the arthropod species do not have identical patterns in all Proteaceae.

Figure 2.8 and tables 2.6 – 2.13, shows that the blocks Sylvia, Sheila, Susara, Susara (S) and Safari sunset correlated, while Seedling, "Wild" and King protea were uncorrelated (significantly different from each other) as well as from the rest of the other blocks.

Most key pest species were associated with the King protea block, and no key pest arthropod species were linked to the Seedling block. Only one key pest, the scarab beetle *Genuchus hottentottus* was associated with the "Wild" block. Most spider species were rare but widely associated within all the Proteaceae blocks (Figure 2.8 and Tables 2.6 – 2.13).

Some predator and parasitoid species appeared to be linked to specific Proteaceae blocks where their respective prey and hosts were common (Figure 2.8 and Tables 2.6 – 2.13).

N.B: To avoid problems with collinearity and for clarity of the diagram (Figure 2.8), other variables such as seasonality were not included here.

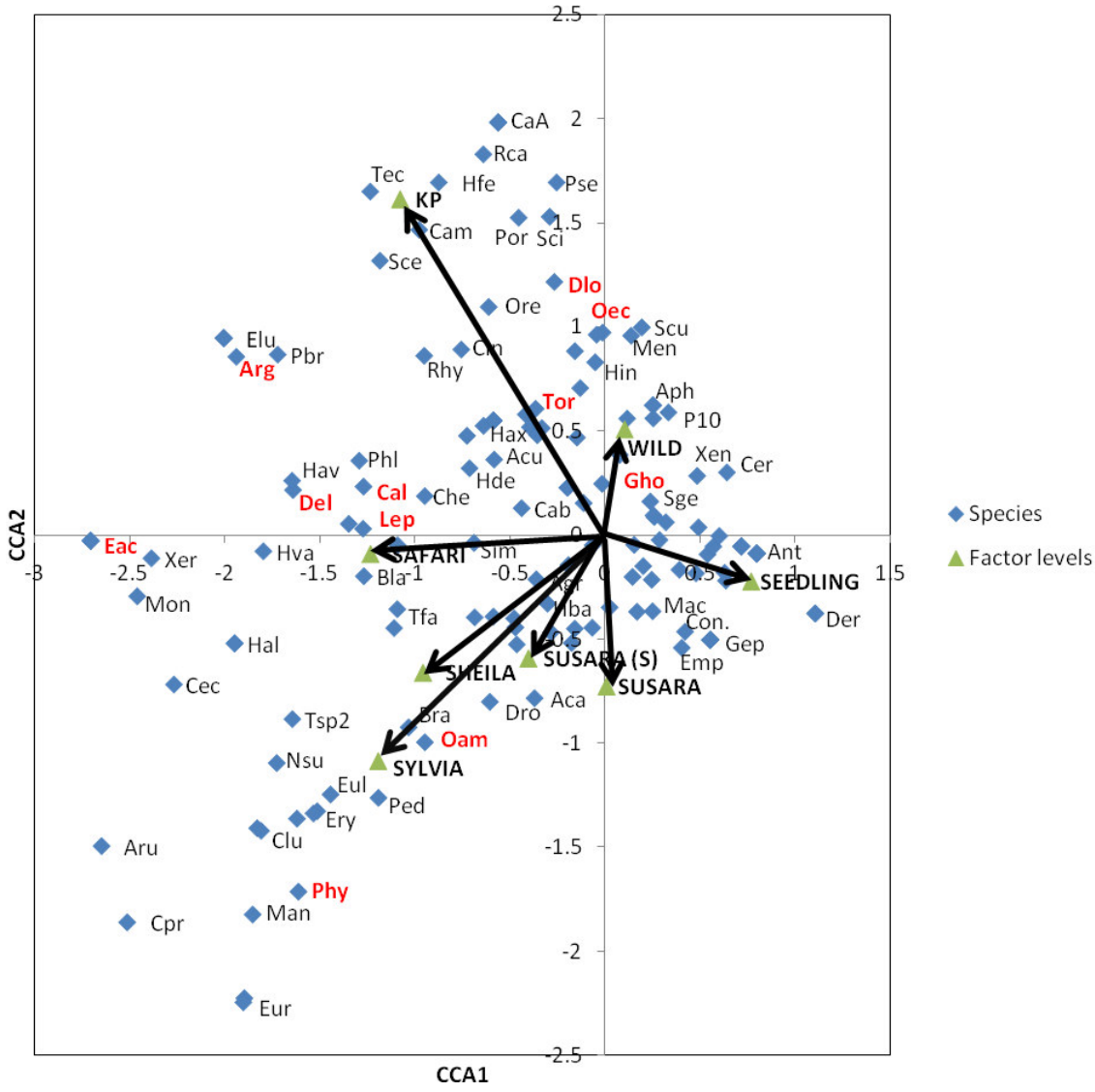

Figure 2.8. Biplot for arthropod species and Proteaceae blocks (Eigen values: CCA1 = 0.64325; CCA2 = 0.52642). N.B: For species full names see Appendix 3. Key Proteaceae pest species are indicated in red and bold typeface. Wild here represents the "Wild" block.

Guild structures

The free living/flower visitors guild was the most abundant of all the guilds, with highest numbers in the Seedling block and lowest in the Safari sunset block. The endophagous guild was the second most abundant guild with almost similar recordings throughout the blocks except in the Safari sunset block, where it was the least abundant (Figure 2.9).

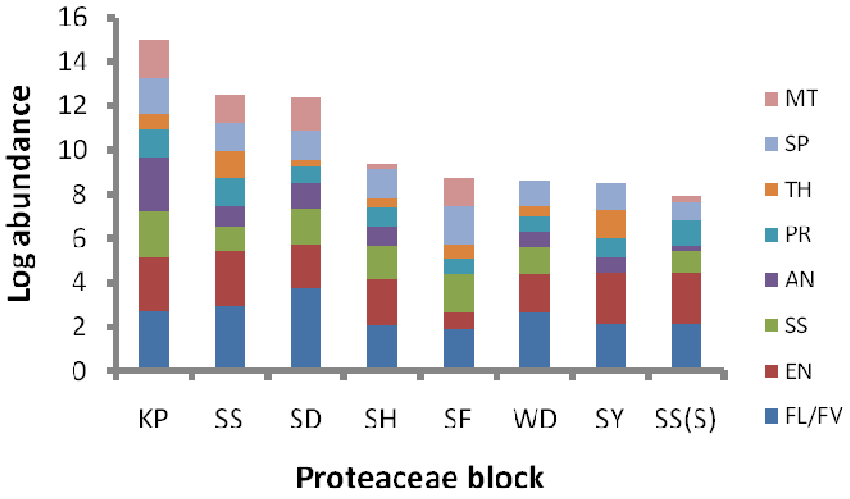

Figure 2.9. Guild abundances per Proteaceae blocks sampled from September 2007 – July 2008 at Molteno Brothers Estate, Elgin, South Africa. KP = King protea, SD = Seedling, SS = Susara, WD = "Wild", SF = Safari sunset, SH = Sheila, SY = Sylvia and SS (S) = pesticides sprayed Susara block. MT = Mites, SP = Spiders, TH = Thysanoptera, PR = Parasitoids, AN = Ants, SS = Sap suckers, EN = Endophagous, FL/FV = Free living/Flower visitors.

Sap suckers, parasitoids and spiders maintained fairly constant abundances throughout the blocks. However, relatively high sap sucker numbers were recorded in the King protea and Safari sunset blocks, and none in the Sylvia block. Ants abundances were relatively high in the King protea block and relatively low in pesticide treated blocks, Sylvia and Susara (S).

Generally, blocks which had relatively high sap suckers had corresponding high ant abundances, except in the Safari sunset block where the ants were totally absent. Spiders were relatively abundant in the Safari sunset block and least in the Susara (S) block. Thrips and mites were the least abundant. Thrips were totally absent in the Susara (S) block while mites were absent in the Sylvia and "Wild" blocks.

Free living/flower visitors comprised most of the species, followed by endophagous and, the spider guild (which had relatively lower abundance) with each having uniform species richness throughout the blocks (Figure 2.10). Parasitoids and sap suckers had almost uniform number of species throughout all the blocks, with no sap sucking species recorded in the Sylvia block. Ant species were relatively high in the King protea block and relatively low in the Susara blocks. Generally, blocks which had more sap sucker species had corresponding high ant species richness, except in the Safari sunset block where the ants were totally absent. Thrips and mite guilds were the least speciose, with no mites recorded in the "Wild" and Sylvia blocks and no thrips in the Susara (S) block (Figure 2.10).

The ectophagous guild was not recorded in many blocks (omitted from the figures because they were negligible) except in the Seedling, Safari sunset and King protea blocks where only the grasshoppers *Vitticatantops humeralis* and *Acanthacris ruficornis* were the only strict ectophagous species recorded. Generally, there was slight leaf damage in Proteaceae (A.S., pers. obs.).

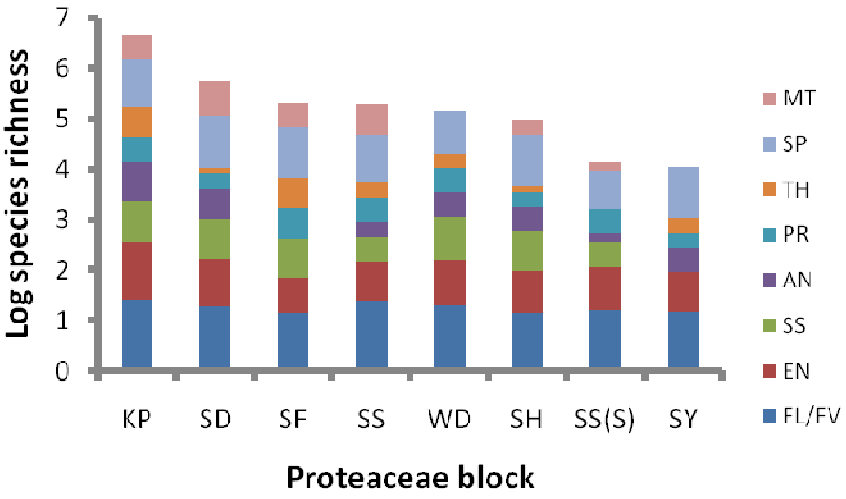

Figure 2.10. Guild species richness per Proteaceae blocks sampled from September 2007 – July 2008 at Molteno Brothers Estate, Elgin, South Africa. KP = King protea, SD = Seedling, SS = Susara, WD = "Wild", SF = Safari sunset, SH = Sheila, SY = Sylvia and SS (S) = pesticides sprayed Susara block. MT = Mites, SP = Spiders, TH = Thysanoptera, PR = Parasitoids, AN = Ants, SS = Sap Suckers, EN = Endophagous, FL/FV = Free Living/Flower Visitors.

Arthropods associated with the Sheila block (*P. magnifica* x P. *burchellii*)

44 species were collected from the Sheila block and only a single species was directly recorded under the ectophagous guild.

Free living and flower visitors: Nine out of eleven of these species in the Sheila block were coleopterans.

Endophagous species: Except for Agromyzidae larva, all the larvae found in the Sheila block were lepidopterans (notably *Orophia ammopleura*).

Sap suckers: Mealybugs were more abundant than the true bugs and aphids, the other components of this guild.

Ants: Three ant species were collected from the Sheila block and these were usually associated with the foliage and older inflorescences.

Parasitoids: The eulophid *Pediobius* sp. was the only parasitoid recorded in this block.

Thrips: Only one species of thrips was associated with the Sheila block.

Spiders: This was the most diverse group of arthropods associated with the Sheila block and consisted of 10 different species. Spiders were mostly found to be associated with foliage.

Mites: A probably new mite species possibly belonging to the family Diplogyniidea was among the four other mite species that were found to be associated with the Sheila block.

Table 2.6. Arthropods associated with the Sheila block (*P. magnifica* x *P. burchellii*) at Molteno Brothers Estate, Elgin, South Africa.

ORDER	FAMILY	GENUS	SPECIES
FLOWER VISITORS AND FREE LIVING			
Coleoptera	Staphylinidae	*Phloenomus*	*Phloenomus* sp.
	Rhizophagidae	*Phyconomus*	*P. tricolor* Woll.
	Staphylinidae (larva)	indet.	
	Melolonthidae	*Diaplochelus*	*D. longipes* (Fabricius)
	Chrysomelidae	*Chirodica*	*Chirodica* sp.1
	Histeridae	*Platysoma*	*P. capensis* Wied.
	Nitidulidae	*Pria*	*P. cinerascens* Er.
	Coccinellidae	*Hippodamia*	*H. variegata* (Goeze)
	Cryptophagidae	*Cryptophagus*	*C. milleri* Reitter
	Lathrididae	*Conimus*	*Conimus* sp.
Diptera	Drosophilidae	*Drosophila*	*Drosophila* sp.
Psocoptera	indet.		
Diplopoda (class)	indet.		
ENDOPHAGOUS SPECIES			
Lepidoptera	Phyllocnistidae	*Phyllocnistis*	*Phyllocnistis* sp.
	Oecophoridae	*Orophia*	*O. ammopleura* (Meyrick)
	Oecophoridae	indet.	
	Lycaenidae	*Capys*	*C. alphaeus* (Cramer)
Lepidoptera	indet.		
Diptera	Agromyzidae	indet.	
Diptera	indet.		
SAP SUCKERS			
Hemiptera	Pseudococcidae	*Delottococcus*	*Delottococcus* sp.
	Pentatomidae	*Antestia*	*A. astrosignata* Stål
	Lygaidae	*Nysius*	*Nysius* sp.
	Anthocoridae	*Orius*	*Orius* sp.
	Rhopalidae	*Agraphosus*	*Agraphosus* sp.
ANTS			
Hymenoptera	Formicidae	*Technomyrmex*	*T. albipes* (F. Smith)
	Formicidae	*Lepisiota*	*Lepisiota* sp.1
	Formicidae	*Monomorium*	*Monomorium* sp.

PARASITOIDS			
Hymenoptera	Eulophidae	*Pediobius*	*Pediobius* sp.
THRIPS			
Thysanoptera	Thripidae	*Synaptothrips*	*S. gezinae* (Faure)
SPIDERS			
Araneae	Clubionidae	*Clubiona*	*C. abbajensis* Strand
	Theridiidae	*Theridion*	*Theridion* sp.1
	Theridiidae	*Theridion*	*Theridion* sp.2
	Gnaphosidae	*Echemus*	*Echemus* sp.1
	Salticidae	*Heliophanus*	*H. debilis* Simon.
	Miturgidae	*Cheiracanthium*	*Cheiracanthium* sp.1
	Amaurobiidae	*Chresiona*	*Chresiona* sp.2
	Amaurobiidae	*Chresiona*	*C. invalida* (Simon)
	Thomisidae	*Synema*	*S. imitator* (Pavesi)
	Corinnidae	*Trachelus*	*Trachelus* sp.1
MITES			
Acarina	Histiostommatidae	*Histiostoma*	*H. feroniarum* (Durfour)
	Ameroseiidae	*Ameroseius*	*Ameroseius* sp.
	Glycyphagidae	*Glycyphagus*	*Glycyphagus* sp.
	Diplogyniidea	indet.	

Arthropods associated with the Seedling block (*P. neriifolia*, *P. lacticolor*, *P. repens*, *P. susannae*, *P. neriifolia* x *P. laurifolia* and *P. mundii* x *P. aurea*).

This was the second most diverse block with 60 different arthropod species.

Free living and flower visitors: 22 arthropod species, mostly beetles, were associated with the different Proteaceae species making up this block.

Endophagous species: Lepidoptera and Coleoptera borers both inhabited mostly the seed heads.

Sap suckers: Six sap suckers were recorded in the Seedling block**,** a scale insect, mealybugs and true bugs

Ectophagous species

Protea lacticolor was the only protea that had significant damage from leaf herbivores. Most *P. lacticolor* plants were left with serrated leaves.

Ants: Four ant species were recorded in the Seedling block.

Parasitoids: An undetermined eucoilid was the only parasitoid recorded in this block.

Thrips: Probably a new thrip species to South Africa was found in the Seedling block.

Spiders: Eight different species of spiders were associated with Proteaceae in the Seedling block.

Mites: A variety of mites were identified from the Seedling block.

Table 2.7. Arthropods associated with the Seedling block at Molteno Brothers Estate, Elgin, South Africa.

ORDER	FAMILY	GENUS	SPECIES
FLOWER VISITORS AND FREE LIVING			
Coleoptera	Staphylinidae	*Phloenomus*	*Phloenomus* sp.
	Rhizophagidae	*Phyconomus*	*P. tricolor* Woll.
	Staphylinidae (larva)	indet.	
	Melolonthidae	*Diaplochelus*	*D. longipes* (Fabricius)
	Chrysomelidae	*Chirodica*	*Chirodica* sp.1
	Chrysomelidae	*Chirodica*	*Chirodica* sp.2
	Histeridae	*Platysoma*	*P. capensis* Wied.
	Nitidulidae	*Pria*	*P. cinerascens* Er.
	Nitidulidae	indet.	
	Coccinellidae	*Harmonia*	*H. axyridis* (Pallas)
	Cryptophagidae	*Cryptophagus*	*C. milleri* Reitter
	Anthicidae	*Formicomus*	*F. coeruleus* Thunb.
	Chrysomelidae	*Xenoomorphus*	*Xenoomorphus* sp.
	Ceutorhynchinae	*Isorhynchus*	*Isorhynchus* sp.1
	Tenebrionidae	indet.	
Diptera	Drosophilidae	*Drosophila*	*Drosophila* sp.
	Empididae	indet.	
Hymenoptera	Apidae	*Apis*	*A. mellifera capensis* (Eschscholtz, 1822)
	Vespidae	*Polistes*	*Polistes* sp.
Psocoptera	indet.		
Diplopoda (class)	indet.		
Dermaptera	indet.		
ENDOPHAGOUS SPECIES			
Lepidoptera	Phyllocnistidae	*Phyllocnistis*	*Phyllocnistis* sp.
	Oecophoridae	*Orophia*	*O. ammopleura* (Meyrick)
	Oecophoridae	indet.	
	Tortricidae	indet.	
Lepidoptera	indet.		
Coleoptera	Scarabaidae	*Genuchus*	*G. hottentottus* (Fabricius)
Coleoptera	Carabidae	indet.	
Diptera	Agromyzidae	indet.	
Diptera (larva 1)	indet.		
Diptera (larva 2)	indet.		

SAP SUCKERS			
Hemiptera	Pseudococcidae	*Delottococcus*	*Delottococcus* sp.
	Lygaidae	*Oxycarenus*	*O. maculatus* Stål
	Lygaidae	*Nysius*	*Nysius* sp.
	Pentatomidae	*Antestia*	*A. astrosignata* Stål
	Psyllidae	indet.	
	Anthophoridae	indet.	
ECTOPHAGOUS SPECIES			
Orthoptera	Acrididae	*Vitticatantops*	*V. humeralis* (Thunberg)
ANTS			
Hymenoptera	Formicidae	*Technomyrmex*	*T. albipes* (F. Smith)
	Formicidae	*Pheidole*	*Pheidole* sp.1
	Formicidae	*Lepisiota*	*Lepisiota* sp.1
	Formicidae	indet.	
PARASITOIDS			
Hymenoptera	Eucoilidae	indet.	
THRIPS			
Thysanoptera	Phlaeothripidae	*Bactothrips*	*Bactothrips* sp.
SPIDERS			
Araneae	Clubionidae	*Clubiona*	*C. abbajensis* Strand
	Gnaphosidae	*Echemus*	*Echemus* sp.1
	Thomisidae	*Synema*	*S. imitator* (Pavesi)
	Theridiidae	*Euryopis*	*Euryopis* sp.
	Salticidae	*Heliophanus*	*H. insperatus* (Wesolowska)
	Salticidae	*Massagris*	*M. regina* (Wesolowska)
	Philodromidae	*Philodromous*	*Philodromus* sp.1
Araneae	indet.		
MITES			
Acarina	Histiostommatidae	*Histiostoma*	*H. feroniarum* (Durfour)
	Macrochelidae	*Macrocheles*	*Macrocheles* sp.
	Ameroseiidae	*Ameroseius*	*Ameroseius* sp.
	Ascidae	*Proctolaelaps*	*P. vandenbergi* (Ryke)
	Glycyphagidae	*Glycyphagus*	*Glycyphagus* sp.

Acaroidea	indet.
Diplogyniidea	indet.

Arthropods associated with the Sylvia block (*P. eximia* x *P. susannae*)

38 species were found to be associated with the Sylvia block and no sap sucking insects were recorded in this block.

Free living and flower visitors: 15 species visited the Sylvia block, probably in search of food or shelter. A diverse number of coccinellids were collected in this block.

Endophagous species: Seven borer and miner species, mainly lepidopterans and dipterans, were found.

Ants: Three ant species were collected.

Parasitoids: Two parasitoid species were recorded in this block.

Thrips: The two common thrip species, *Haplothrips bagnali* and *Synaptothrips gezinae* were recorded.

Spiders: Nine spider species were recorded.

Table 2.8. Arthropods associated with the Sylvia block (*P. eximia* x *P. susannae*) at Molteno Brothers Estate, Elgin, South Africa.

ORDER	FAMILY	GENUS	SPECIES
FLOWER VISITORS AND FREE LIVING			
Coleoptera	Staphylinidae	*Phloenomus*	*Phloenomus* sp.
	Rhizophagidae	*Phyconomus*	*P. tricolor* Woll.
	Melolonthidae	*Diaplochelus*	*D. longipes* (Fabricius)
	Chrysomelidae	*Chirodica*	*Chirodica* sp.1
	Histeridae	*Platysoma*	*P. capensis* Wied.
	Nitidulidae	*Pria*	*P. cinerascens* Er.
	Coccinellidae	*Hippodamia*	*H. variegata* (Goeze)
	Coccinellidae	*Harmonia*	*H. axyridis* (Pallas)
	Coccinellidae	*Cheilomenes*	*C. propinqua* (Mulsant)
	Coccinellidae	*Cheilomenes*	*C. lunata* (Fabricius)
	Scarabaeidae:	*Trichostetha*	*T. fascicularis* (Linnaeus)
Hymenoptera	Apidae	*Apis*	*A. mellifera capensis* (Eschscholtz)
Diptera	Drosophilidae	*Drosophila*	*Drosophila* sp.
Diptera	Empididae	indet.	
Collembola (class)	indet.		
ENDOPHAGOUS			
Lepidoptera	Phyllocnistidae	*Phyllocnistis*	*Phyllocnistis* sp.
	Lycaenidae	*Capys*	*C. alphaeus* (Cramer)
	Oecoephoridae	*Orophia*	*O. ammopleura* (Meyrick)
Lepidoptera	indet.		
Diptera	Agromyzidae	indet.	
	Cecidomyiidae	indet.	
Diptera (larva 1)	indet.		
ANTS			
Hymenoptera	Formicidae	*Technomyrmex*	*T. albipes* (F. Smith)
	Formicidae	*Pheidole*	*Pheidole* sp.3
	Formicidae	indet.	
PARASITOIDS			
Hymenoptera	Eulophidae	*Pediobius*	*Pediobius* sp.
	Braconidae	indet.	
THRIPS			
Thysanoptera	Phlaeothripidae	*Haplothrips*	*H. bagnali* (Tryborn)
	Thripidae	*Synaptothrips*	*S. gezinae* (Faure)
SPIDERS			
Araneae	Clubionidae	*Clubiona*	*C. abbajensis* Strand
	Theridiidae	*Theridion*	*Theridion* sp.1
	Gnaphosidae	*Echemus*	*Echemus* sp.1

Salticidae	*Baryphus*	*B. ahenus* Simon
Linyphiidae	*Pelecopsis*	*P. janus* Jocque
Theridiidae	*Euryopis*	*Euryopis* sp.
Araneidae	*Neoscona*	*N. subfusca* (C.L.Koch)
Philodromidae	*Tibellus*	*Tibellus* sp.
Theridiosomatid	indet.	

Arthropods associated with the "Wild" Proteaceae block

Generally lower arthropod abundances were recorded in this block but with relatively high species richness (50 species) and no ectophagous species were recorded. This was the only block which was affected by fire in July 2007, i.e. two months before systematic sampling began.

Free living and flower visitors: A high number and diversity (21 species) of free living and flower visiting species were recorded on the "Wild" Proteaceae block.

Endophagous species: Eight borer species and leaf miners were recorded in the "Wild" block. This is the only block where *Sphenoptera cupreosplendens* (Buprestidae) was collected.

Sap suckers: Mostly true bugs and an aphid species were recorded in this block, with no mealybugs.

Ants: This was the only block where *Technomyrmex albipes* was absent.

Parasitoids: The only block where the parasitic wasp *Cerhysiella* sp. (Encyrtidae) was collected.

Thrips: Thrips common to other blocks were recorded, i.e. *S. gezinae* and *H. bagnali*.

Spiders: Surprisingly, low spider species richness (7 species) was found on the "Wild" Proteaceae block.

Table 2.9. Arthropods associated with the "Wild" block at Molteno Brothers Estate, Elgin, South Africa.

ORDER	FAMILY	GENUS	SPECIES
FLOWER VISITORS AND FREE LIVING			
Coleoptera	Staphylinidae	*Phloenomus*	*Phloenomus* sp.
	Rhizophagidae	*Phyconomus*	*P. tricolor* Woll.
	Staphylinidae (larva)	indet.	
	Melolonthidae	*Diaplochelus*	*D. longipes* (Fabricius)
	Chrysomelidae	*Chirodica*	*Chirodica* sp.1
	Nitidulidae	*Pria*	*P. cinerascens* Er.
	Nitidulidae	indet.	
	Coccinellidae	*Hippodamia*	*H. variegata* (Goeze)
	Coccinellidae	*Harmonia*	*H. axyridis* (Pallas)
	Cryptophagidae	*Cryptophagus*	*C. milleri* Reitter
	Chrysomelidae	*Xenoomorphus*	*Xenoomorphus* sp.
	Scarabaiedae	*Trichostetha*	*T. fascicularis* (L.)
	Buprestidae	*Sphenoptera*	*S. cupreosplendens* (Gory & Laporte)
	*Curculionidae	*Euderes*	*E. linecolis* Wiedemann
	*Curculionidae	*Sitophilus*	*Sitophilus* sp.
Hymenoptera	Vespidae	*Polistes*	*Polistes* sp.
Hymenoptera	indet.		
Diptera	Sciaride	indet.	
Mantodea	indet.		
Psocoptera	indet.		
Diplopoda (class)	indet.		
ENDOPHAGOUS SPECIES			
Lepidoptera	Phyllocnistidae	*Phyllocnistis*	*Phyllocnistis* sp.
	Tortricidae	indet.	
	Oecophoridae	indet.	
Lepidoptera	indet.		
Diptera	Agromyzidae	indet.	
Diptera (larva 1)	indet.		
Coleoptera	Scarabaidae	*Genuchus*	*G. hottentottus* (Fabricius)
	Buprestidae	*Sphenoptera*	*S. cupreosplendens* (Gory & Laporte)
SAP SUCKERS			
Hemiptera	Lygaidae	*Oxycarenus*	*O. maculatus* Stål

	Pentatomidae	*Antestia*	*A. astrosignata* Stål
	*Pentatomidae	*Nezara*	*N. viridula* (Linnaeus)
	Rhopalidae	*Stictopleurus*	*S. scutellaris* (Dallas)
	Anthocoridae	*Orius*	*Orius* sp.
	Psyllidae	indet.	
	*Aphididae	indet.	
ANTS			
Hymenoptera	Formicidae	*Lepisiota*	*Lepisota* sp.1
	*Formicidae	*Pheidole*	*Pheidole* sp.2
	Formicidae	indet.	
PARASITOIDS			
Hymenoptera	Eulophidae	*Pediobius*	*Pediobius* sp.
	*Encyrtidae	*Cerhysiella*	*Cerhysiella* sp.
THRIPS			
Thysanoptera	Phlaeothripidae	*Haplothrips*	*H. bagnali* (Tryborn)
	Thripidae	*Synaptothrips*	*S. gezinae* (Faure)
SPIDERS			
Araneae	Clubionidae	*Clubiona*	*C. abbajensis* Strand
	Theridiidae	*Theridion*	*Theridion* sp.1
	Theridiidae	*Theridion*	*Theridion* sp.2
	Gnaphosidae	*Xerophaeus*	*Xerophaeus* sp.1
	Salticidae	*Heliophanus*	*H. debilis* Simon
	Salticidae	*Menemerus*	*Menemerus* sp.
	Linyphiidae	*Pelecopsis*	*P. janus* Jocque

*species limited to "Wild" Proteaceae block only.

Arthropods associated with the Susara block (*P. magnifica* x *P. susannae*)

This was recorded as the third most diverse block with 55 species.

Free living and flower visitors: 26 arthropod species were recorded as either free living or as flower visitors and largely comprised of beetles.

Endophagous species: The micro-lepidopteran leafminer, *Phyllocnistis* sp. was well established affecting the new leaves. Affecting the new shoots and immature infructescences was *O. ammopleura* larvae. Moreover, Susara was the only block where no flower-head parasitizing Agromyzidae was recorded.

Sap suckers: Only three sap sucking arthropods were recorded.

Ants: This was the only site where the invasive Argentine ant (*Linepithema humile*) was collected.

Parasitoids: The micro-lepidopteran (*Phyllocnistis* sp.) parasitoid, *Pediobius* sp. (Eulophidae) was prevalent in this block than in any other blocks.

Thrips: Only two thrips species common to some other blocks were recorded.

Spiders: Lowest spider species richness (6 species) was collected at this site.

Mites: Very high numbers (too numerous to count) of the itch mite, *Proctolaelaps vandenbergi* were found usually associated with mature inflorescences.

Table 2.10. Arthropods associated with the Susara block (*P. magnifica* x *P. susannae*) at Molteno Brothers Estate, South Africa.

ORDER	FAMILY	GENUS	SPECIES
FLOWER VISITORS AND FREE LIVING			
Coleoptera	Staphylinidae	*Phloenomus*	*Phloenomus* sp.
	Rhizophagidae	*Phyconomus*	*P. tricolor* Woll.
	Staphylinidae (larva)	indet.	
	Melolonthidae	*Diaplochelus*	*D. longipes* (Fabricius)
	Chrysomelidae	*Chirodica*	*Chirodica* sp.1
	Nitidulidae	*Pria*	*P. cinerascens* Er.
	Nitidulidae	indet.	
	Coccinellidae	*Hippodamia*	*H. variegata* (Goeze)
	Coccinellidae	*Harmonia*	*H. axyridis* (Pallas)
	Cryptophagidae	*Cryptophagus*	*C. milleri* Reitter
	Scarabaiedae	*Trichostetha*	*T. fascicularis* (Linnaeus)
	Lathridiidae	*Conimus*	*Conimus* sp.
	Elateridae	*Heteroderes*	*Heteroderes* sp.1
	Bruchidae	*Spermophagous*	*Spermophagous* sp.
	Chrysomelidae	*Meligethus*	*Meligethus* sp.
Diptera	Drosophilidae	*Drosophila*	*Drosophila* sp.
	Tulipidae	indet.	
	Empididae	indet.	
Hymenoptera	Apidae	*Apis*	*A. mellifera capensis* (Eschscholtz, 1822)
	Halictidae	*Lasioglossum*	*Lasioglossum* sp.
Blattodea	Blaberidae	indet.	
Mantodea	indet.	indet.	
Isopoda	indet.	*Porcelia*	*Porcelia* sp.
Psocoptera	indet.		
Diplopoda (class)	indet.		
Collembola (class)	indet.		
ENDOPHAGOUS			
Lepidoptera	Phyllocnistidae	*Phyllocnisitis*	*Phyllocnistis* sp.
	Oecophoridae	*Orophia*	*O. ammopleura* (Meyrick)
	Tortricidae	indet.	
Lepidoptera	indet.		
Coleoptera	Scarabaidae	*Genuchus*	*G. hottentottus* (Fabricius)
Diptera (larva 1)	indet.		
Diptera (larva 2)	indet.		

SAP SUCKERS			
Hemiptera	Pseudococcidae	*Delottococcus*	*Delottococcus* sp.
	Lygaidae	*Oxycarenus*	*O. maculatus* Stål
	Pentatomidae	*Antestia*	*A. astrosignata* Stål
ANTS			
Hymenoptera	Formicidae	*Technomyrmex*	*T. albipes* (F. Smith)
	Formicidae	*Linepithema*	*L. humile* (Mayr)
PARASITOIDS			
Hymenoptera	Eulophidae	*Pediobius*	*Pediobius* sp.
	Eulophidae	indet.	
	Eurytomidae	indet.	
	Braconidae	indet.	
THRIPS			
Thysanoptera	Phlaeothripidae	*Haplothips*	*H. bagnali* (Tryborn)
	Thripidae	*Synaptothrips*	*S. gezinae* (Faure)
SPIDERS			
Araneae	Clubionidae	*Clubiona*	*C. abbajensis* Strand
	Theridiidae	*Theridion*	*Theridion* sp.1
	Salticidae	*Heliophanus*	*H. debilis* Simon
	Thomisidae	*Synema*	*S. imitator* (Pavesi)
	Philodromidae	*Gephyrota*	*Gephyrota* sp.1
	Lycosidae	*Pardosa*	*Pardosa* sp.1
MITES			
Acarina	Ameroseiidae	*Ameroseius*	*Ameroseius* sp.
	Macrochelidae	*Macrocheles*	*Macrocheles* sp.
	Ascidae	*Proctolaelaps*	*P. vandenbergi* (Ryke)
	Acaroidea	indet.	
	Glycyphagidae	*Glycyphagus*	*Glycyphagus* sp.

Arthropods associated with the Susara (S) block (*P. magnifica* x P. *susannae*)

This block recorded lowest species richness (39 species) relative to the other blocks.

Free living and flower visitors: 15 free living and flower visiting species were recorded in the sprayed block of Susara, unlike in the unsprayed Susara block, only *Harmonia axyridis* and no *Hippodamia variegata* were recorded.

Endophagous species: In spite of spraying, this block remained the second most important for *O. ammopleura* and *Phyllocnistis* sp.

Sap suckers: Exactly the same sap sucking species associated with unsprayed Susara block were found in the sprayed block.

Ants: *T. albipes* was the only ant species present.

Parasitoids: Two eulophid parasitoids and *Anagyrus* sp. (Encyrtidae) were recorded.

Thrips: No thrips were recorded.

Spiders: Nine spider species were recorded.

Mites: Just like in the unsprayed block, *P. vandenbergi* was the only mite recorded.

Table 2.11. Arthropods associated with the Susara (S) block (*P. magnifica* x *P. susannae*) at Molteno Brothers Estate, Elgin, South Africa.

ORDER	FAMILY	GENUS	SPECIES
FLOWER VISITORS AND FREE LIVING			
Coleoptera	Staphylinidae	*Phloenomus*	*Phloenomus* sp.
	Rhizophagidae	*Phyconomus*	*P. tricolor* Woll.
	Staphylinidae (larva)	indet.	
	Melolonthidae	*Diaplochelus*	*D. longipes* (Fabricius)
	Chrysomelidae	*Chirodica*	*Chirodica* sp.1
	Nitidulidae	*Pria*	*P. cinerascens* Er.
	Nitidulidae	indet.	
	Histeridae	*Platysoma*	*P. capensis* Wied.
	Coccinellidae	*Harmonia*	*H. axyridis* (Pallas)
	Coccinellidae	*Rhyzobius*	*Rhyzobius* sp.
Diptera	Drosophilidae	*Drosophila*	*Drosophila* sp.
Hymenoptera	Apidae	*Apis*	*A. mellifera capensis* (Eschscholtz, 1822)
Psocoptera	indet.		
Collembola (class)	indet.		
Diplopoda (class)	indet.		
ENDOPHAGOUS			
Lepidoptera	Phyllocnistidae	*Phyllocnisitis*	*Phyllocnistis* sp.
	Oecophoridae	*Orophia*	*O. ammopleura* (Meyrick)
	Oecophoridae	indet.	
	Tortricidae	indet.	
Lepidoptera	indet.		
Diptera	Agromyzidae	indet.	
Diptera (larva 1)	indet.		
SAP SUCKERS			
Hemiptera	Pseudococcidae	*Delottococcus*	*Delottococcus* sp.
	Lygaidae	*Oxycarenus*	*O. maculatus* Stål
	Pentatomidae	*Antestia*	*A. astrosignata* Stål
ANTS			
Hymenoptera	Formicidae	*Technomyrmex*	*T. albipes* (F. Smith)
PARASITOIDS			
Hymenoptera	Encyrtidae	*Anagyrus*	*Anagyrus* sp.

	Eulophidae	*Pediobius*	*Pediobius* sp.
	Eulophidae	indet.	
SPIDERS			
Araneae	Clubionidae	*Clubiona*	*C. abbajensis* Strand
	Theridiidae	*Theridion*	*Theridion* sp.1
	Gnaphosidae	*Echemus*	*Echemus* sp.1
	Amaurobiidae	*Chresiona*	*Chresiona* sp.2
	Thomisidae	*Synema*	*S. imitator* (Pavesi)
	Araneidae	*Neoscona*	*N. subfusca* (C.L. Koch)
	Salticidae	*Baryphus*	*B. ahenus* Simon
	Salticidae	*Heliophanus*	*H. insperatus* (Wesolowska)
	Salticidae	*Thyene*	*Thyene* sp.1
MITES			
Acarina	Ascidae	*Proctolaelaps*	*P. vandenbergi* (Ryke)

Arthropods associated with the Safari sunset block (*L. salignum* x *L. laureolum*).

Even though the Safari sunset block had the lowest overall abundance (Figure 2.6), it recorded relatively high species richness (46 species) (Figure 2.7).

Free living and flower visitors: Fourteen free living and flower visiting species were recorded. *Formicomus coeruleus* (Anthicidae) was common to in this block.

Endophagous species

This is the only site where the leaf damaging *E. acerbella* was collected.

Sap suckers: *Macrosiphum euphorbiae* (Aphididae) and an uncertain aphid species, *Pemphigus* sp. were only recorded in the Safari sunset block. Moreover, *Delottococcus* sp. had a relatively high abundance after the *P. cynaroides* block.

Ectophagous species: A grasshopper *A. ruficornis* was collected at the site.

Ants: *T. albipes* was the only ant recorded.

Parasitoids: Three parasitoid wasps were collected at the site.

Thrips: Four thrips species were recorded in the Safari sunset block.

Spiders: Ten spider species were recorded at the site.

Mites: *Tyrophagus putrescentiae*, a mite usually associated with stored products (Ueckermann, E. pers. comm.) was only recorded in this block.

Table 2.12. Arthropods associated with the Safari sunset block (*L. salignum* x *L. laureolum*) at Molteno Brothers Estate, South Africa.

ORDER	FAMILY	GENUS	SPECIES
FLOWER VISITORS AND FREE LIVING SPECIES			
Coleoptera	Staphylinidae	*Phloenomus*	*Phloenomus* sp.
	Rhizophagidae	*Phyconomus*	*P. tricolor* Woll.
	Melolonthidae	*Diaplochelus*	*D. longipes* (Fabricius)
	Chrysomelidae	*Chirodica*	*Chirodica* sp.1
	Chrysomelidae	*Chirodica*	*Chirodica* sp.2
	Nitidulidae	*Pria*	*P. cinerascens* Er.
	Coccinelidae	*Hippodamia*	*H. variegata* (Goeze)
	Coccinelidae	*Harmonia*	*H. axyridis* (Pallas)
	Coccinelidae	*Rhyzobius*	*Rhyzobius* sp.
	Anthicidae	*Formicomus*	*F. coeruleus* Thunb.
Hymenoptera	Apidae	*Apis*	*A. mellifera capensis* (Eschscholtz, 1822)
	Bethylidae	indet.	
	Vespidae	*Polistes*	*Polistes* sp.
Isopoda	indet.	*Porcelia*	*Porcelia* sp.
ENDOPHAGOUS			
Lepidoptera	Phyllocnistidae	*Phyllocnistis*	*Phyllocnistis* sp.
	Tortricidae	*Epichoristodes*	*E. acerbella* (Walker)
	Tortricidae	indet.	
Coleoptera	Scarabaidae	*Genuchus*	*G. hottentottus* (Fabricius)
Diptera	Agromyzidae	indet.	
SAP SUCKERS			
Hemiptera	Pseudococcidae	*Delottococcus*	*Delottococcus* sp.
	Aphididae	*Macrosiphum*	*M. euphorbiae* (Thomas)
	Aphididae	*Pemphigus*	*Pemphigus* sp.
	Pentatomidae	*Orthoschizops*	*O. reticulata* Stål
	Anthocoridae	*Orius*	*Orius* sp.
ECTOPHAGOUS			
Orthoptera	Acrididae	*Acanthacris*	*A. ruficornis* (Fabricius)
ANTS			
Hymenoptera	Formicidae	*Technomyrmex*	*T. albipes* (F. Smith)

PARASITOIDS			
Hymenoptera	Encyrtidae	*Anagyrus*	*Anagyrus* sp.
	Braconidae	indet.	
	Platygastridae	indet.	
THRIPS			
Thysanoptera	Phlaeothripidae	*Haplothrips*	*H. bagnali* (Tryborn)
	Phlaeothripidae	*Haplothrips*	*H. avenae* Priesner
	Phlaeothripidae	indet.	
	Thripidae	*Synaptothrips*	*S. gezinae* (Faure)
SPIDERS			
Araneae	Clubionidae	*Clubiona*	*C. abbajensis* Strand
	Theridiidae	*Theridion*	*Theridion* sp.1
	Theridiidae	*Theridion*	*Theridion* sp.2
	Amaurobiidae	*Chresiona*	*Chresiona* sp.2
	Miturgidae	*Cheiracanthium*	*Cheiracanthium* sp.1
	Salticidae	*Baryphus*	*B. ahenus* Simon
	Salticidae	*Phlegra*	*P. bresnieri* (Lucas)
	Thomisidae	*Synema*	*S. imitator* (Pavesi)
	Thomisidae	*Holopelus*	*H. almiae* (Dippenaar-Schoeman)
Araneae	indet.		
MITES			
Acarina	Ameroseiidae	*Ameroseius*	*Ameroseius* sp.
	Acaridae	*Acarus*	*Acarus* cf *immobilis* (Griffiths)
	Acaridae	*Tyrophagus*	*T. putrescentiae* (Schrank)

Arthropods associated with the King protea block (*P. cynaroides*)

This was the most diverse of all blocks with 71 species, and with a high arthropod overall abundance (Figure 2.6).

Free living and flower visitors: 26 species were recorded including borer species adults, such as the eucalyptus longhorned borer *Phoracantha semipunctata* and *S. cupreosplendens* (Buprestidae) (Coetzee 1989, Wright 1990).

Endophagous species: A record number of 12 species were made in this block and *Capys alphaeus* was abundant. This was the only block where *Argyroploce* sp. and pyrallid borers (Pyrallidae) were recorded and did not have the leafminer, *Phyllocnistis* sp.

Sap suckers: Highest mealybug (*Delottococcus* sp.) abundance was recorded in the *P. cynaroides* block.

Ectophagous species: This was one of the only two blocks where the grasshopper *V. humeralis* was collected.

Ants: *T. albipes* highest abundance was recorded in the *P. cynaroides* block. In addition, five other ant species were recorded at the site.

Parasitoids: Three parasitoid species were collected at the site.

Thrips: Four thrips were recorded.

Spiders: Nine spider species were recorded at the site.

Mites: *Histiostoma feroniarum* was common in this block.

Table 2.13. Arthropods associated with the King protea block (*P. cynaroides*) at Molteno Brothers Estate, Elgin, South Africa.

ORDER	FAMILY	GENUS	SPECIES
FLOWER VISITORS AND FREE LIVING SPECIES			
Coleoptera	Staphylinidae	*Phloenomus*	*Phloenomus* sp.
	Rhizophagidae	*Phyconomus*	*P. tricolor* Woll.
	Staphylinidae (larva)	indet.	
	Melolonthidae	*Diaplochelus*	*D. longipes* (Fabricius)
	Chrysomelidae	*Chirodica*	*Chirodica* sp.1
	Histeridae	*Platysoma*	*P. capensis* Wied.
	Nitidulidae	*Pria*	*P. cinerascens* Er.
	Coccinelidae	*Hippodamia*	*H. variegata* (Goeze)
	Coccinelidae	*Harmonia*	*H. axyridis* (Pallas)
	Coccinelidae	*Rhyzobius*	*Rhyzobius* sp.
	Cryptophagidae	*Cryptophagus*	*C. milleri* Reitter
	Scarabaeidae	*Trichostetha*	*T. fascicularis* (Linnaeus)
	Buprestidae	*Sphenoptera*	*S. cupreosplendens* (Gory & Laporte)
	Elateridae	*Heteroderes*	*Heteroderes* sp.
	Curculionidae	*Sibinia*	*S. cervina* Fahraeus, OI in Schonherr, CJ
	Coccinelidae	*Rodolia*	*R. cardinalis* (Mulsant)
	Cerambycidae	*Phoracantha*	*P. semipunctata* (Fabricius)
Diptera	Drosophilidae	*Drosophila*	*Drosophila* sp.
Diptera	Sciaridae	indet.	
Hymenoptera	indet.		
Blattodea	Blaberidae	indet.	
Isopoda	indet.	*Porcelia*	*Porcelia* sp.
Collembola (class)	indet.		
Chilopoda (class)	indet.		
Diplopoda (class)	indet.		
Psocoptera	indet.		
ENDOPHAGOUS			
Lepidoptera	Lycaenidae	*Capys*	*C. alphaeus* (Cramer)
	Oecophoridae	*Orophia*	*O. ammopleura* (Meyrick)
	Oecophoridae	indet.	
	Tortricidae	indet.	
	Tortricidae	*Argyroploce*	*Argyroploce* sp.
	Pyrallidae	indet.	

Lepidoptera	indet.		
Coleoptera	Scarabaeidae	*Genuchus*	*G. hottentottus* (Fabricius)
	Carabidae	indet.	
Diptera	Agromyzidae	indet.	
Diptera	Cecidomyiidae	indet.	
Diptera (larva 2)	indet.		
SAP SUCKERS			
Hemiptera	Pseudococcidae	*Delottococcus*	*Delottococcus* sp.
	Lygaeidae	*Oxycarenus*	*O. maculatus* Stål
	Lygaidae	*Nysius*	*Nysius* sp.
	Rhopalidae	*Stictopleurus*	*Stictopleurus scutellaris* (Dallas)
	Pentatomidae	*Antestia*	*A. astrosignata* Stål
	Pentatomidae	*Orthoschizops*	*O. reticulata* Stål
	Psyllidae	indet.	
ECTOPHAGOUS			
Orthoptera	Acrididae	*Vitticatantops*	*V. humeralis* (Thunberg)
ANTS			
Hymenoptera	Formicidae	*Technomyrmex*	*T. albipes* (F. Smith)
		Monomorium	*Monomorium* sp.
		Meranoplus	*M. peringueyi* Emery
		Camponotus	*Camponotus* sp.1
		Camponotus	*Camponotus* sp.2
		Plagiolepis	*Plagiolepis* sp.1
PARASITOIDS			
Hymenoptera	Encyrtidae	*Anagyrus*	*Anagyrus* sp.
	Elasmidae	*Elasmus*	*Elasmus* sp.
	Eulophidae	indet.	
THRIPS			
Thysanoptera	Thripidae	*Synaptothrips*	*S. gezinae* (Faure)
	Phlaeothripidae	*Haplothrips*	*H. aveneae* Priesner
	Phlaeothripidae	*Haplothrips*	*H. bagnali* (Tryborn)
	Phlaeothripidae	indet.	
SPIDERS			
Araneae	Clubionidae	*Clubiona*	*C. abbajensis* Strand
	Gnaphosidae	*Xerophaeus*	*Xerophaeus* sp.1
	Gnaphosidae	*Echemus*	*Echemus* sp.1

	Thomisidae	*Synema*	*S. imitator* (Pavesi)
	Miturgidae	*Cheiracanthium*	*Cheiracanthium* sp.1
	Amaurobiidae	*Chresiona*	*Chresiona* sp.2
	Salticidae	*Phlegra*	*P. bresnieri* (Lucas)
	Salticidae	*Menemerus*	*Menemerus* sp.1
	Salticidae	*Heliophanus*	*H. debilis* Simon
MITES			
Acarina	Histiostommatidae	*Histiostoma*	*H. feroniarum* (Durfour)
	Ascidae	*Proctolaelaps*	*P. vandenbergi* (Ryke)
	Acaroidea	indet.	

2.3.3 Arthropods associated with other crops in South Africa

Approximately 93% of the arthropods recorded in this study are restricted to the protea family (Gess 1968, Myburgh *et al*. 1974, Annecke and Moran 1982, Coetzee and Giliomee 1985, 1987a, b, Coetzee *et al*. 1986, Coetzee 1989, Hattingh and Giliomee 1989, Wright and Giliomee 1990, Visser 1992, Wright and Giliomee 1992, Visser *et al*. 1996, Coetzee *et al*. 1997, Visser *et al*. 1999, Wright and Samways 1999, 2000, Fleming and Nicolson 2003, Roets *et al*. 2006). According to the literature available, *E. acerbella* was the only major arthropod pest found here in commercial Proteaceae, associated with other crops in the Western Cape Province, South Africa. *Epichoristodes acerbella* has been mainly reported in pear, apple and grapes in South Africa (Annecke and Moran 1982, De Villiers 2006, Timm *et al*. 2010). Eucalyptus longhorned borer, *P. semipunctata* (Annecke and Moran 1982), the aphids, *M. euphorbiae* a polyphagous but largely associated with potatoes and tomatoes (Srinivasan 2007) and *Pemphigus* sp. reported in pomegranates (Wohlfarter *et al*. 2010) were also recorded here. Less important arthropod pests of other crops included the flies, *Drosophila* sp. and an Agromyzidae (indet.) (parasitized the flower head), *L. humile*, *Nezara viridula* (Pentatomidae) (Annecke and Moran 1982, Wright and Saunderson 1995), *T. albipes* (Samways *et al*. 1982), *T. putrescentiae* (Acaridae) (Ramasodi 2008). Coccinellids well known to be associated with other crops, *H. variegata*, *Cheilomenes lunata* (Annecke and Moran 1982,) and *H. axyridis* (Stal and Prinsloo 2007) were also recorded in this study. All these species are of exotic origin, except *E. acerbella* with some of them being renowned invasive species.

2.3.4 Arthropods regarded as of economic importance to Proteaceae

Based on information mainly from grey literature sources, e.g. Wright (unpubl.), Wright *et al*. (1991), Lubbe (2006); published literature, Coetzee and Latsky (1986), Coetzee and Giliomee (1987), Myburgh (1990); E. Louw and M. Hyusamer (pers. comm.) and personal observations from the field and laboratory analysis (Appendix 4), the arthropods listed below (Table 2.14) can be regarded as major pests (important arthropods that causes damage and leaves the plant unmarketable) of cultivated Proteaceae in the Western Cape, South Africa. All of these species fell under the major (abundant) species of Proteaceae according to the rank-abundance curve (Figure 2.5).

Due to their high numbers and feeding behaviour (serious damage to the plant parts and renders them unmarketable) (Figure 2.11), *Phyllocnistis* sp., *C. alphaeus*, *O. ammopleura*, *Argyroploce* sp., *Delottococcus* sp. and *E. acerbella* (to a certain extent) can be regarded as the "most devastating" key pest species. Tortricidae (indet.), Lepidoptera (indet.), Oecophoridae (indet.), *G. hottentottus* and *Diaplochelus longipes* can be regarded as "less devastating" key pest species because of their minimal damage effect to the essential plant parts (yield product) compared to the "most devastating" pests.

2.3.5 Non-arthropod groups

Gastropoda (Order Stylommatophora) was the only non-arthropod invertebrate group recorded in this study.

Table 2.14. Arthropods regarded as major pests on South African Proteaceae.

Taxon	Guild	SH	SD	SY	W	S	S (S)	SF	KP
Lepidoptera									
Phyllocnistis sp.	LM	*	*	*	*	*	*	*	-
Capys alphaeus	EN	*	-	*	-	-	-	-	*
Orophia ammopleura	EN	*	*	*	-	*	*	-	*
Argyroploce sp.	EN	-	-	-	-	-	-	-	*
#*Epichoristodes acerbella*	EC	-	-	-	-	-	-	*	-
Oecophoridae (indet.)	EN	*	*	-	*	-	*	-	*
Tortricidae (indet.)	EN	-	*	-	*	*	*	*	*
Lepidoptera (indet.)	EN	*	*	*	*	*	*	-	*
Coleoptera									
Genuchus hottentottus	EN	-	*	-	*	*	-	*	*
Diaplochelus longipes	FV	*	*	*	*	*	*	*	*
Hemiptera									
Delottococcus sp.	SS	*	*	-	-	*	*	*	*
TOTAL		**6**	**6**	**4**	**4**	**6**	**5**	**5**	**7**

also a serious pest of other crops

LM - leaf miner, EN - endophagous, EC - ectophagous, FV - flower visitors, SS - sap sucker.

SH - Sheila, SD - Seedling, SY - Sylvia, W - "Wild", S - Susara, S (S) - sprayed Susara, SF - Safari sunset, KP - King protea

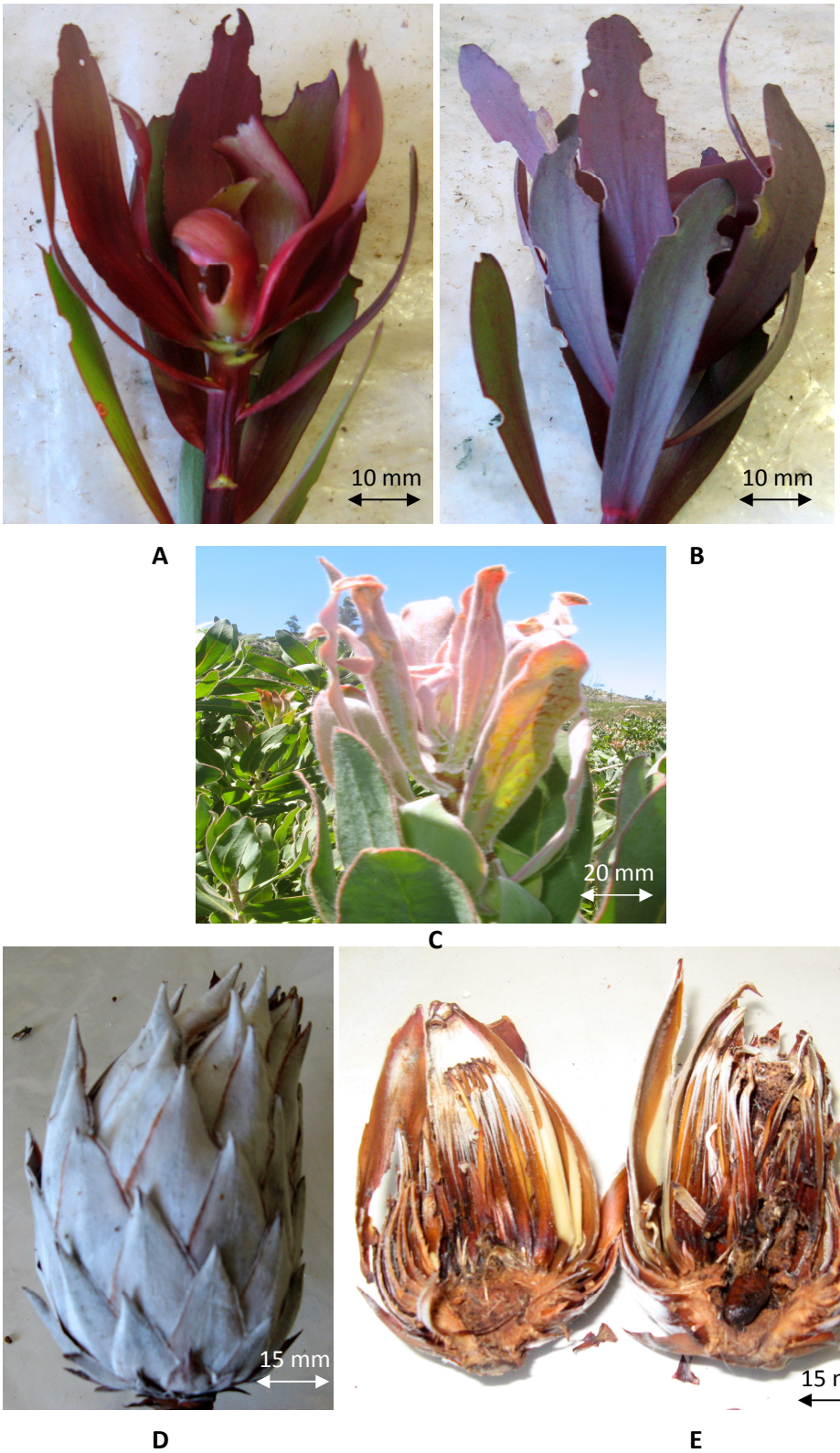

Figure 2.11. Arthropod damage on Proteaceae: A & B – *E. acerbella* damage on Safari sunset cultivar leaves, C – *Phyllocnistis* sp. damage on Susara cultivar new flush leaves, D & E – *C. alphaeus* damage on King protea species infructescence.

2.4 Discussion

2.4.1 Arthropod assemblages

Higher arthropod abundance was observed in this study compared to other studies on Proteaceae in South Africa, e.g. Myburgh *et al*. (1973), Wright (1990) and Roets *et al.* (2006), except for Coetzee (1989). This may support the hypothesis that monocultures promote high arthropod abundance, as there is very minimal energy lost on food search as it is readily available, and thus allowing the energy channeled into reproduction (Coetzee 1986). Nonetheless, these different arthropod numbers could also have been affected by sample sizes of the plant species and sampling methods used in these different studies.

As in all the other Proteaceae studies, insects were dominant. At order level, Coleoptera, Lepidoptera, Diptera, Hymenoptera and Hemiptera were the most abundant (Figure 2.3) and these made up a large number of the pestiferous species, except for Hymenoptera (Table 2.14). Generally, most of the species that were categorized as major species (Appendix 1) comprised most of the species that are regarded as the most destructive (Table 2.14). However, for species richness (Figure 2.4), some orders that were not abundant had high species richness and vice versa (Figure 2.3). For instance, Araneae and Hymenoptera (mostly parasitoids and ants) were not abundant but high in species richness. On the other hand, Lepidoptera and Hemiptera (mostly pestiferous species) were in low species richness but relatively high in abundance. Economic loss due to pests is primarily a function of population density (Flint and van den Bosch 1981).

This trend is likely to be explained by the fact that most of the pestiferous species are *r*-strategists, i.e. they concentrate most of their energy on reproduction, thereby increasing their numbers rapidly (Dent 1991). Looking at this from a predator-prey dynamics angle, it is most likely that this balance is caused by selection in nature. It is likely that predatory and parasitic

groups such as spiders (Araneae) and hymenopterans (with diverse species) stay at low numbers but in a position to regulate the pestiferous groups (e.g. hemipterans and lepidopterans) at equilibrium levels. Nature entails pestiferous species population regulation and not total elimination, hence the lower natural enemy abundances and high prey species abundances.

Only 30% of all the arthropod species fell under the major species with the rest being labeled as minor (rare) species. This suggests that about 70% of the arthropods that occur on Proteaceae appear occasionally (see Chapter 3). Moreover, it has often been observed that in samples from communities and in more complete censuses, most species are represented by a small number of individuals, while most individuals belong to a few abundant species (Gaston 1994). On issue of the species accumulation curve for the arthropod species from Proteaceae over the sampling period not approaching an asymptote, it shows that more sampling effort (more time for sampling) is required for more complete censuses of arthropods from Proteaceae. Since time for sampling might be a limiting factor, maybe estimates of arthropod diversity (e.g., Erwin`s estimate of arthropod diversity) may be used to approximate the overall arthropod species richness associated with Proteaceae.

2.4.2 Arthropod per Proteaceae blocks

Type of Proteaceae block (species/cultivar) was found to have a significant effect on both arthropod abundance and species richness. Significant differences were observed among the Proteaceae blocks for species abundances. However, for species richness there was a significant interaction between season and Proteaceae block (significant interaction results between Proteaceae block and season were presented and discussed in chapter 3: seasonal pattern of arthropod species in Proteaceae).

The Seedling block had the highest abundance of all the blocks and was significantly different from the other blocks, except the King protea block. This difference between the Seedling block and the other blocks is likely to be explained by the various *Protea* species and cultivars being grown together for breeding purposes. All the *Protea* species in the Seedling block tend to retain their seeds in the infructescences (Rebelo 1995). The flowers were not harvested or the foliage pruned as in most blocks, thus leaving more food and habitat sources for arthropods to exploit most of the time. According to Wallner (1987), size, growth form and variety of resources offered by host plants influences the arthropod numbers that feed on them.

Another factor that could have contributed to the higher abundance in the Seedling block was the nature of arthropod species that were mostly occupying that block. High ranking species (major species with very high abundance – Appendix 1) such as *Phloenomus* sp., *Phyconomus tricolor*, Staphylinidae larvae (saproxylic species) dominated in the Seedling block. This is most probably because they could utilize the old remnants of wooden material (Djupstrom *et al*. 2008). It is known that particular species of arthropods are associated with plants of a certain age or size (Lawton 1983).

The lack of a significant difference between the Seedling block and the King protea block might have been due to the nature of these two blocks. The Seedling block was made up of many different *Protea* species with complex structures (Rebelo 1995). On the other hand, King protea is a complex shrub with a height of about 1-2 m and bears very large flowers (120 mm-300 mm) which could further support many arthropods. The slight difference recorded might have been caused by the fact that King protea inflorescences/infructescences

could not support high ranking species (most abundant major species) and saproxylic beetle species (e.g. *Phloenomus* sp., *P. tricolor*) that were supported in the Seedling block.

Even though the Seedling block recorded the highest abundance (Figure 2.6), the King protea block recorded highest species richness (Figure 2.7). The high species richness in the King protea block might mean high interspecific competition among species and thereby regulating each other`s populations. Furthermore, the King protea block had many more natural enemies than the Seedling block (see Chapter 4). The high presence of natural enemies in the King protea block might also help explain the relatively lower abundances compared to the Seedling block. The natural enemies might have helped in maintaining low herbivore abundances. Natural enemies are more important in complex, perennial systems as they tend to maintain equilibrium population size of many phytophagous arthropods (Royama 1984, Wallner 1987).

According to Lawton`s (1983) hypothesis, plant/habitat complexity determines species diversity. More complex plants/habitats will yield higher species diversity. From this hypothesis we expected to see higher species richness in the Seedling block (with diverse plants) than in the King protea block (monoculture). A clear explanation for this trend however could not be found. Probably the fact that King protea flower all year round, unlike most protea species/cultivars in the Seedling block which flower mostly in the autumn-spring period (Rebelo 1995) might have played a role. Food availability throughout the year might have made the King protea block more stable and become highly favored by many arthropod species.

Least abundance was recorded in the Safari sunset block which was significantly different from the Seedling, Susara and King protea blocks. This further gives a suggestion that the

structure/growth form of plants is likely to be the factor that affected the species abundances among the sampling blocks (Wallner 1987). Safari sunset is structurally simple with rigorous erect growth, small leaves and small inflorescences relative to other Proteaceae species/cultivars (Matthews 2002). This simple structure possibly cannot sustain a large number of arthropod species as few habitats are available to support large numbers of arthropods. The large presence of spiders (general predators) in the Safari sunset block (Figures 2.9, 2.10 and Table 2.12) might also have an influence in reducing overall arthropod abundance in that block.

As in the Seedling block, there was no flower harvesting or foliage pruning in the "Wild" block with arthropods having relatively lower (intermediate) abundance and richness. It was expected that the "Wild" block would record the highest species richness and abundance since there was a high diversity of plants (more niches) that can be utilized by the arthropods. According to Lawton (1983) and results from Adeduntan *et al.* (2007), higher plant species diversity in the study site, is expected to yield a higher arthropod species diversity. Moreover, there were no control measures (e.g. pesticides application) that could disrupt arthropod population growth. However, this was not the case, as some cultivated Proteaceae blocks had high species richness and abundances (e.g. King protea), with some others not significantly different from the "Wild" block.

A number of factors must have affected the numbers of arthropods recorded in the "Wild" protea block. Factors like use of fertilizing components (Rustamani *et al.* 1999, Altieri and Nicolls 2003) and cultivars in the commercial fields might attract more arthropods than in the "Wild" block. Coetzee (1986), found that varying flowering times using cultivars may affect arthropod presence or absence. For example, *P. repens* cultivar Guerna, which flowers in

summer was found to be attacked by the larvae of the protea butterfly *C. alphaeus*, which is not a problem on winter flowering *P. repens*. Also, factors such as fire, as in the case here seem to play a vital role in regulating species present in the "Wild" Proteaceae by directly eliminating some of the arthropods or through the destruction of some plant structures which can be utilized by arthropods, for example, seed heads (Swengel 2001).

Furthermore, the majority of protea species in the "Wild" block are structurally simple (Table 2.3) and cannot support many arthropod species (Lawton 1983). This is in comparison with the other protea species/cultivars making up the other blocks, e.g. the Seedling block (Table 2.2). In addition, other blocks such as the Seedling block had a high plant density (which could further support many arthropods) compared to the "Wild" block which had spaced plants.

Overall, the "Wild" block had a stable (balanced/intermediate) pattern of arthropod levels (i.e. species richness and abundance) compared to other blocks and recorded only a few species (all minor species) which were not present on any other site (Table 2.9). The arthropod species recorded from the commercial Proteaceae blocks but absent from the "Wild" block were 87 species (61.27% of the total species recorded in this study) (Tables 2.6-2.13). Interestingly, five out of the listed nine key pest species (major species) of Proteaceae were not recorded in the "Wild" block (Tables 2.9 and 2.14). The diversity-stability hypothesis (Andow 1991) might best explain these patterns of arthropod levels in the "Wild" block. The "Wild" block was supported by a high diverse of plant species.

Stability hypothesis states that the greater is the biological diversity of a community, the greater is the stability of that community. The natural enemies, which prefer stable communities, maintain the arthropod species populations at equilibrium (Royama 1984).

However, this did not apply on the Seedling block which was composed of several cultivated protea species/cultivars. The likely reason being that of high plant density of cultivated proteas in the Seedling block provided ready and plenty food sources which could support many pestiferous species (*r*-strategists). According to Coetzee (1986), in cultivated fields, less energy is spent on food searches (as it is readily available) resulting in the rest of the energy being exerted on reproduction.

The absence of 87 arthropod species, including five of the key pest species from the "Wild" block but present in the cultivated blocks should be an effect of agriculture. According to Whitehouse (2005), monocultures are considered beneficial for pestiferous and some other species which require such disturbed conditions/habitats which simulate early successional habitats.

We cannot however rule out the effect of fire in the "Wild" block as this might have played a major role in eliminating some of the species. Swengel (2001) reported that many arthropods (insects) groups decline markedly immediately after a fire. She went further stating that niche diversity is lower in recently burned habitat. Ferrenberg *et al*. (2006) reported that fire decreases arthropod abundance but increases diversity. This could have promoted the intermediate species richness in this block, while intermediate species abundance was promoted by the ability of the species to regain access to the regrowing vegetation (Swengel 2001).

However, compared with the previous arthropod-Proteaceae studies conducted in the Western Cape, 33 new species have been recorded in this study. These arthropod species are likely to have been introduced through agriculture. For example, through the use of new cultivars and/or large monocultures (Coetzee 1986), and the use of fertilizers, which makes the plants

more attractive to pests (Rustamani *et al*. 1999). Also, since fynbos arthropod identifications are generally poor (Coetzee 1989, Roets *et al*. 2006) some of the newly recorded species might have been present all along but could not be identified. Generally, it looks like most fynbos arthropods are not yet recorded and described. Only about 37% of the species recorded in this study were identified to species level, 36% to genus, 19% to family level, with 4% and 1% only to order and class level respectively, despite expert opinions from taxonomists.

Of major concern was the presence of the Asian multicolored ladybird beetle *H. axyridis* in the "Wild" block. This coccinellid have been recorded in agroecosystems in the Western Cape, South Africa (e.g. Stal and Prinsloo 2007). It is likely that this coccinellid was introduced from the agroecosystems into the fynbos patches. According to Cottrell and Yeargan (1998), Cottrell (2005) and Stal and Prinsloo (2007) this coccinellid is highly invasive, very dispersive, polyphagous and capable of displacing the native coccinellid species. The presence of this ladybird beetle in fynbos vegetation may pose an ecological risk as it may outcompete and displace the native species. However, with the evident contamination of the remnant fynbos vegetation (the presence of *P. eximia* and *L. patersonii*), it is highly likely that arthropod species known to be confined to agricultural fields get introduced into the semi-natural and natural fynbos.

However, the lowest species recordings in the Sylvia and Susara (S) blocks, especially for species richness are likely attributed to pesticide sprays applied to these blocks. Since species abundances in the sprayed blocks were relatively higher compared to other blocks (Figure 2.6), there is a possibility that the pesticides were affecting certain species (probably rare

species which lack prior exposure to pesticides) as the species richness was lowest in these blocks (Figure 2.7).

2.4.3 Arthropod specificity in Proteaceae and similarities among the blocks

It has been shown in terms of abundance and species richness that arthropod distributions vary among the Proteaceae blocks. The trend for species abundance was Safari sunset < Sheila < "Wild" < Sylvia <Susara (S) < Susara < King protea < Seedling (Figure 2.6), and Susara (S) < Sylvia < Sheila < Safari sunset < "Wild" < Susara < Seedling < King protea for species richness (Figure 2.7). Proteaceae block was a determinant of the species distribution patterns, with more structurally complex plants/blocks inhabiting more arthropod species.

Per Proteaceae block, Sheila, Susara, Susara (S), Sylvia, and to a certain extent Safari sunset, had many species in common. King protea was linked with a high number of arthropod species which were scarce in other Proteaceae blocks (e.g. *H. feroniarum*, *T. albipes*, *Camponotus* sp.) (Figure 2.8 and Tables 2.6 - 2.13). Even most key pest species such as *C. alphaeus*, *D. longipes*, *Delottococcus* sp., Tortricidae (indet.), Lepidoptera (indet.) (Figure 2.8 and Table 2.14) were more common in King protea than in other blocks. The only key pest species which was exclusive to the King protea block was *Argyroploce* sp. (Table 2.14). *O. ammopleura* was linked to the Susara, Susara (S) and Sheila blocks, while *Phyllocnistis* sp. was widespread in the Susara, Susara (S) and Sylvia blocks. *Epichoristodes acerbella* was exclusive to the Safari sunset block with *G. hottentottus* more linked to the "Wild" block (Figure 2.8).

More species in the King protea might have been driven by the plant complexity (Lawton 1983) and perhaps also as the plants flower all year round (Matthews 2002), i.e. food available all year. More complex plants provide more microhabitats that can be utilized by

various arthropod species (Lawton 1983). Surprisingly, no key pest species were specific to the Seedling and "Wild" blocks, except for *G. hottentottus* in the "Wild" block. Since *G. hottentottus* is a seed eater (Coetzee and Giliomee 1987b), it might have been utilizing plenty seed heads retained in the wild. The confinement of key pests in the commercial fields might have been triggered by the effect of monocultures, which are not biodiversity stable. As mentioned earlier, pest species often require disturbed conditions which simulate early successional habitats (Whitehouse 2005).

The criteria for plant host selection by the arthropods are unknown and according to Novotny *et al*. (2002), host specificity is difficult to measure. According to Jermy (1984) plant host selection by arthropods is believed to be a behavioral process, and the emergence of specific arthropod-host plant relationships probably results from evolutionary change in the arthropod`s chemosensory system. Generally, most of the major species seemed to be generalist species as they were found in many Proteaceae blocks, although they could also be highly abundant in one or a few blocks. For example, *Phloenomus* sp., *Chirodica* sp.1, *P. tricolor*, *Pria cinerascens* were present in all the Proteaceae blocks but abundant in particular blocks. This corresponds with the study of Novotny *et al*. (2002) which showed that most herbivores feed on several closely related congeneric plant species. Rare (minor) species were only recorded from few Proteaceae species/cultivars. For example, *Acarus* cf *immobilis*, *Pheidole* sp., *T. putrescentiae* (Acaridae) were exclusive to certain Proteaceae species/cultivars. It is likely that rare species appeared on Proteaceae species/cultivars that provided distinct ecological niches for these species.

Predator and parasitoid species tended to favor those blocks which had more of their prey species. For example, coccinellid species *H. variegata* and *H. axyridis* were more in the

Safari sunset and King protea blocks where mealybugs, *Delottococcus* sp. were abundant. The parasitoids *Pediobius* sp. (Eulophidae) and Braconidae (indet.) were closely associated with the blocks where their hosts, *Phyllocnistis* sp. and *O. ammopleura*, occurred. Spiders were widely distributed in the Proteaceae blocks, even though they were slightly higher in the *Leucadendron* cultivar, the Safari sunset block (this corresponds with Coetzee *et al*. 1990).

Susara and Sheila cultivars shared the same parent *P. magnifica*, while Susara and Sylvia shared the same parent *P. susannae*, and these were found to have more arthropod species in common. This might lead to suggestions that breeding without targeting plant resistance may not affect arthropod pest attack. It will be best to include a pest resistance perspective when breeding for other traits as this will aid in pest control. For instance, it is not economical to breed and come up with a quality flower but highly affected by pests. Even if the flower has a high market value, considerable resources will need to be spent on pest control.

2.4.4 Guild structures

The high ranking (major species) coleopteran species (which were mainly visiting the flowers for nectar) (Appendix 1) contributed significantly to the free-living/flower visitors' guild and was dominant in the Seedling block because of a wide range of habitats in this block where no pruning or harvesting (more flowers) was done. The lowest free living/flower visitor abundance was recorded in the Safari sunset block, most probably because of its simple structure, which offers few resources (food and refugia) which can be utilized by the arthropods.

Endophagous species abundance was not very different among all the blocks, except in the Safari sunset block, where lowest numbers were recorded. The thin stems, simple heads and leaves apparently could not support a number of endophagous species (borers and leaf

miners). Despite simple structure, relatively highest sap sucker numbers were recorded on the Safari sunset cultivar. The reason for this is unknown. However, Matthews (2002) recorded that *Leucandendron* species are sweet and likely to draw large numbers of sap sucking species. The absence of sap sucking species on the Sylvia block is probably due to the effect of sprays and/or effect of diverse number of coccinellids in this block (Table 2.8). The low numbers recorded on the Susara (S) block, even though it was sprayed, just as on the Sylvia block, might have been a result of the fairly complex head of Susara, compared to Sylvia. Susara head is relatively bigger and offers more habitats for the bugs to hide from the sprays compared to that of Sylvia. Moreover, involucral bracts of Susara have sericeous hairy cover which according to Leandro *et al*. (2006) makes them difficult to wet, and are also tightly closed.

High species richness (even for pestiferous groups including mealybugs) in the King protea block might have attracted far more ants and parasitoids, while this was the opposite in the Safari sunset block where ants were absent and parasitoids had lowest numbers. The ants and parasitoids guilds (usually associated with sap suckers, e.g. mealybugs (Brown and Schmitt 2001, Daane *et al*. 2007, Mgocheki and Addison 2010,)) in the Safari sunset block most probably was affected by the high levels of predators, e.g. spiders (inter-guild competition) (see Figures 2.9 and 2.10). Spider species abundances and richness were relatively higher in the Safari sunset block than in any other block, an observation which was also made by Coetzee *et al*. (1990). Hajer and Hruba (2007) reported mealybugs being attacked by spiders to the extent that these authors suggested use of spiders as biological control agents of mealybugs. Moreover, unlike in Safari sunset, in the King protea block the mealybugs grow below the tightly closed flower bud bracts becoming inaccessible to most general predators, except for small sized parasites (Leandro *et al*. 2006). The accompanying high numbers of

ants might have been tending the mealybugs for honeydew. As in other cases, Susara (S) had the lowest number of spider species, most probably because of pesticide sprays. Generally, feeding guilds species richness trends were similar to those of abundances.

Spiders were more diverse relative to other guilds and showed a preference for inhabiting the foliage rather than any other structure. However, each species had relatively low abundance, except for *Clubiona abbajensis* (Clubionidae), which was one of the few spiders to fall under the major species category. When in high abundance, spider species occurred across all the Proteaceae blocks, i.e. typical generalist.

Mites and thrips were the least abundant of all the guilds both in terms of species abundances or species richness and were absent in the pesticides treated Sylvia and Susara (S) blocks respectively (*P. vandenbergi* abundance was excluded because it was too numerous to count individuals). No literature was found on pesticides and/or pesticides resistance on the specific members of the mite and thrips groups recorded in this study. Probably their absence in these sprayed blocks is a direct effect of pesticides. Surprisingly, no mites were recorded in the "Wild" block. This and the absence of mites and thrips from the Sylvia and Susara (S) blocks respectively most probably reflects that the sampling techniques used in this study were not appropriate for these guilds (with tiny specimens) or more sampling effort was required. It might also be the case that the sampling techniques were not applied at the right time. For example, adults of *Diacritus aciculatus* (Ichneumonidae) were regarded as exceedingly rare, until sampling was carried out during the narrow window of 10 days or so in the UK early summer when they were caught in large numbers (Gaston 1994).

Interestingly, both the thrips and mite guilds recorded probably new species to South Africa, i.e. *Bactothrips* sp. and a diplogyniidean (Diplogyniidea indet.) mite species respectively. The

database of thrips in South Africa provides a detailed list of species that are significant pests on other crops, and the identified from Proteaceae might become quarantine species, even though their effect on flowers has not yet been identified (M. Stiller pers. com.).

Strictly ectophagous arthropod species were scarce in Proteaceae except for the two grasshopper species, *V. humeralis* and *A. ruficornis*, which were found in the Seedling, Safari sunset, and King protea blocks. Moreover, damage on the leaves was at minimal. This result is likely to have been caused by anti-herbivory mechanisms expressed by the Proteaceae plant leaves, i.e. high tannin and phenolic compounds as well as the presence of trichomes on the young leaves (Coetzee 1989, Wright and Giliomee 1992, Coetzee *et al*. 1997).

One of the reasons of the absence of other well known arthropods associated with other surrounding crops might have been that of poor nutritional content of Proteaceae (Wright and Giliomee 1992). The other arthropods from the surrounding crops might also have been hindered by the defense mechanisms of Proteaceae. For example, herbivorous species are known to be affected by trichomes on young leaves of proteas (Wright and Giliomee 1992, Coetzee *et al*. 1997).

Epichoristodes acerbella (carnation worm) was the only devastating arthropod known to affect other commercial plants (apples and pears) grown in the Western Cape Province, South Africa (Annecke and Moran 1982, De Villiers 2006). Carnation worm might have been using Proteaceae as alternate hosts when apple and pear orchards shed their leaves. This kind of behaviour has also been reported in Portugal where the corn stalk borer *Sesamia nonagrioides* has been using Proteaceae as alternate hosts when its primary host, maize was out of season (Leandro *et al*. 2006). *Delottococcus confusus*, recorded in Portugal (Leandro *et al*. 2006), is believed to be of southern African origin (Mazzeo *et al*. 2009). Wright and

Saunderson (1995) suspected that *E. acerbella* and *Argyroploce* sp. were also affecting Proteaceae in Zimbabwe, although this has not been confirmed. These cases reflect the potential of South African arthropod pests to spread to other Proteaceae growing regions.

Most species (≈ 70%) fell under the rare species bracket in this study. According to Gaston (1994), this might be a result that a species is out of its range or extent of occurrence. In other words, a "rare" species might be abundant somewhere else, and it could just be affected by factors such as weather, competition and predation in areas where it is least abundant. In short, some of the species recorded as rare in this study might be abundant somewhere else. Given a chance they might be important pests of Proteaceae in those regions. This might also help explain why proteas being grown in non-traditional Proteaceae growing regions is being affected by many "new" arthropod species. For example, when Proteaceae was introduced in Portugal, a number of "new" arthropod species became important pests (Leandro *et al*. 2003).

Like has been mentioned earlier, there is also the case of renowned invasive species recorded in Proteaceae, *H. axyridis* in seven out of the eight sampled blocks, including the "Wild" block and *L. humile* on the Susara block. These species may destabilize the natural enemy-prey balance in Proteaceae. *L. humile* has been reported to disrupt parasitoid wasps in the biocontrol of mealybugs (Daane *et al*. 2007, Mgocheki and Addison 2009), while *H. axyridis* has been reported to negatively affect native species (Michaud 2002, Cottrell 2005). Looking at the Susara block where *L. humile* was recorded, very few ant species were recorded in that block, unlike in blocks where it was absent. The presence of *H. axyridis* in the "Wild" block shows the capability of this species to establish in fynbos.

2.5 Conclusion

There is a diverse set of arthropod species associated with Proteaceae in the Western Cape Province, but clearly our taxonomic knowledge is severely limited. It is mainly their feeding habits and abundance which are of importance to commercial Proteaceae farmers. Lepidoptera contains most of the major Proteaceae pest species. However, most of the arthropod species are rare, i.e. appear in low abundance. The major pest species make up a small proportion of the overall arthropod species richness but nevertheless contribute the most to species abundance.

Agroecosystems are considered areas with depauperate biodiversity (Myers 1988), but from this study we can see that a wide variety of arthropod species was recorded in this agricultural system. Moreover, the majority of the arthropod species recorded in this study are restricted to the protea family. The fact that these plants are grown in their natural habitat might have caused this high diversity and abundance. Even though adverse for Proteaceae farming in the Western Cape Province, these fields are playing a role in biodiversity conservation in the fynbos.

The particular Proteaceae species/cultivar had an effect on arthropod species abundance and richness. Structurally complex Proteaceae species/cultivars and blocks appeared to lead to high levels of arthropod species richness and abundance. However, in the "Wild" protea block, even though there were diverse genera and complex Proteaceae plants species, relatively lower (intermediate) arthropod levels were recorded, showing us that in the natural or semi-natural environment there are processes which occur that regulate arthropod population sizes and composition, e.g. occasional fire outbreaks.

Proteaceae cultivars that shared a parent species were very similar in the arthropods associated with them. Also, there is some degree of specificity in arthropods associated with Proteaceae species/cultivars, especially minor species. However, few species of strictly ectophagous were recorded. This likely explains the little leaf damage that was observed in Proteaceae species/cultivars. Leaf mining species were found to severely damage leaves and young stems.

2.6 Recommendations

There is a need for more detailed studies of arthropods on Proteaceae and fynbos as a whole to facilitate the identification and investigations of ecology of many poorly known species. There is also a need to develop strict monitoring on all exported Proteaceae material from South Africa, to reduce the spread of pests to other regions.

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Chapter 3

Seasonal pattern of absence and presence of arthropod species associated with Proteaceae and the biology of key pests

Abstract

Arthropods were collected from commercial (seven blocks) and a block of wild Proteaceae at Molteno Brothers Estate (Western Cape Province) twice every season (spring, summer, autumn, winter) for one year. Inflorescences, infructescences and foliage of different seasons were sampled for arthropods, and an intense search for eggs and other developmental stages was conducted using both active searching and collection. Season had no significant effect on arthropod abundance. However, there was a significant interaction between season and Proteaceae species/cultivar on species richness. Adult specimens dominated throughout the whole year, except in January (dry and hot), where pupae dominated. Flower visiting/free living arthropods were the most abundant and speciose guild throughout the year, likely the result of abundant nectar resources on the flowering plants. Most of the key pest species were recorded throughout the year (suggesting that they are multivoltine), except for the tortricid, *Epichoristodes acerbella* which was only recorded once in June. There were very slight differences on pest species occurring at different sampling periods. However, relatively higher pest species richness was recorded during winter (June-July). *r*-pest species (e.g. *Phyllocnistis* sp., *Delottococcus* sp.) were more abundant than the K-pests (e.g. *Capys alphaeus*, *Orophia ammopleura*), which were mostly in larval form. Plant architecture and phenology might have had an important effect on the arthropod assemblages, especially the flowering time. The general life cycles of the key protea pests are presented here.

3.1 Introduction

A number of arthropod studies have been carried out in Proteaceae in South Africa, including arthropod surveys, destructive effects of arthropods on different Proteaceae species, and on topics related to pest control (e.g. Gess 1968, Myburgh *et al*. 1973, Myburgh and Rust 1975, Coetzee and Latsky 1986, Coetzee 1989, Wright 1990, 1995, Roets *et al*. 2006). From this, a firm foundation has been laid for arthropod studies on proteas in South Africa. Also, these studies reveal that the Proteaceae is associated with a number of arthropods ranging from flower visitors, borers, leafminers, leaf chewers and a suite of predators and parasitoids. The major reason why Proteaceae species are associated with such a diverse array and usually abundant arthropods is that they are grown in their natural environment. According to Coetzee (1986), a plant which is grown in its natural environment is expected to be affected by a diverse array of arthropods since the arthropods have had much time to adapt to their host plants (evolutionary time). He further added that the natural vegetation surrounding the commercial fields remains a source of reinfestation.

The diverse array of arthropods associated with Proteaceae has been one of the major challenges facing the Proteaceae industry in South Africa (Coetzee 1986, Wright and Saunderson 1995). It is mainly the feeding of these arthropods that causes problems in commercial Proteaceae, but they can also cause phytosanitary issues. Borers can destroy inflorescences, as well as infructescences, with leafminers and leaf chewers affecting the leaves (Myburgh and Rust 1975, Wright and Giliomee 1992). This feeding reduces the yield and quality of the flowers, while no arthropods must be present on export flowers (according to the requirements set by the importing countries, e.g. most western European countries and U.S.A) (Coetzee 1986).

Research has assessed the destruction caused by certain species and possible control measures (e.g. Wright unpubl.). A number of control strategies have been proposed, with many yielding unsuccessful results. Coetzee (1986) and Wright (1995) proposed the implementation of an integrated pest management (IPM) programme to control the wide spectrum of pests associated with commercial Proteaceae. Surprisingly nothing has been done to date. Coetzee (1986) urged that without an efficient pest control programme, proteas cannot be cultivated successfully in their natural habitat. IPM includes use of biological, cultural and chemical control (with the pesticides playing a subordinate role). To put in place such a programme, there is need of thorough knowledge of the biology and ecology of the different pests involved.

Surprisingly, there has been little research on the aspects of seasonal distribution and arthropod biology of key pests on Proteaceae. Only Coetzee (1989), Wright and Giliomee (1990) and Roets *et al*. (2006) touched on seasonal distribution of arthropods in Proteaceae. These data play a vital role in determining the general pattern of arthropods in Proteaceae, but have their own limitations. For instance, all these data have been collected from wild Proteaceae. Yet, with the growing of Proteaceae in the commercial fields involving use of new cultivars, some patterns may change. For example, the selection of new cultivars can result in changes in the flowering period. This can have adverse effects on certain arthropods which attack the flowers. Coetzee (1986) presented the case of *Capys alphaeus* which infests on *Protea repens*, and where the larva is not a problem in winter on flowering plants, but a major problem in summer on flowers of *P. repens* cultivar, Guerna. It is because of such patterns that there is the need for further and thorough research on the aspects of arthropod seasonal distribution and biology in commercial Proteaceae.

Information on seasonal occurrence of pests is needed for planning the initiation of monitoring, and for determining when damage can be expected. Monitoring is one of the important tools of IPM (Dent 1991, De Villiers 2006) as it determines when to implement control action on the pest species. Monitoring leads to timely decision-making, i.e. before the pests have caused significant damage (economic damage) to the crops. Knowledge of the biology and ecology of the pests provides information such as which life stages to control, and which plant parts to target. For example, in the Hex River Valley (South Africa) vineyards, it is known that *Epichoristodes acerbella* moth substantially increases from May, remaining high in June, until August (Blomefield and Du Plessis 2000). With this information, the farmers know that soon thereafter there will be an increase in the damaging larval populations of *E. acerbella* (De Villiers 2006) and hence they can prepare to take action.

It is this kind of information which is lacking and needed in commercial Proteaceae to facilitate pest control programmes. Hence, in this chapter, attention will be given to arthropod species population dynamics throughout the year in the fields, and to aspects of the biology of key pest species in commercial Proteaceae in the Western Cape, South Africa.

3.1.1 Objective

- To determine the seasonal distribution of the arthropods in Proteaceae and to understand the biology of key arthropod pest species to facilitate the development of improved control measures.

In this study, protea (common collective name for all Proteaceae) refers to Proteaceae, while *Protea* refers to members of the genus *Protea*. “Wild” block refers to remnant fynbos vegetation surrounding the cultivated protea fields.

3.2 Materials and methods

3.2.1 Study area and study period

Arthropods were collected from mainly commercial and a block of "Wild" protea at Molteno Brothers Estate (34° 08 S, 19° 02 E), Elgin, Western Cape Province, South Africa (Figure 3.1). Arthropod sampling was conducted twice every season (spring, summer, autumn, winter) from September 2007 to July 2008. In this study, the months September and October were considered as spring; December and January, summer; March and April, autumn with June and July as winter.

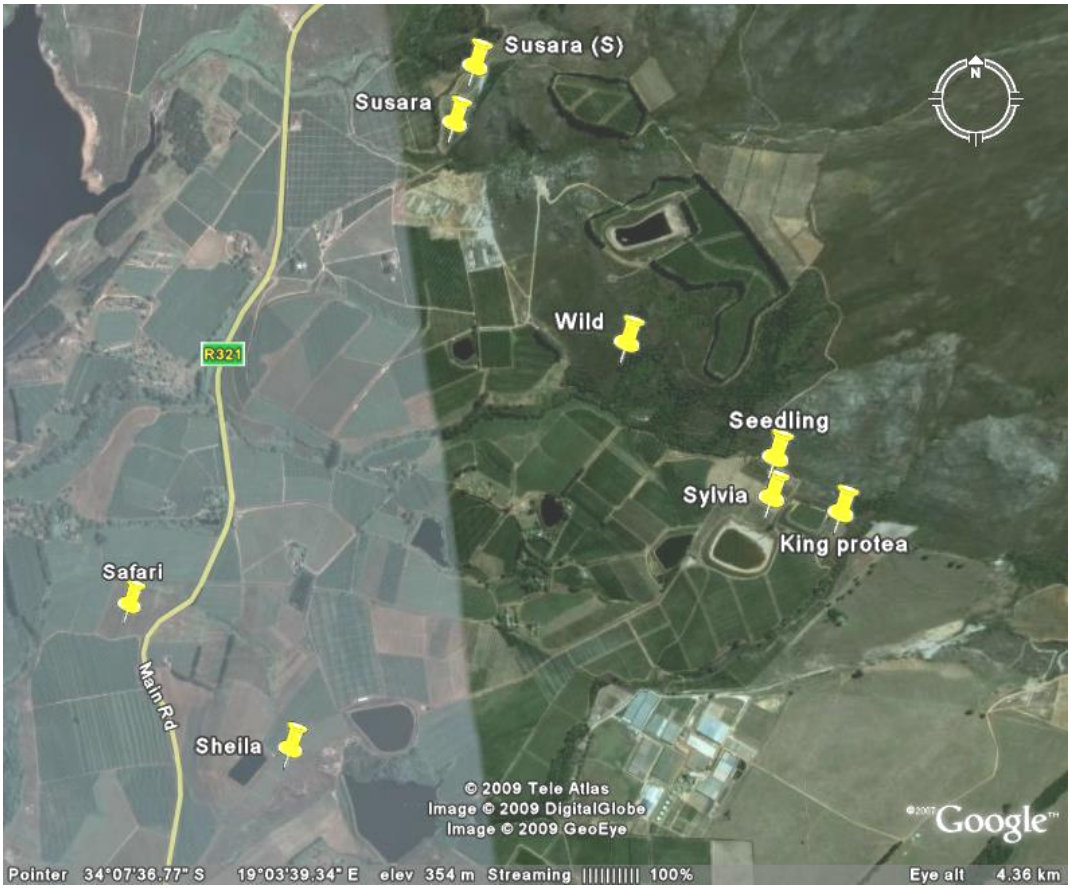


Figure 3.1. Distribution of the Proteaceae sampling blocks at Molteno Brothers Estate, Elgin, Western Cape Province, South Africa.

3.2.2 Study plants

The sampling blocks were designated as Sheila, Seedling, Sylvia, "Wild", Susara, Susara (S), Safari sunset and King protea. Sheila is a low shrub Proteaceae cultivar derived from *Protea magnifica* x *P. burchellii* with an average height of about 1 m and 0.5 m in diameter. The Seedling block is designed for breeding purposes and composed of different Proteaceae species (*P. neriifolia*, *P. eximia*, *P. lacticolor*, *P. repens* and *P. susannae*) and cultivars (*P. neriifolia* x *P. laurifolia*, *P. mundii* x *P. aurea*). Sylvia (*P. eximia* x *P. susannae*) is a low water tolerant Proteaceae cultivar with an upright growth of 1.8 – 2.4 m, 1 – 1.5 m in width and produce pink flowers mainly in November – February (summer). The "Wild" block was made up of different Proteaceae species (*P. eximia*, *P. neriifolia*, *Leucadendron tinctum*, *L. laureolum*, *L. conocarpodendron* and *L. patersonii*) growing in the remnant vegetation of fynbos on the north eastern side of the estate.

Susara is an architecturally complex Proteaceae cultivar derived from *P. magnifica* x *P. susannae* which usually flowers from January to May (summer-autumn), and can reach as high as 3 m. Susara (S) was the Susara block that was treated with pesticides throughout the sampling period (almost on a monthly basis). Safari sunset was a *Leucadendron* cultivar block (*L. salignum* x *L. laureolum*). It is a vigorous tall and erect grower with an average height of about 2.5 m, and a diameter of about 1.5 m, with red and yellow simple structured flowers, which mainly occur from summer to autumn. King protea (*P. cynaroides*) was the only Proteaceae species grown for direct cut flower harvesting in this study (about 80 naturally occurring variants of this species have been recorded). King protea is generally a broad, bushy shrub with an average height of 1 - 2 m and a diameter of 1.3 m and flowers from autumn-spring, however, with some scattered bloom throughout the year. It produces

large pink flower heads measuring about 120 - 300 mm in diameter. *P. cynaroides* also seems to benefit from summer moisture and is adaptable to very sunny conditions (Matthews 2002).

3.2.3 Arthropod collection methods and identification

Each focal site (Proteaceae block) was sub-divided into four quadrants. Within each quadrant, twelve protea plants were selected at random in a way that covers the full expanse of the quadrant. The sampled plants were separated by at least 5 m distance. Care was taken not to sample the same plant during successive sampling periods. To ensure this, the sampled plant was marked with small red colored tag on the stem.

Three of each of inflorescences, infructescences and small branch stems (<15 cm) were sampled from the selected plants in the quadrants for arthropods. These plant parts were cut using pruning shears and placed in transparent polythene plastic bags (240 mm x 330 mm), and then dissected in the laboratory to procure all the arthropods inhabiting them. The plant parts of different seasons were sampled. However, inflorescences and infructescences samples depended on availability, otherwise when absent, they were replaced by stems. Intense searches for eggs and other developmental stages were carried out and quantified.

Active collection and active searching (spot check) were the sampling methods employed. Active collection employed systematic sampling, and involved collection of leaves, inflorescences and infructescences. Active searching was conducted after active collection, and involved sampling on visibly-damaged plants, and was standardized as five minutes per quadrant. Microhabitat preferences of the arthropod and all its developmental stages on the plant, for example, favourable egg laying places were noted. Care was also exercised, to minimize disturbances on the plant when collecting samples as many arthropods could be dislodged (Satchel and Mountford 1962). There was also a lookout for small arthropods and

developmental stages (e.g. eggs) as these can be easily overlooked during sampling (Condrashoff 1967). 70% ethanol in 70 ml vacutainers were used as the preservation medium.

3.2.4 Key pests and feeding guilds determination

To determine key Proteaceae pests, information on feeding guilds was required and was acquired from literature as well as from field observations. For key Proteaceae pests, mainly crop loss surveys (Mulaa 1995), personal observations from the field and laboratory analysis of plant material, as well as literature (including grey literature form) were used.

Personal interviews were conducted with a group of protea farmers (South African Protea Producers and Exporters - SAPPEX) for the crop loss surveys. The surveys were undertaken simply to determine the types of losses occurring and their main causes (Walker 1987). The plant material (inflorescences, infructescences and <15 cm long stems) collected from the field were closely analysed for any arthropod damage. The damage on the plants was then associated with an arthropod. The numbers of damaged plant material by an arthropod per block were tallied (Appendix 4). The arthropods that affected most plant materials collected from the field were considered key pests. Those that damage the essential plant parts (harvestable product) to the extent that renders them completely unmarketable were designated as “most devastating” pests. Those arthropod species that had instead their numbers (abundant) being a problem and usually not directly affecting the essential plant materials (of phytosanitary importance) were labelled as “less devastating” pests.

The arthropod specimens were put into the following guilds: free living/flower visitors (FL/FV), endophagous (EN), ectophagous (EC), sap suckers (SS), ants (AN), parasitoids (PR), spiders (SP), mites (MT) and thrips (TH). The guilds were allocated based on

consulting literature, Moran and Southwood (1982), Coetzee (1989) and Wright and Giliomee (1990) and personal observations (from the field and on laboratory analysis of the plant material collected from the field). All arthropods collected from inflorescences were put under the flower visitors/free living guild, species which bore into plant structures and mined in leaves were grouped as endophagous. Species which fed on the leaf and/or chewed other outward plant structures were labelled as ectophagous. All sap sucking arthropods were classified as sap suckers. Due to the unique feeding and general behaviour of ants, parasitoids, spiders, mites and thrips, these were classified as separate, independent guilds.

3.2.5 Weather data and statistical analysis

Weather data, i.e. temperature and rainfall were collected from the farm weather stations. The weather data were used to show the trend between weather and arthropods population patterns. Factorial ANOVA using Statistica 8 (StatSoft Inc, USA) was conducted on the seasonal arthropod data collected. Post hoc Bonferroni tests (Statistica 8, StatSoft Inc, USA) were carried out to further define the significant differences between the Proteaceae blocks per season.

3.3 Results

3.3.1 Overall seasonal pattern of arthropods associated with commercial Proteaceae

Overall arthropod abundances did not vary significantly seasonally, i.e. from one sampling period to the other ($p>0.05$) (Figure 3.2A). However, relatively low arthropod abundance was recorded in December-March period, which corresponded with high temperatures and low rainfall (Figure 3.2B), and July (which corresponded with lowest temperatures and highest rainfall, figure 3.2B).

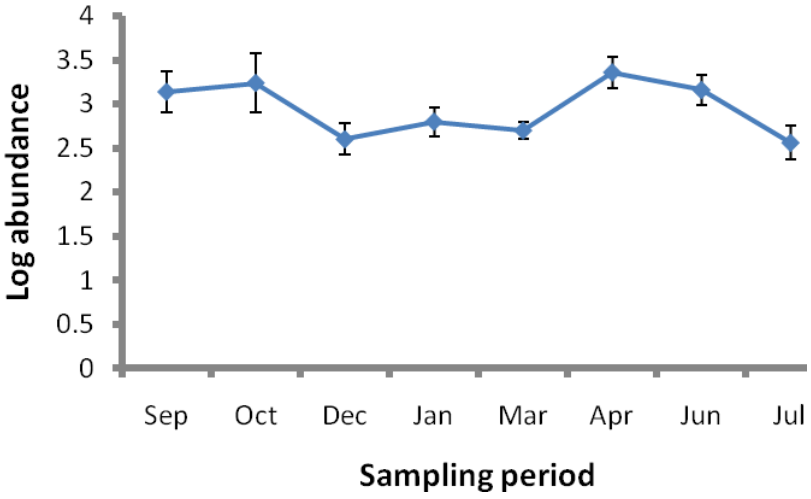


Figure 3.2A. Total arthropod abundance on Proteaceae throughout the year (September 2007 – July 2008) at Molteno Brothers Estate, Elgin, South Africa. Error bars indicate Standard Error.

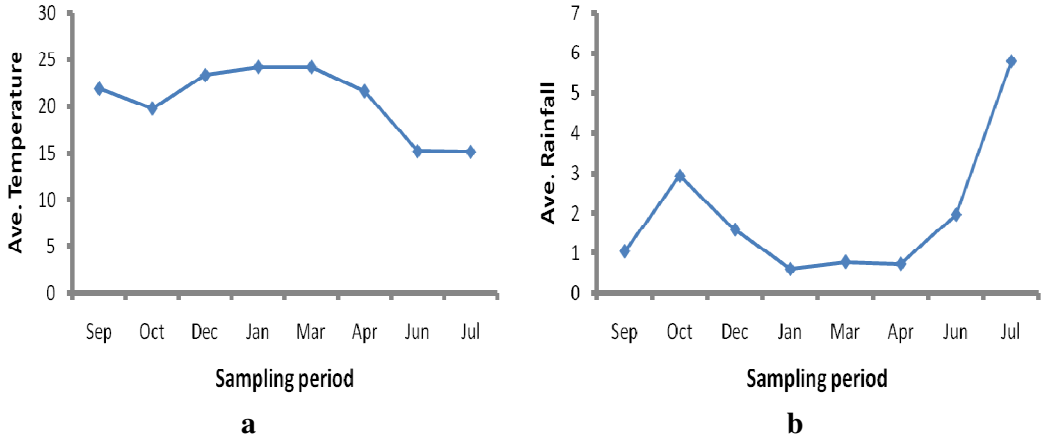


Figure 3.2B. a: Average temperature, b: average rainfall recorded at Molteno Brothers Estate, Elgin over the sampling period (September 2007 – July 2008).

However, there was a significant interaction between season and Proteaceae block ($F = 15.63$, $df = 21$, $p<0.05$) on species richness. Significant differences in species richness among seasons were noted on all the blocks, except for King protea, Sheila and Susara (S) (Figure 3.3 and Appendix 2). There was not a clear trend on species richness, except in the Safari sunset block, where there was an increase in species richness from spring to winter. In the "Wild", Seedling and Safari sunset blocks, there were significant differences between summer and the other seasons.

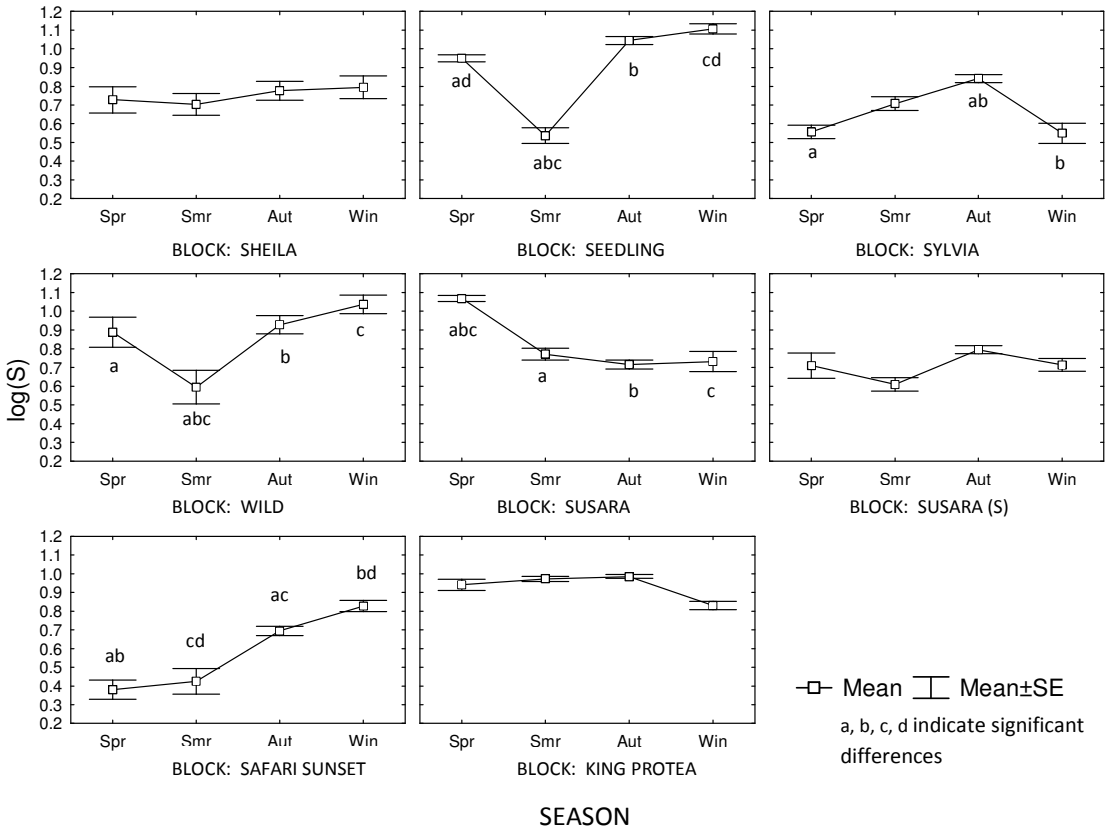


Figure 3.3. Variation in arthropod species richness at Molteno Brothers Estate, Elgin, South Africa over the year per Proteaceae blocks. log (S) = log of species richness and Season = annual seasons (Spr = spring, Smr = summer, Aut = autumn and Win = winter). Wild represent the "Wild" block.

The Safari sunset block recorded the lowest species richness in all seasons except in winter where the Sylvia block had a marked decrease in species richness. Highest species richness was recorded in the Seedling and Susara blocks during winter and spring respectively. Greater variance in arthropod species richness on Proteaceae blocks was recorded in spring and winter (Figure 3.4).

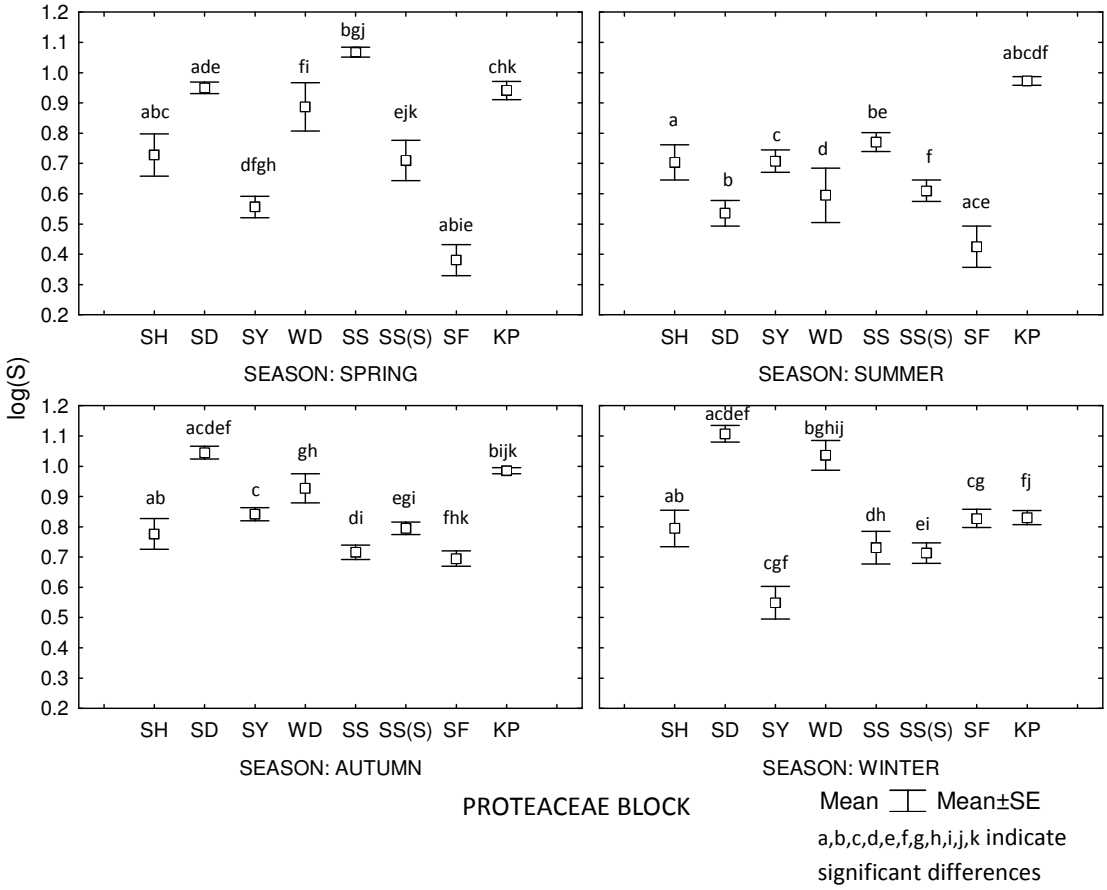


Figure 3.4. Variation in arthropod species richness at Molteno Brothers Estate, Elgin, South Africa per Proteaceae block throughout the year (September 2007 – July 2008). log (S) = log of species richness and Proteaceae block = Proteaceae species/cultivars (SH = Sheila, SD = Seedling, SY = Sylvia, WD = "Wild", SS = Susara, SS (S) = sprayed Susara, SF = Safari sunset and KP = King protea).

3.3.2 Seasonal variation of all arthropods developmental stages

Adults dominated the whole sampling period, except in January, where pupa abundance was slightly above the adults. Generally, pupa levels were high during December-March and lowest during April, which coincided with highest adult abundance. Highest larva abundance was recorded in June and the levels remained generally high throughout the sampling period. Highest egg numbers were recorded during the September-January period (spring-summer), and started decreasing towards winter, June-July while no eggs were recorded in July (Figure 3.5).

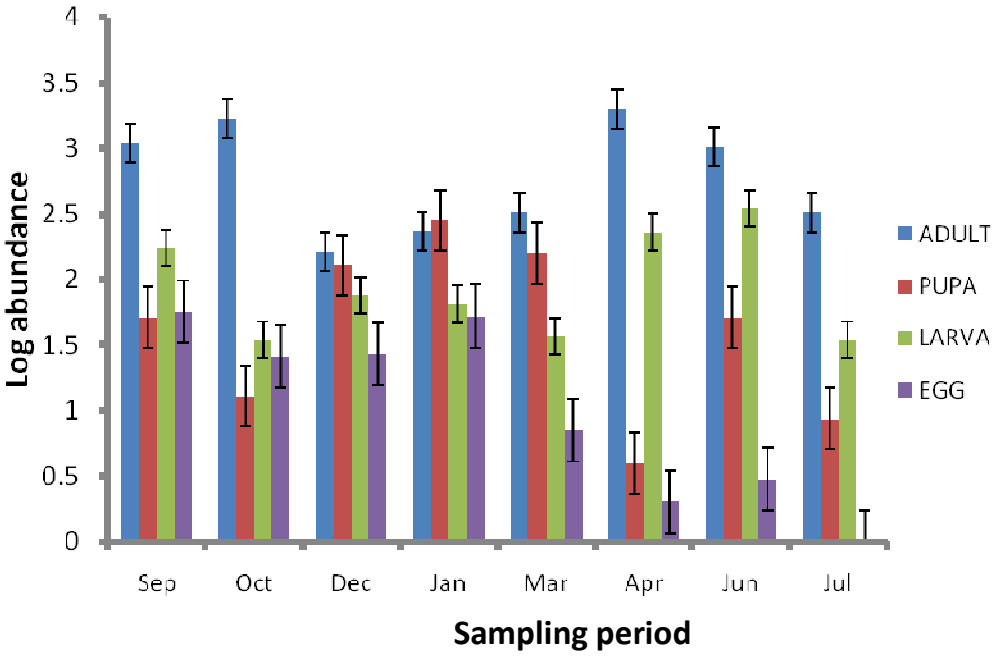


Figure 3.5. Variation in abundance of different developmental stages in Proteaceae at Molteno Brothers Estate, Elgin, South Africa throughout the year (September 2007 – July 2008). Log abundance = log of arthropod developmental stages (e.g. eggs, larvae, pupae) abundance. Sampling period = time of the year sampling was conducted (Sep = September,

Oct = October, Dec = December, Jan = January, Mar = March, Apr = April, Jun = June and Jul = July). Error bars indicate Standard Error.

3.3.3 Guilds seasonal distribution

Flower visiting/free living arthropods were the most abundant, and generally their numbers varied little throughout the year, except in January, when they were at their notably lowest number. Endophagous species (borers and leafminers) were the second most abundant guild, with relatively low numbers in October and July (Figure 3.6).

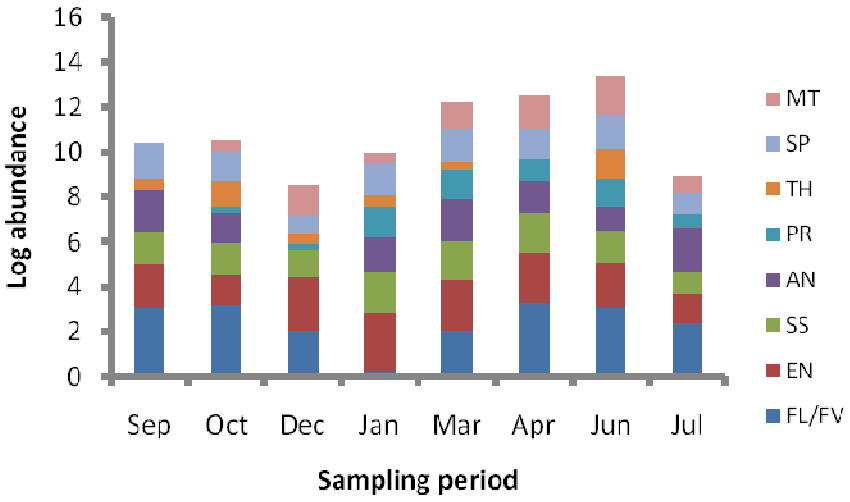


Figure 3.6. Variation in abundance of guilds based on species abundance in Proteaceae throughout the year. MT = Mites, SP = Spiders, TH = Thysanoptera, PR = Parasitoids, AN = Ants, SS = Sap suckers, EN = Endophagous, FL/FV = Free living/flower visitors. Log abundance = log of abundance of guilds based on species abundance in Proteaceae. Sampling period = Time of the year sampling was conducted (Sep = September, Oct = October, Dec = December, Jan = January, Mar = March, Apr = April, Jun = June and Jul = July).

Sap suckers were generally equally abundant throughout all the seasons, but relatively more abundant from January to April, with least numbers recorded in July. Also, relative high ant abundances corresponded with relative high sap suckers abundances. No ant species were recorded in December.

Parasitoids population was lowest during the first three months of sampling, i.e. from September to December as well as in July. However, relatively high parasitoid numbers were recorded during the January to June period. Thrips were the guild that generally recorded low population levels throughout the sampling period. No thrips were recorded in April and July, while relatively high numbers were recorded in October and June. No mites were found in September, and only low numbers were recorded in October, January and July. Spiders were a relatively abundant guild, which generally kept constant population levels throughout the seasons, although with relatively low numbers in December and July (Figure 3.6).

As with guild abundance, free living and flower visitors had high species richness which remained fairly constant throughout the year, although with a slight decrease in December, January and July. Endophagous and spider guilds followed the free living/flower visiting guild in maintaining constant species richness throughout the whole sampling period. In addition, these three guilds had the highest species richness.

The endophagous guild recorded relatively low species richness during October (spring), with spiders low in December. Lowest species richness of sap suckers was recorded especially from the January to March period (the opposite for species abundances) and relatively high in April and June. Relatively high species numbers of ants were recorded in September and October, relatively low in April to July and absent in December. Parasitoids had relatively high number of species in January, March and June, and absent in September. No thrips

species were recorded in April and July, and no mites in September. December and January recorded the second lowest thrip and mite species (richness) respectively (Figure 3.7).

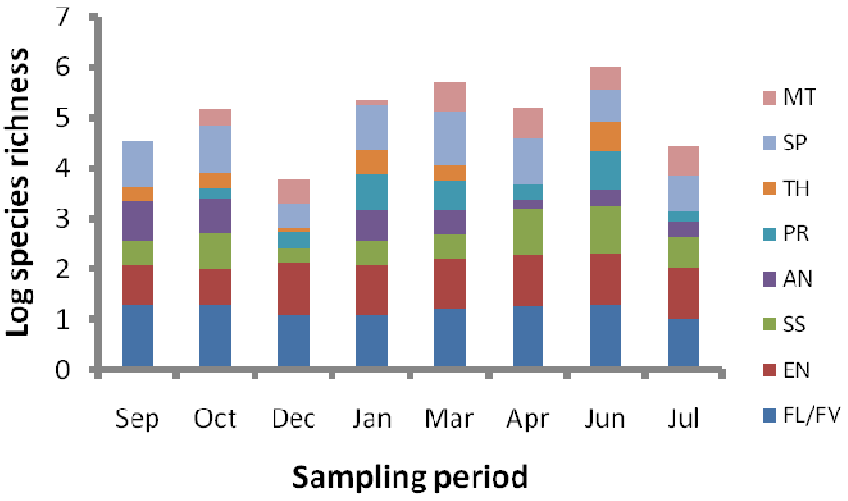


Figure 3.7. Variation in species richness of guilds in Proteaceae based on species richness throughout the year (September 2007 – July 2008). MT = Mites, SP = Spiders, TH = Thysanoptera, PR = Parasitoids, AN = Ants, SS = Sap suckers, EN = Endophagous, FL/FV = Free living/Flower visitors. Log species richness = log of species richness of guilds in Proteaceae based on species richness. Sampling period = Time of the year sampling was conducted (Sep = September, Oct = October, Dec = December, Jan = January, Mar = March, Apr = April, Jun = June and Jul = July).

Generally, guild species abundances and richness had an overall same pattern with lowest recordings in December and July, and with highest recordings in March-June.

3.3.4 Seasonal distribution and biology of key pest species

3.3.4.1 Seasonal distribution of key pest species

From literature (grey literature, e.g. Wright (unpubl.), Wright *et al*. (1991), Lubbe (2006)), Coetzee and Latsky (1986), Coetzee and Giliomee (1987), Myburgh (1990); personal communication (E. Louw, M. Huysamer), and recorded here, only 7.86% (n = 11) of the total arthropod species (n = 142) recorded to date associated with commercial Proteaceae can be regarded as major key pests of economic significance (Table 3.1). The arthropods regarded as major key pest species were the ones that were found to cause serious damage (probably due to feeding) to the plant parts resulting in them being unmarketable. Furthermore, only six out of the eleven species regarded as key pests of economic significance can be classified as "most devastating" key pests, with the rest falling under "less devastating" key pests. "Most devastating" key pests were the ones that were causing intensive and direct damage to the harvestable plant parts, while "less devastating" key pests were relatively less harmful (mainly of phytosanitary importance) to the essential plant parts. Lepidopterans made up most of the key pest species. Generally, most of the species recorded their presence almost throughout the year, except for *E. acerbella*, which was only recorded once in June (Table 3.1). There were very slight differences between months on the number of pest species occurring at a time. However relatively low species richness was recorded in September-October (spring), when a total of six species were recorded, and relatively higher species richness in June-July (winter), with about ten species recorded.

"Most devastating" key pests

Unlike the general overall trend for arthropod abundance, where relatively low numbers were recorded during summer (December-January) (see Figure 3.2A), it was the opposite for the "most devastating" pestiferous species, which were relatively abundant in summer

(December-January) (Figure 3.8). These pest species all followed a more or less similar pattern over the sampling period, with relatively high numbers in the October-April period (summer-autumn) and lowest during the winter months, June and July. Non-borer species, i.e. the leafminer, *Phyllocnistis* sp. and mealybug, *Delottococcus* sp., were the most abundant of the "most devastating" pests (Figure 3.8). *Epichoristodes acerbella* (Figure 3.9) was very scarce and rarely sampled here, with only a few larvae recorded in July, although its damage was severe during that same period (A.S. pers. obs.).

Table 3.1. Arthropods regarded as major pests on South African Proteaceae.

Taxon	Guild	SEP	OCT	DEC	JAN	MAR	APR	JUN	JUL
Lepidoptera									
# *Phyllocnistis* sp.	EN	-	-	*	*	*	*	*	-
# *Capys alphaeus*	EN	*	*	*	*	*	*	*	*
# *Orophia ammopleura*	EN	-	*	*	*	*	*	*	*
# *Argyroploce* sp.	EN	*	-	*	*	*	-	-	*
# *Epichoristodes acerbella*	EC	-	-	-	-	-	-	*	-
Oecophoridae (indet.)	EN	*	*	-	*	-	-	*	*
Tortricidae (indet.)	EN	-	*	*	*	*	*	*	*
Lepidoptera (indet.)	EN	*	*	*	*	*	*	*	*
Coleoptera									
Genuchus hottentottus	EN	-	-	*	*	*	*	*	*
Diaplochelus longipes	FV	*	*	*	-	*	*	*	*
Hemiptera									
#Delottococcus sp.	SS	*	*	*	*	*	*	*	*
TOTAL		**6**	**7**	**9**	**9**	**9**	**8**	**10**	**9**

"most devastating" key pest species

EN - endophagous, EC - ectophagous, FV - flower visitors, SS - sap suckers.

SEP - September, OCT - October, DEC - December, JAN - January, MAR - March, APR - April, JUN - June, JUL - July.

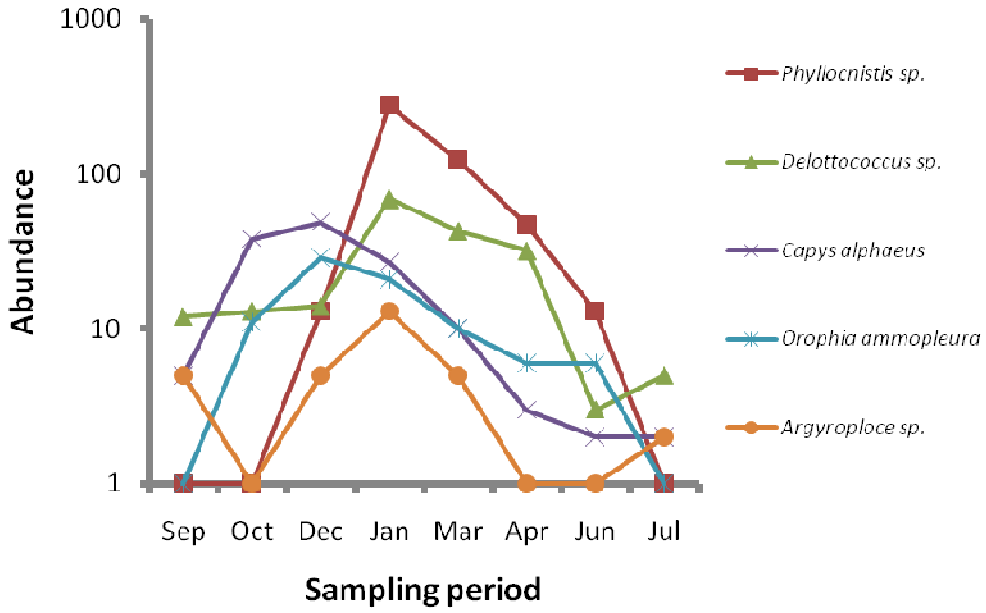
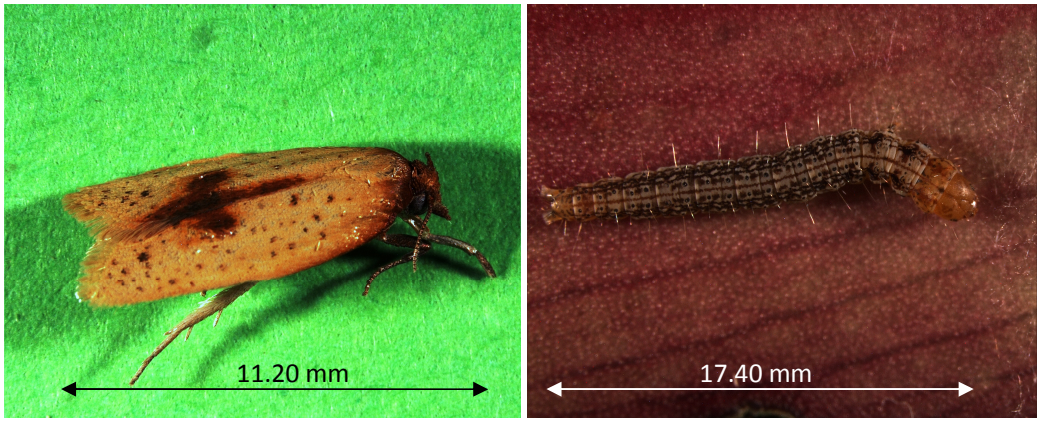


Figure 3.8. Seasonal distribution of Proteaceae "most devastating" key pests throughout the year (September 2007 – July 2008). Abundance = total abundance of "most devastating" key pests on all Proteaceae blocks.



A **B**

Figure 3.9. *Epichoristodes acerbella* A - adult and B - larva recorded in the field.

"Less devastating" key pests

For clarification, the "less devastating" pest species were separated into lepidopteran (Figure 3.10) and coleopteran (Figure 3.11) species. No clear pattern was revealed by the lepidopteran pest species, with the tortricids being the most abundant during April-June (autumn-winter). The Lepidoptera (indet.) peaked in December, and were then low in April, with a slight increase in June.

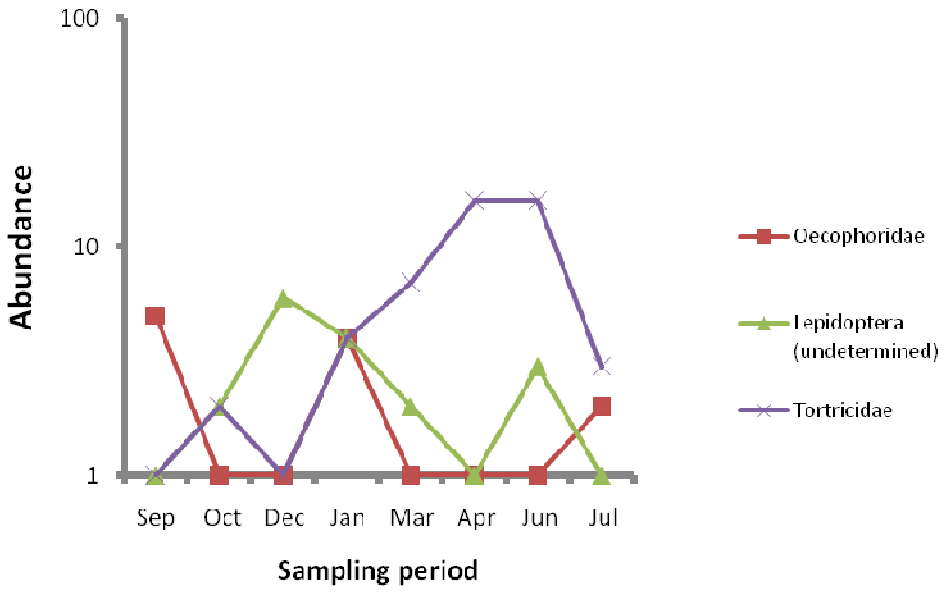


Figure 3.10. Seasonal distribution of Proteaceae "less devastating" key pests (lepidopterans) throughout the year (September 2007 – July 2008). Abundance = total abundance of "less devastating" key pests (lepidopterans) on all Proteaceae blocks.

The coleopteran "less devastating" pest species, unlike the "most devastating" pest species, were generally less abundant during the December-January period (summer), and most abundant in April (autumn) (Figure 3.11). *Diaplochelus longipes* adult was the most abundant, and is only classified as a pest because it is of phytosanitary importance when

abundant. *Genuchus hottentottus* larvae was far less abundant than *D. longipes*, and became of importance because it destroys Proteaceae seeds (which might not be as important in the cut flower industry) in the seed heads that remain in the fields.

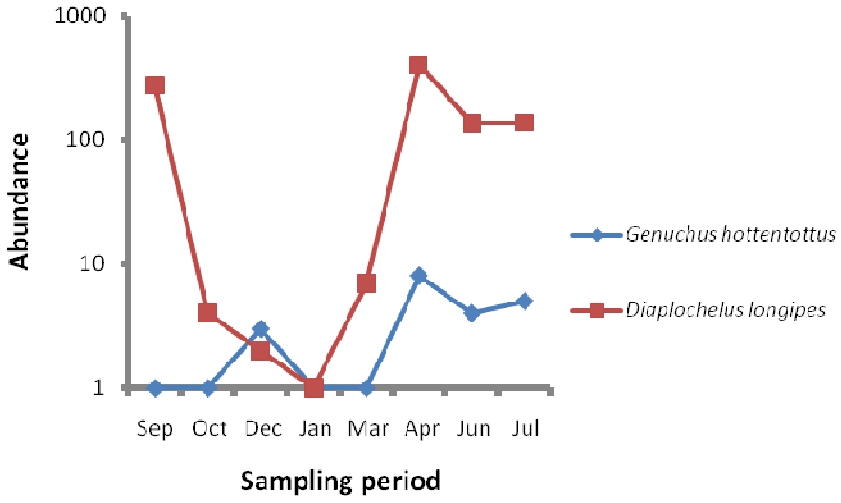


Figure 3.11. Seasonal distribution of Proteaceae "less devastating" key pests (coleopterans) throughout the year (September 2007 – July 2008). Abundance = total abundance of "less devastating" key pests (coleopterans) on all Proteaceae blocks.

3.3.4.2 Biology of the "most devastating" key pest species

"Borer species" were mostly sampled as larva infesting stems, inflorescences, infructescences and receptacles, except *C. alphaeus* which was abundant in egg form. Very few "borer species" adult specimens were collected from the field. The channel leafminer, *Phyllocnistis* sp. was mostly sampled as pupae, as well as some adults. *Delottococcus* sp. was dominated by adults, sometimes with crawlers and eggs sacs picked.

Capys alphaeus (Cramer) - Lepidoptera: Lycaenidae

Common name: Protea scarlet

Life cycle

Dull white and dome-shaped eggs are laid on the lower side (base) of young Proteaceae buds, usually one per bud. The eggs were recorded throughout the sampling period, i.e. from September (spring) till July (winter), but recorded a high peak in October (spring) and December (summer) (Figure 3.12). The eggs are relatively large (which makes them easy to see) with a diameter of about 1.6 mm and have a tracery on the surface which can be seen clearly under microscope (Figure 3.13A). The egg stage is reported to take 6-10 days (Clark and Dickson 1952, 1971).

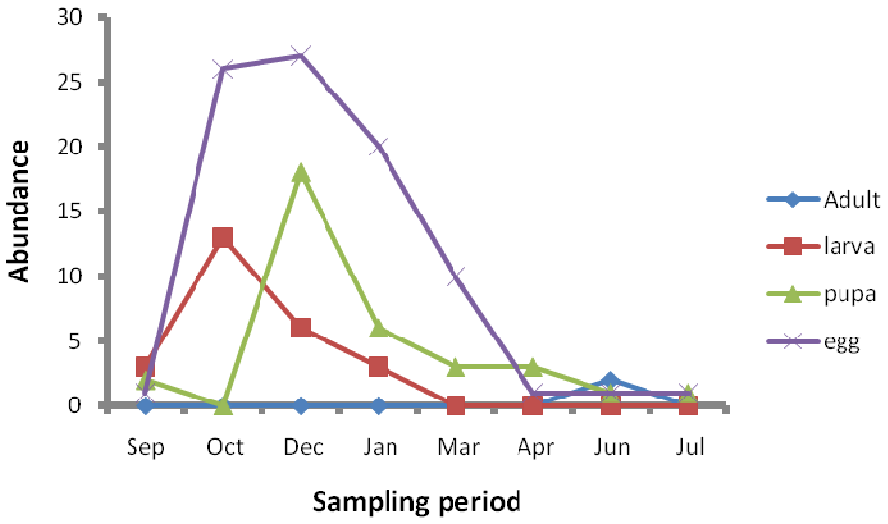


Figure 3.12. Seasonal variation in abundance of *C. alphaeus* developmental stages in Proteaceae blocks throughout the year (September 2007 – July 2008).

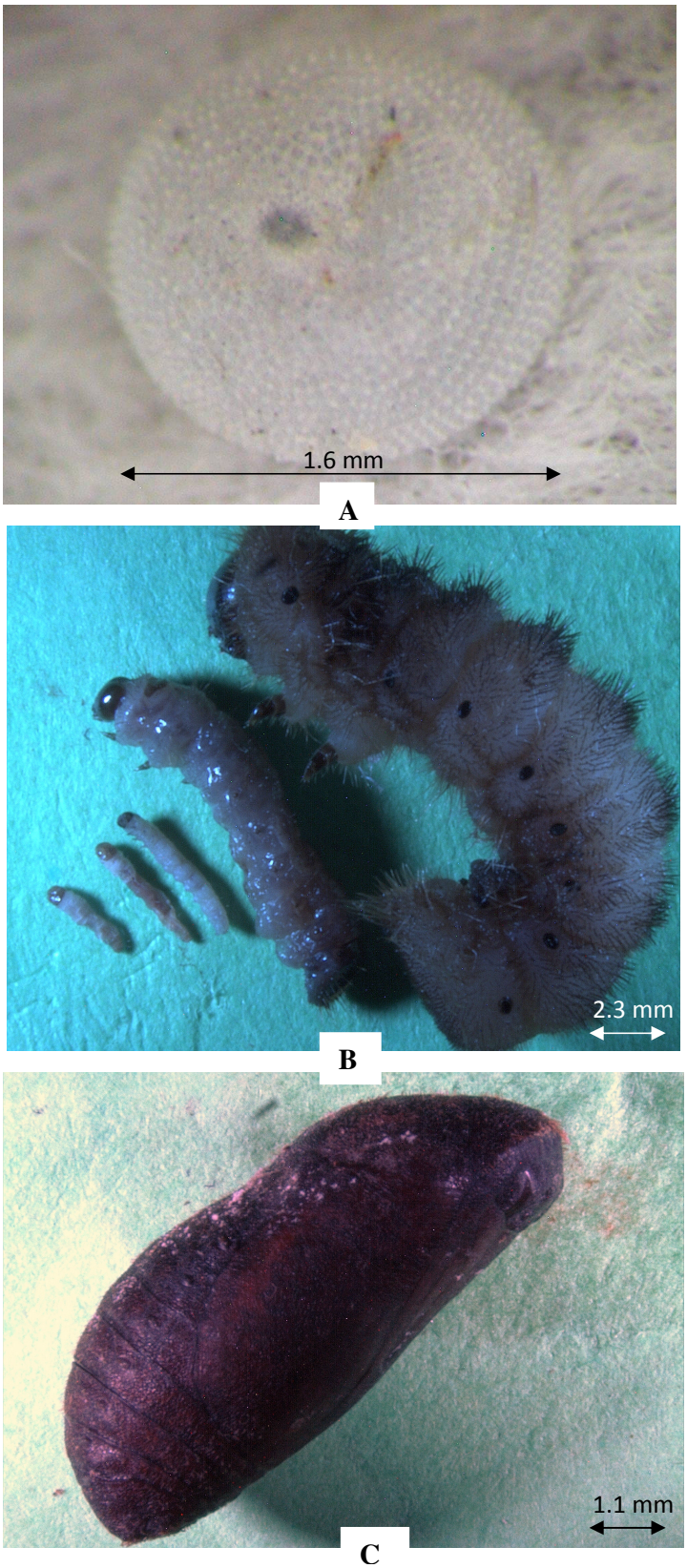


Figure 3.13. Life stages of *C. alphaeus*, A - egg, B - larvae (1st to 5th) and C - pupa.

Larvae were recorded from the beginning of sampling in September, through to January, with a peak in October. The larva bores into the flower bud, where it feeds (starting on the stylets) and develops until it completes all its five larval stages (Figure 3.13B) (Clark and Dickson 1952, 1971, pers. obs.). Claassens (2000) reported that the larvae emerging from the eggs last about 5 days and are approximately 3 mm long, whitish in colour with a black head and setae. According to Wright (unpubl.), the second larval stage is about 6-9.5 mm long, the third approximately 9.5-13.5 mm, and the fourth, about 13.5-18 mm, with each subsequent larval stage lasting for 6 days. The 5th and final instar larva feeds on the receptacle (lower core of the head), usually leaving a hollow space sufficient for occupation by the pupal stage, which follows. The 5th instar grows to become approximately 25 mm long, with short setae and white markings on the rest of the body, within 15 days of occupying the receptacle. The whole larval period lasts for 38-42 days and their presence can often be detected by excreta being pushed out through a small opening, usually at the base of the flower bud. The larva has a vestigial honey gland that lacks tubercles, as the final segment of the larva is flattened, and has a black shield on it and a periphery of spines (Clark and Dickson 1952, 1971, pers. obs.).

Pupae were recorded in abundance precisely after the larval peak, i.e. in December (summer) (Figure 3.12). The lycaenid butterfly pupa is stout and brown, usually about 10 mm long for females and about 8 mm long for males (Figure 3.13C). According to Clark and Dickson (1971) and Claassens (2000), the adult will emerge after 14-18 days, and the entire cycle takes 52-60 days under optimal conditions.

The adult was very scarce in the field, with only a few recorded in June (winter) (Figure 3.12). Clark and Dickson (1952, 1971) reported that the adults are common in the Western

Cape from September to March, but may be found throughout the year when conditions are favourable. This butterfly is relatively large, with a wingspan of 32-45 mm, and a fast flyer (Clark and Dickson 1952, 1971).

Delottococcus sp. – Hemiptera: Pseudococcidae

Life cycle

Delottococcus sp. was found all year round (Table 3.1 and Figure 3.14) with a population peak from December-April, i.e. summer and autumn, but decreased significantly during winter (June-July). *Delottococcus* sp. is oviparous and has three basic life stages: eggs, crawlers (instars) and adults (Figure 3.15).

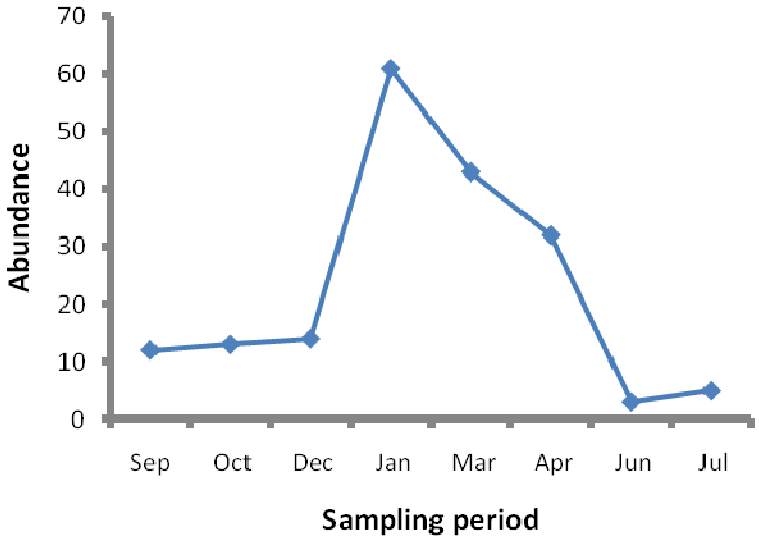


Figure 3.14. Seasonal abundance of *Delottococcus* sp. (crawlers and adults) on all Proteaceae blocks throughout the year (September 2007 – July 2008).

Egg sacs were most conspicuous during summer, although egg counts could not be made, as they were inside egg sacs. Most of the time, eggs, crawlers (instars) and adults were present at the same time, suggesting that there are multiple generations (multivoltine) during the year.

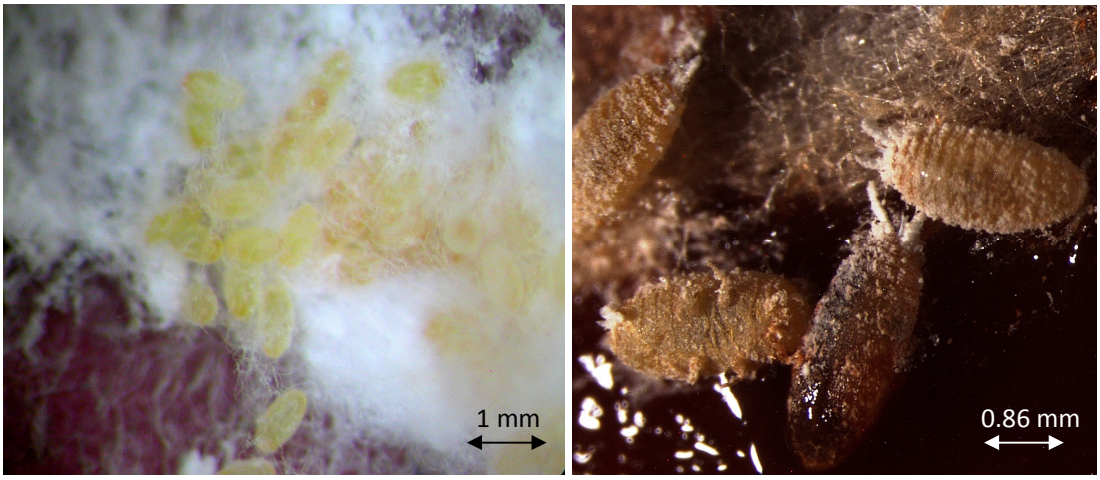


Figure 3.15. *Delottococcus* sp. A - eggs in an ovisac, with some emerging crawlers, and B - adults.

Orophia ammopleura (Meyrick) - Lepidoptera: Oecophoridae

Common name: Speckled protea borer

Life cycle

The larva was the dominate life stage, and was present from October-July, with a population peak in December. It appears that this larva does well during the dry and warm period (October-March) (Figure 3.16).

Surprisingly, *O. ammopleura* eggs were not readily recorded in the field. However, according to Wright (unpubl.), the flattened, pink red colour eggs are laid between bracts on buds or on young shoots.

A 1-2 mm long whitish larva hatches from the eggs and tunnels into the young shoots and buds, where it feeds and develops until it completes all its five larval stages. The early larval stages were detected mainly in December-January period (summer), with the subsequent larval stages following in later months. Unlike *C. alphaeus*, *O. ammopleura* develops

relatively slowly, taking about 9-10 months to complete all the five larval stages. From the second larval stage, the borer develops a speckled-grey colour with a brown head and the final stage is dark speckled pinkish colour (15-20 mm long). When it is about to pupate, the larva leaves the stem/infructescence (flower bud). Larvae that originate from the infructescences usually eat their way down the stem after destroying the bud. The larvae that originate from the stem eat their way up, until they get into the developing infructescence where they destroy all the developing flower structures. The presence of the early larval stages can be detected by the presence of a tiny (pin size) hole which sometimes has excreta deposits along a young stem. Other signs of the larval presence include the wilting apex leaves of the stem (usually for mid larval stages), or a deformed stem signalling the presence of the late larval stages.

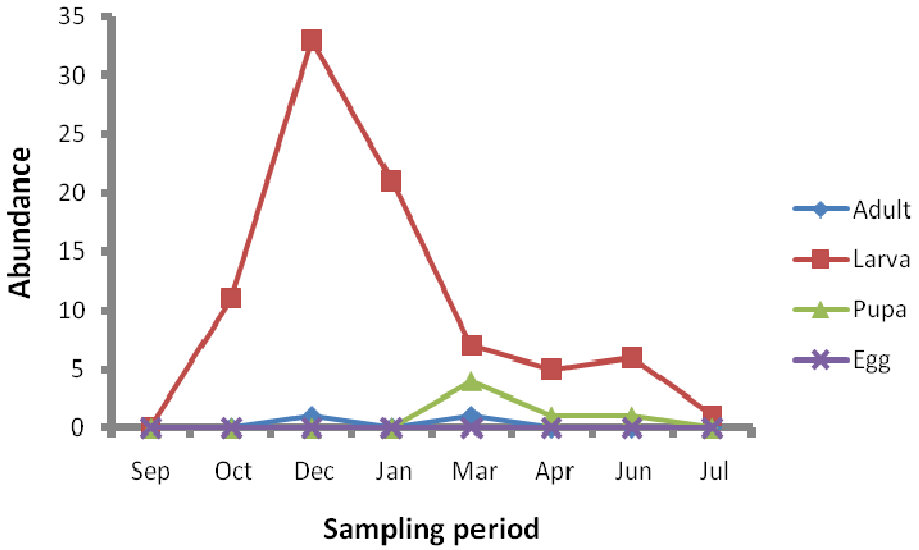


Figure 3.16. Changes in abundance of *O. ammopleura* developmental stages in all Proteaceae blocks throughout the year (September 2007 – July 2008).

As with the eggs, the pupa (Figure 3.17) was scarce in the field, with only a few specimens collected, mainly in March (although it was still recorded until June), a period when few larvae were beginning to be recorded (Figure 3.16). *Orophia ammopleura* pupa is generally uniformly brown coloured, with a granular structure, and is formed hanging from the plant substrate.

The adult stage is a relatively small moth, with a wing-span of about 20 mm. Only a few adults were recorded, during summer and autumn. However, Wright (unpubl.) reported an emergence from September (spring), followed by egg laying onto young plant material.

Figure 3.17. *Orophia ammopleura* pupa recorded in the field.

Phyllocnistis sp.: Lepidoptera – Phyllocnistidae

Common name: Channel leafminer

Life cycle

Phyllocnistis sp. was not recorded from the sampling blocks during the first two months of sampling, i.e. September and October (spring). Pupae were first recorded in December (with a population peak in January), with adults also showing a population peak in January. Both the pupa and adults decreased gradually until no adults were recorded in June, and no pupae in July (Figure 3.18).

Phyllocnistis sp. eggs were scarce and recorded on very young Proteaceae leaves (new flush- not older than a month).

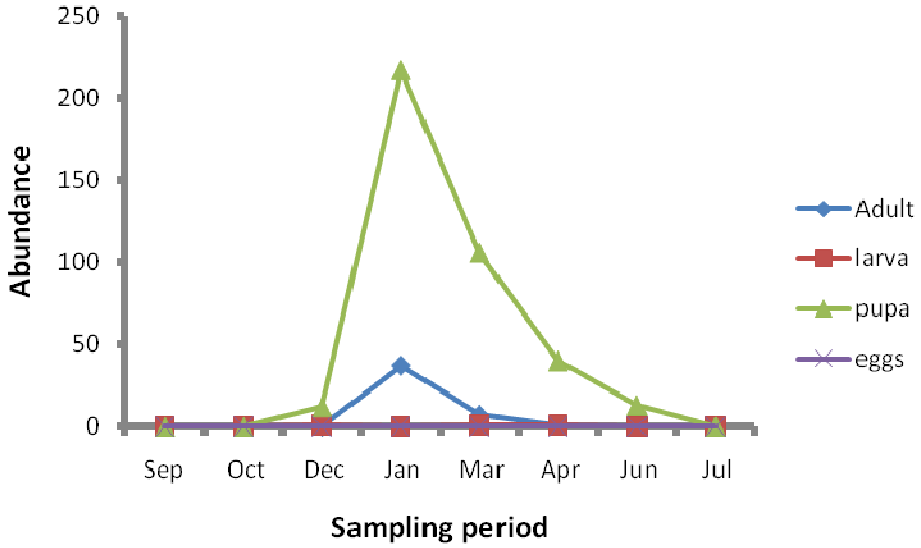


Figure 3.18. Variation in abundance of *Phyllocnistis* sp. developmental stages in all Proteaceae blocks throughout the year (September 2007 – July 2008).

The eggs hatch into minute yellow larvae which burrow into the leaf, creating characteristic tunnels on the leaf. The larva develops rapidly (within two-three weeks) to form a 5 mm,

bright yellow small pupa (pre-pupa) on leaf edges, causing the leaf-margin to fold over and form a protective chamber. With time, the pupa turns tan to brown and the adult microlepidoptera emerges, leaving the pupal shell protruding from the protective fold chamber.

The adult *Phyllocnistis* sp. is a minute moth, with a wingspan of about 5 mm and with grey-brownish forewings marked with two simple, and parallel black lines on each wing (Figure 3.19). As soon as the adult emerges from the pupa, it deposits eggs onto the young leaves.

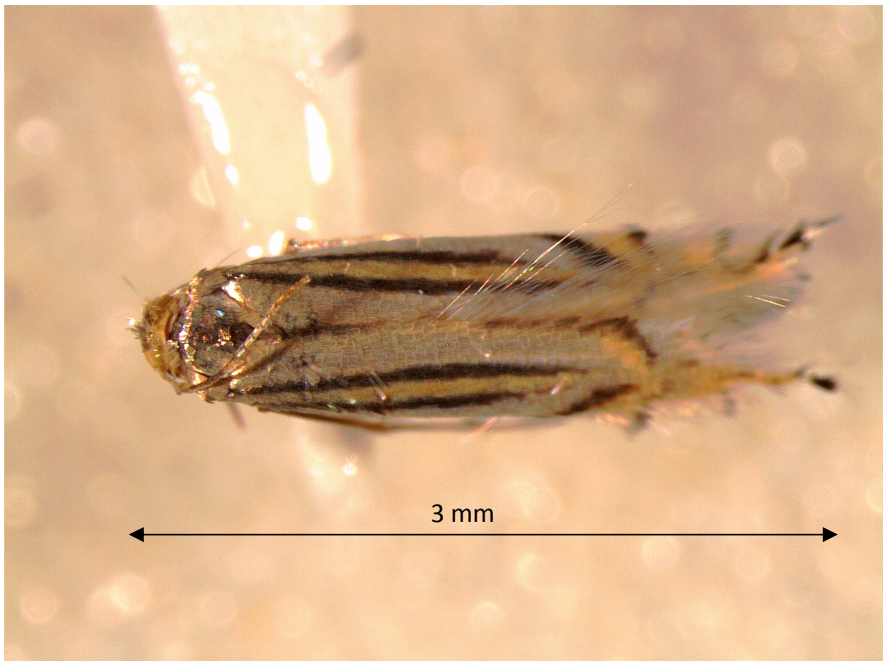


Figure 3.19. *Phyllocnistis* sp. adult recorded in the field.

Argyroploce sp.: Lepidoptera - Tortricidae

Life cycle

Argyroploce sp. larvae were recorded throughout the sampling period, with no adults and eggs. The highest numbers were recorded in January, followed by March and September. In October, April and June none were recorded and very few in July (Figure 3.20). It appears that *Argyroploce* sp. favours dry and hot conditions.

Wright (unpubl.) reported that the eggs of *Argyroploce* sp. are flat and whitish usually laid between the bracts of Proteaceae buds or on the young plant shoots. Wright (unpubl.) further reported that the eggs hatch into cream coloured larva, which turns pink during later stages. As with *O. ammopleura* larva, *Argyroploce* sp. larvae takes a number of months to develop, and hence were encountered almost all year.

Adults are relatively small moths with a wingspan of about 20 mm, and are reported to emerge during December-March, with most moths emerging from February-March. However, this depends on weather conditions (Wright unpubl). It has been further reported that soon after emergence, the moths will commence depositing eggs onto foliage (Wright unpubl.).

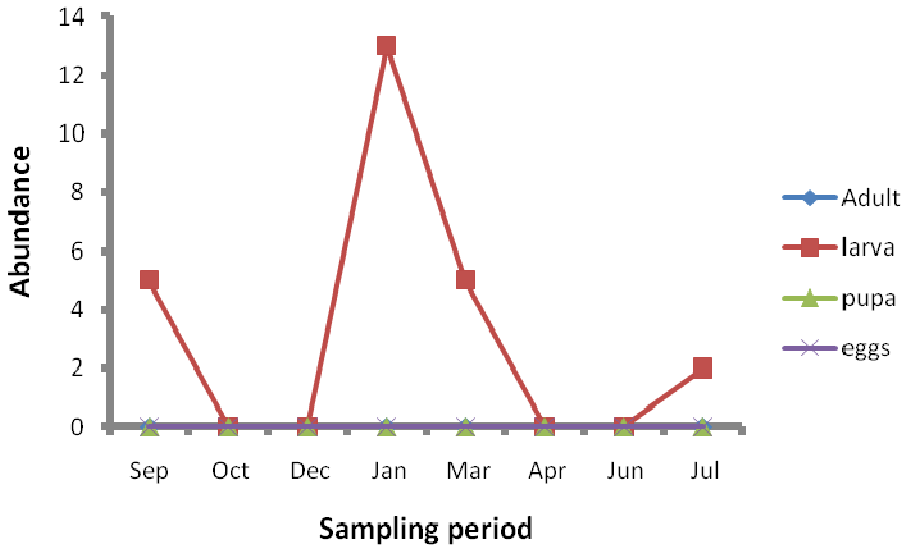


Figure 3.20. Changes in abundance of *Argyroploce* sp. developmental stages in all Proteaceae blocks throughout the year (September 2007 – July 2008).

3.4 Discussion

3.4.1 Seasonal pattern of species abundance and richness

Arthropod abundances did not vary significantly seasonally. There was only slight variation in overall arthropod abundance throughout the year. Slightly (relative) higher abundance was observed in April (autumn) and June (early winter). Relatively low numbers occurred in the dry and hot January-December (summer), and cold and wet July (mid-late winter) periods (Figure 3.2B). This corresponds with Coetzee (1989) and Roets *et al*. (2006), but not to Wright and Giliomee (1990), who found positive peaks in arthropod abundance in Proteaceae in summer. However, Roets *et al*. (2006) was restricted to arthropods from older infructescences, and it is likely that some arthropods were sheltering from the cold and wet weather in the heads. Slightly higher abundance in April and June might have been due to the cooler conditions (Figure 3.2B) which may be favourable for reproduction. The peak of winter (low temperatures and high rainfall – Figure 3.2B) could not support many arthropods probably due to the harsh weather. According to Wallner (1987) arthropod abundance can be influenced by small aberrations in rainfall. Moreover, the relative abundant species recorded in this study comes at a time when most Proteaceae used in this study come into flower (i.e. during autumn season) (Matthews 2002) and most arthropods could have been utilising the flowers as food (nectar).

Unlike arthropod abundance, there was a significant interaction between season and Proteaceae block (species/cultivar) in terms of species richness. This meant that the species richness occurring in different seasons varied per Proteaceae block (species/cultivars) and vice versa, however with no significant changes in the overall species abundance (Figure 3.2A). In other words, different species occurred in different seasons yet maintained the same

overall abundances (i.e. with no significant differences in abundance). This was likely effected by the major (high ranking) species (i.e. species which had very high abundances) such as *Chirodica* sp.1, *Phloenomus* sp., and *D. longipes*, which had similar abundances, (Appendix 1) but occurring in different seasons. This is likely promoted by the seasonal changes of plant architectural complexity (Berenbaum 1981, Lawton 1983). Seasonally plants tend to develop a variety of above ground parts, e.g. flowers heads and new flush leaves. These new additional plant structures may support some arthropod species more than the others.

Summer (hot and dry) had a negative impact on species richness among the various Proteaceae blocks, (just like in relative species abundances) as significantly low recordings were obtained during that time of the year, especially in the "Wild", Seedling and Safari sunset blocks. The dry and hot summer did not appear to support a number of species, which were likely aestivating to avoid desiccation. This could also have been enhanced by few plants not flowering during summer, especially in the "Wild" and Seedling blocks (Rebelo 1995) and hence these attracted few arthropod species.

No clear trend in population variation per Proteaceae block occurred over the seasons, except in the Safari sunset cultivar, where species richness gradually increased from spring until winter. The gradual increase in species richness from spring until winter in Safari sunset was possibly due to absence of flowers in spring. Pruning which takes place towards spring might also have affected the species diversity. When the plants are heavily pruned (a requirement in Safari sunset (Matthews 2002)), it leaves the plants with less arthropod refugia. With time, the plants developed a new flush and flower, until winter, when the rains further trigger rapid growth of stems providing refugia and food resources for the arthropods. According to

Lawton (1983) arthropods can be affected by the plant seasonal development, and as the plant architectural complexity declines/increases, so too does diversity of associated arthropods.

There were significant differences on species richness in all the Proteaceae blocks over the seasons, except in the King protea, Sheila and Susara (S) blocks. Significant differences were likely caused by the seasonal changes in plant growth form, i.e. change in plant architecture of the Proteaceae cultivars/species seasonally (Lawton`s (1983) hypothesis). As mentioned earlier, plant structures usually vary from one season to the other through development of flowers and new flush leaves. These new structures may attract and become utilised by new arthropod species as food or habitat sources. Since King protea and Sheila cultivar/species flower all year round, this could explain the lack of significant differences in the blocks, as there were constant food resources and refugia for the arthropods most of the time. Susara (S) was likely affected by the pesticides sprays, (see Chapter 4) considering that in the unsprayed Susara block, a different pattern was observed. The pesticides could have kept regulating the arthropod species from one season to the other. The pesticides were being applied almost on a monthly basis.

Considering that Safari sunset was affected by pruning especially after harvesting (i.e. from spring), and in full foliage development in winter, this could explain why Safari sunset recorded lowest in species richness in all the seasons, except in winter, where Sylvia recorded the lowest (Figure 3.4). Safari sunset was the least complex of all the proteas in this study, and according to Lawton`s (1983) hypothesis, it is the structurally complex plants that support high species diversity. Indeed, the relatively high arthropod species richness in winter coincided with the time when the plants have profuse foliage prompted by winter rainfall (i.e.

more microhabitats for the arthropod species to take refuge). This can be further supported by the appearance (in this block) of species such as *E. acerbella* in winter.

Highest species richness recorded in spring was on the, Susara; summer, King protea; and autumn and winter (as well as overall), the Seedling block. These trends between arthropods and Proteaceae block can be explained, for example, the high species diversity in the Susara block during spring were associated with new flush development, i.e. food sources. King protea generally recorded the high richness, possibly as this plant flowers all year round and its complex structure could support many arthropods for extended periods of time. Moreover, this plant is reported to do well even during moisture stress periods. Matthews (2002) reported that King protea does benefit from summer moisture and it is adapted to very sunny conditions. This could result in the plant doing well and attractive to many arthropod species even during the hot and dry summer periods.

Given that most species in the Seedling block flowered mainly in autumn and winter (Rebelo 1995), this could explain highest numbers recorded during that time in that block. Moreover, the Seedling block recorded the highest arthropod species richness overall. This can be explained by the fact that it was one of the most plant diverse blocks. Furthermore, there was no pruning or harvesting, leaving the plants in that block with a diverse array of structures (e.g. infructescences). Plant/habitat complexity promotes high arthropod diversity (Lawton 1983). However, there was no clear reason for the great variance among Proteaceae blocks in winter and spring. Nonetheless, unstable weather especially in winter (very cold and wet) may have played a role.

3.4.2 Seasonal variation of all arthropods developmental stages

Different patterns of the developmental stages were recorded throughout the different sampling seasons. Pupae were highest during the hot and dry December-March period, possible because most arthropods maintained a low activity (i.e. pupal stage) during the harsh weather conditions. Moreover, this was the time when most key pest species larvae pupated, and contributed significantly to the total pupal abundance (e.g. Figures 3.12 and 3.18). This was also true for the Agromyzidae species.

Adults dominated throughout the sampling period, except during January, when pupae were most abundant. Most adult stages could have been aestivating during the hot and dry January period. Highest numbers of adults were recorded in April (cooler and wetter) and this coincided with the lowest number of pupae. Possibly, because of the cooler and not too dry weather conditions, the pupa developed immediately into adults.

Highest egg numbers were recorded in September-January period, larva numbers in June, adults in April and lowest pupa and eggs in April and June-July period respectively. This corresponds with the developmental cycles. For example, egg numbers dropped in June when the larvae became abundant. Following this, larvae bored into plant structures to feed and develop (pass all its instar stages) during the cold and wet winter conditions. When adult numbers rose, the pupae levels dropped. However, some irregularities were present because some of the most abundant species (e.g. monkey beetles *D. longipes*) were not recorded in their early developmental stages. Some of the developmental stages were difficult to sample in the field, hence patterns might have been affected to a certain extent. For example, eggs of some species such as *Argyroploce* sp. were difficult to identify. Also, the presence of high

numbers of predators such as spiders might have reduced some developmental stages such as eggs and larvae (Nyfeller *et al.* 1990, Visser *et al.* 1999).

During the hot, dry summer months, i.e. December and January, overall various developmental stages were abundant (high numbers). This was unlike during the cooler, wet months, i.e. from April-July where most of the developmental stages were recorded in very low numbers. Possibly, rain was having an impact on the various developmental stages. Also we cannot leave out the possibility of the effect of seasonal changes of the host plant on seasonal distribution of arthropod developmental stages. As mentioned earlier, plants develop a variety of above ground parts such as new flush at certain times of the year. The presence of these new plant structures might determine population levels of certain developmental stages, for example, high leafminer larvae numbers are likely to be associated with new flush leaves.

3.4.3 Seasonal distribution of guilds

Abundance

The flower visitors/free living guild was the most abundant throughout most of the year, except summer, especially January, when they were almost absent, and also in March (probably because of dry and hot weather as well as not favourable flowering time). This was similar to the finding of Coetzee (1989), even though he separated flower visitors and tourist species into different guilds. Coetzee (1989) attributed the overall high flower visitors/free living abundance to the abundant nectar on the flowers. Endophagous species (mostly at their larval stage) were the second most abundant guild, however**,** recorded their relatively lower numbers in October and July (which also corresponded with low larval stages on developmental stages seasonal distribution – see Figure 3.5). Perhaps larvae had developed into other developmental stages forms, e.g. pupae or adults. Surprisingly, relatively high

abundance of this guild was recorded in January (dry and hot weather). Endophagous species endured the dry and hot weather in high abundance most probably because they were inside the plant structures, such as stems and flowering heads, where they were protected from desiccation.

The parasitoid guild was lowest in the first three months of sampling and in July, probably due to the overall low levels of potential hosts in those months. Indeed, the overall total abundances of all guilds were lowest during the first three months of sampling as well as in July (Figure 3.6). On the other hand, relatively high parasitoid abundances corresponded with the months where overall high levels of total guilds were recorded. It was during those peak months, when high ranking pests and potential hosts for the parasitoids, e.g. sap suckers such as mealybugs (*Delottococcus* sp.) were most abundant (Figure 3.6). The parasitoids, for example *Anagyrus* sp. could have utilised the plentiful hosts available to boost up their population levels.

Sap suckers guild generally maintained uniform numbers most of the year. This means neither the phenology of the plants nor seasonal weather pattern seemed to considerably affect members of this guild. Generally, relatively high ant abundances corresponded with relative high sap suckers abundances. This might be a reflection of a close relationship between these two guilds. The ants might have been taming the honey-dew producing sap suckers like mealybugs and protecting them from predators and parasitoids. The relatively abundant sap suckers, mealybugs (*Delottococcus* sp.) could have been mutualistically protected by the relatively abundant ants (especially *Technomyrmex albipes*) from parasitoids (e.g. *Anagyrus* sp.) (Weissling *et al.* 1998). The sap suckers were relatively abundant in the January to April period (dry and hot weather), but least in July (cold and wet weather). This

reflects how sap suckers, especially the relatively abundant mealybug (*Delottococcus* sp.) are temperature dependent (Hembram *et al*. 2007). Sap suckers such as mealybugs might have survived the dry and hot weather and avoids desiccation as they are found under tightly closed involucral bracts. However, this was unlike the ants which were absent in December, most probably due to the effect hot and dry weather, which could cause desiccation.

Spiders were relatively abundant and kept almost constant numbers, although abundance was relatively lower in December and July. This is most probably because of general lack of prey, most species decreased in abundance during those months (Figure 3.2A). Coetzee *et al*. (1990), found a decrease in spider numbers during the winter on five Proteaceae species. Mites in general (e.g. *Acarus* cf *immobilis*, *Tyrophagus putrescentiae* and *Glycyphagus* sp.) recorded high abundances and species richness during wetter months because that is when fungi, on which most of these arthropods are thought to feed, are present (Roets *et al*. 2005, 2006).

Mites and thrips guilds had low numbers, and they were the only guilds which were totally absent during certain months. Thrips pupate underground and since this study only covered above ground stages, absence could have been recorded when thrips were in the pupal stage with no mobile stages (Berndt *et al*. 2004).

Species richness

Free living/flower visitors and endophagous guilds had fairly high and constant species richness throughout the sampling period. This might explain why members of these guilds were most common and successful key pests of Proteaceae. Ten out of the eleven key pests of Proteaceae fall under the free living/flower visitors and endophagous guilds. Spiders, even though recorded relatively low abundances compared to most abundant guilds, recorded

relatively higher species richness. The presence of abundant and diverse array of arthropods (especially the free living/flower visitors species) might have attracted many spider species on proteas, as more and diverse prey items became available. Wise (1979) stated that increase in prey density influence the reproductive rate of spiders. As with abundance, spider species richness was less diverse in December, possibly because of reduced levels of prey.

Relatively low sap suckers species richness was recorded from January to March, which was the opposite for guild (sap suckers) abundances which were relatively higher during that same period. This seems to confirm that only a few species dominated this guild during that period, e.g. the mealybug *Delottococcus* sp.. Ants' richness was relatively high in September and October probably because of the favourable weather conditions during those months (dry and cooler weather). However, ants absence in December was likely due to hot and dry weather which could have caused desiccation. The lower ant richness recorded in April and July is likely the effect of rain and cold weather. Rain could easily wash away the nests of arboreal species such as *T. albipes*. More parasitoids species occurred during the months where the overall species richness of all the guilds were recorded highest, i.e. January, March and June (Figure 3.7). Most probably, the parasitoids could utilise many potential host species available.

Mites and thrips guilds were the least diverse, and were totally absent during certain months. Just like in species abundance, these patterns might be explained by the fact that, thrips pupate underground and since this study only covered above ground stages, absence could have been recorded when thrips were in the pupal stage with no mobile stages (Berndt *et al*. 2004). Considering the small sizes of the thrips and mites, there might be a suggestion that

the methods used in collecting arthropods in this study might not have been appropriate for these guilds.

Generally, guild species abundances and richness had an overall same pattern with lowest recordings in December and July, and with highest in March-June. This same pattern was observed in the overall arthropod abundance (Figure 3.2A). The low abundance in December (dry and hot) and July (wet and cold) might have been a response to the harsh weather conditions. The high abundance in March-June (wetter and cooler) might have been due to favourable weather conditions prevailing during that period (see Figure 3.2B).

3.4.4 Key pest species trend over the seasons

There was no month when all the key pest species were recorded. June had highest, when ten key pest species were recorded, with only *Argyroploce* sp. being absent. The rest of the months were fairly high in species richness (nine species), with September recording the least number of species (six species) (Table 3.1). These differences were likely caused by competition for food sources and habitat among the pest species and differently phased life cycles. Most probably due to competition, no more than one borer species was found to affect the same plant. For example, no other borer species were recorded on a plant where *C. alphaeus* was recorded. This might mean that when a borer pest invades a plant, it might limit the invasion of that same plant by other borers. In addition, most of these pest species have different development times, i.e. their life cycles. When one is abundant in its most damaging form such as larvae (for borer species), the other one might be in another form, which usually might be scarce in the field (e.g. most adults for borers species in this study), and hence might be recorded as absent. Moreover, some of the pest species tend to be multivoltine i.e. have more than one life cycle per annum, and hence found throughout the year. This is unlike other

key pests which tend to have a single generation per annum and hence might not be recorded during certain times.

Capys alphaeus, Lepidoptera (indet.) and *Delottococcus* sp. were recorded throughout the sampling period, suggesting that these species are multivoltine. *Epichoristodes acerbella* was recorded only once in June, with the rest of the pest species fairly abundant throughout the sampling period. The *E. acerbella* results correspond with those of De Villiers and Pringle (2008), who found high peaks in winter months in the Western Cape.

A number of the "most devastating" pest species were relatively abundant in summer (Figure 3.8). However, most of these species were at the larva and pupa stages (Figures 3.12, 3.16, 3.18, 3.20). This corresponds with the earlier mentioned hypothesis that most of the species in protea were keeping a low activity to avoid desiccation from the hot and dry summer weather (see figure 3.2A). Indeed, pupa is a stage of low activity. The larvae bore inside plant tissues where they could avoid desiccation, thereby causing damage to the plants. Most of the key pests were endophagous.

In general, the "most devastating" pest species were relatively abundant when the rest of the other species were relatively low, and least abundant when the other arthropod species numbers were relatively high, i.e. during June (see Figures 3.2A and 3.8). These patterns may be due to competition food and space. The key pest species seem to be opportunists which do not thrive well when the other arthropods are abundant. Surprisingly, the key pest species were generally, less abundant compared to some of the most outstanding major species such as *Phloenomus* sp., *P. tricolor*, and *Chirodica* sp.1, but nevertheless causing severe damage to the flowers. This is likely caused by their ("most devastating" pests) vicious type of feeding. Dent (1991) referred to these pests ("most devastating" pests) as "low threshold

pests", which feed directly on the harvestable product, causing damage even at very low pest densities.

While the borer species were the most speciose of the key pest species, non-borer species were the most abundant, i.e. *Delottococcus* sp. and *Phyllocnistis* sp. This might have been due to these non-borers having short life cycles and high rate of increase, strong dispersal, good host-finding ability, and small size, i.e. they are *r*-strategists. The females are capable of laying many eggs during their lifetime. Large borers invest a lot of energy in reproduction, resulting in them laying few large eggs i.e. typical K-strategists (Conway 1984, Dent 1991). Also, there might be inter/intra-guild competition for space and food. Dent (1991) characterised K-strategist species as having greater competitive ability, among other characters, such as larger size than *r*-pests, lower potential rate of increase, and a tendency to be more specialised in food preferences. Supporting the competition hypothesis of K-pest species is the fact that no two borers were found inhabiting the same plant structure. It was only a single case where two *G. hottentottus* borers were recorded on an infructescence.

The abundance fluctuations of the borer "less devastating" pests were not synchronised, so that when one was at peak, the other was rare. This might be due to competition for resources between these pest species. Tortricidae (indet.) and Lepidoptera (indet.) were in relatively high numbers around June, when they might have taken the opportunity from low numbers of the "most devastating" pest species, with which they compete for resources (see Figures 3.8 and 3.10).

Coleopterans were the only key pests which were less abundant when the rest of the other pests were abundant, i.e. in summer. This likely further explains the overall lower abundance of all arthropods during summer, as these coleopteran pests (e.g. *D. longipes*) contributed a

significant number to the overall arthropod abundance (Appendix 1). As already hypothesized, it is likely that these species were affected by the hot and dry weather conditions, and the fact that they started to increase only in April, as cooler weather appeared. Furthermore, most protea species in this study were in flower during the cooler and wetter months, i.e. autumn and spring, hence most of *D. longipes* occurring during that time. *Genuchus hottentottus* (a seed eater) was possibly less abundant because it was mainly associated with a few blocks, i.e. the Seedling and "Wild" blocks (Chapter 2). Nevertheless, it followed the *D. longipes* abundance fluctuations, as it was relatively abundant during the cooler period, i.e. autumn to winter.

3.4.5 Life cycles

Some of the arthropod pest species life cycle stages confirm the work of Wright (unpubl.) and the life cycles of the arthropods given here might have been affected by environmental factors (e.g. weather).

The key pest species had different life cycles (mainly different developmental times for borers). Nevertheless, larvae were the most prominent of all the life stages. For example, *O. ammopleura*, spends most of its life cycle, i.e. about 10 months, as a larva. According to Williams (www.atbutterflies.com/intro.htm), this is likely because the larval stage is the only rapaciously-feeding phase of growth, with the egg, pupa and adult stages not being growth phases. Nearly all the damage by the key pests is caused by the larval stage (the only exception being *Delottococcus* sp. and *D. longipes*).

Besides that adult stage was overall relatively abundant (Figure 3.5), adults of moths and butterflies were scarce during the sampling period (e.g. Figures 3.12 and 3.16). This may have been due to the fact that most species, especially moths being night flying were missed

by this diurnal sampling. The presence of eggs, as in the case of *C. alphaeus*, nevertheless reflected the presence of the adults. This suggests that the adults retreat during day time, even possibly outside the commercial fields. Light traps were not used here as they are not a point sampling technique and would have likely drawn individuals from surrounding natural areas. This calls for further studies to determine the dynamics of the key pest species adults in commercial proteas. Also, we cannot discount that some of the patterns of the key pest species observed were determined by the effect of natural enemies (the natural enemy ravine). Dent (1991) emphasized that natural enemies have the capability of reducing pest numbers when the pests have not reached very high numbers.

In most cases, eggs were recorded in relative low numbers (except for *C. alphaeus*), most probably because they were difficult to locate. For example, *Phyllocnistis* sp. has minute eggs, which quickly hatch into minute larva (Pomerinke and Stansly 1998). In the case of *C. alphaeus*, the relatively large size of the eggs (Claassens 2000) must have played a large role in the number of eggs sampled.

3.5 Conclusion

The arthropods associated with the different protea species/cultivars displayed distinct seasonal patterns of species richness, but much less so on abundance. Roets *et al*. (2006) showed that there is an increase in both arthropod abundance and species richness, as the infructescences age. Also, plant architecture and phenology might have had a significant effect on arthropod assemblages. Cultivar development might have also played a part in altering arthropod occurrence in the commercial fields, as compared to the wild (e.g. Coetzee 1986).

The high abundances and species richness of free living/flower visitors and endophagous guilds could explain why these species make a large part of the key pest species of proteas. This suggests that these two guilds are successful groups on Proteaceae. Non-borer key pest species are *r*-strategists, and according to Dent (1991), the damage they cause is often due to high numbers infesting the host plant. Large borer species, in contrast, are generally K-strategists and usually reach pest status because of the character or quality of damage they cause (Conway 1984, Dent 1991).

Most species tend to pupate during the dry and hot (summer) periods most probably to avoid desiccation. Indeed, the pupa is the stage of low activity, while the adults capitalize on cooler weather.

3.6 Recommendations

Roets *et al*. (2006) found that the arthropod numbers accumulate as the fruiting structures (infructescences) ages. There might be a need of such a study specifically looking at arthropod assemblages on inflorescences as they age. This might help determining the correct time to pick the flowers, i.e. before invasion by many arthropod species which can either cause damage or become of phytosanitary importance.

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Chapter 4

Efficacy of the spraying programme and preliminary suggestions for an intergrated pest management (IPM) programme in commercial proteaceae

Abstract

Arthropod pest species have been a major challenge in commercial Proteaceae in the Western Cape. Farmers have been relying solely on chemical pesticides for controlling arthropod pests. However, the efficacy of these pesticides has not been adequately tested. Furthermore, there is a need for environmentally friendly farming, with new, sustainable ways of pest control being sought. The control-impact method was employed to evaluate overall arthropod species in the pesticide sprayed and unsprayed blocks of cultivated Susara (which were of equal sizes and adjacent to each other), as well as at a more distant Sylvia (sprayed) block. Arthropod surveys were also conducted on another five unsprayed Proteaceae blocks. Pesticides were applied on a monthly basis in the designated sprayed blocks. Active collection of plant parts (inflorescences, infructescences and foliage) and active searching (spot check) were the methods used to collect arthropods from the Proteaceae blocks. Focus was mainly on key pests and natural enemy arthropod species between these three blocks, as well as on the rest of the other five Proteaceae blocks. Overall, pesticides had no significant impact on species abundance at any trophic level. However, pesticides had some effect on species richness, with minor (rare) species being most affected, possibly because of sensitivity through lack of resistance. The lack of significant differences between the abundance of the sprayed and unsprayed blocks emphasizes the ineffectiveness of pesticides, despite the fact that they had been applied on a monthly basis. A diverse array of natural enemies (general predators and parasitoids) was found. About 27% of key pest species were

associated with their natural enemies, for example, *Delottococcus* sp. was associated with *Anagyrus* sp., exhibiting a 33.33% parasitism. The presence of a diverse array of natural enemies showed the potential of alternative pest management in proteas. Pest monitoring, threshold values were recommended as pest management tools, as well as the use of biological, cultural, physical and chemical (optimal use) control.

4.1 Introduction

Proteaceae species are endemic, and an important crop, in the Western Cape Province of South Africa (Bond and Goldblatt 1984, Cowling and Lamont 1998). These plant species are widespread and keystone in the functioning of plants and animals in the fynbos (Rourke 1998). Most of these species are confined to nutrient-poor soils derived from Table Mountain Sandstone, while a few occur in limestone and calcareous sands as well as in dry, shale derived soils (Rebelo 1995). Proteaceae plants do well in the Western Cape, mostly because of the suitable soils (nutrient poor) and climate (Coetzee 1986). Wild stands of either the same or mixed Proteaceae species are common (Cowling and Lamont 1998) and an analysis of their distributions reveals clearly defined boundaries (Rebelo 1995).

Formerly commercial flowers were harvested solely from the wild, until the demand could not be met (van Wilgen and Lamb 1986). To meet this demand, especially from European markets, commercial cultivation of Proteaceae was initiated, which resulted in plants being grown in large monoculture fields (Myburgh and Rust 1975, Parvin *et al*. 2003). However, one of the major challenges of growing Proteaceae in the Western Cape is that of arthropod pests, which considerably reduce the cut flower yields (e.g., Myburgh and Rust 1975, Coetzee and Latsky 1986, Wright, unpubl., 2003). Also, the export flowers must comply with strict importation requirements of being free from arthropods (Coetzee 1986).

The diverse array and abundance of arthropods (flower visitors, borers, leafminers and leaf feeders) associated with commercial Proteaceae is likely attributable to the fact that a crop which is grown in its natural habitat is attacked by a wide spectrum of arthropods. In this situation, arthropods have had a chance to overcome the plant defences over a long period of time (evolutionary time). The issue of plants of the same type being grown in the same area

(large monocultures); means that the arthropods will not spend energy on searching for food but channel it all into reproduction (Coetzee 1986).

To address the arthropod pest problem, the South African Proteaceae farmers rely solely on use of chemical pesticides. Due to the relative small size of the industry in South Africa, the Proteaceae industry has not attracted the agrochemical industry to develop and register specific pesticides (Wright 1995). For example, a number of key protea insect pests in South Africa, such as *Capys alphaeus* (Lycaenidae), *Orophia* sp. (Oecophoridae), *Epichoristodes acerbella* (Tortricidae), *Euderes lineicollis* (Curculionidae), *Genuchus hottentottus* (Scarabaeidae) and *Resseliella proteae* (Cecidomyiidae) have no registered insecticides. Their control is only achieved by use of other insecticides that are known to control similar insect pests on other crops, while sometimes combinations of insecticides are required. For example, *E. acerbella* on Proteaceae, is controlled by making use of products available for other ornamental crops, Trichlorfon SP alternated with deltamethrin (Wright, unpubl.).

There is no assurance that these pesticides are effective, and little work has been done to date to verify their usefulness. Furthermore, there is not much information available on the control of Proteaceae-associated arthropod pests in South Africa, except for Wright (1995), and various grey literature in the form of pest information sheets (Wright, unpubl.) and a pest information booklet (Lubbe 2006). However, Wright *et al*. (1991) and Wright (1995) reported the inefficiency of most organophosphate insecticides (parathion EC, fenthion EC and dimethoate EC) for protea insect pests. Furthermore, there have been reports of inefficiency of chemical use in controlling some of the key pests, for example, mealybugs (M. Huysamer, E.J. Louw, pers. com.). Only one organophosphate insecticide, trichlorfon

EC, was reported as effective, as well as the pyrethroid products, permethrin EC and deltamethrin EC (Wright 1995).

Even in the international arena, there is little information available on arthropod pest control in Proteaceae. Only in Portugal, out of about eleven active protea-growing countries, has arthropod pest control been conducted (Leandro *et al*. 2006). As in South Africa, initially there was a dependence on chemical pesticides, followed by use of introduced biological control agents after realising the inefficiency of some of the insecticides. Even though some of the insecticides yielded positive results, e.g. phosalone helped in controlling *Helicoverpa amigera* in Proteaceae varieties, it had no effect on the eggs, which later hatched producing infesting 1st instar larvae. This application required a follow up with other insecticide applications, such as fenoxicarb and λ-cialotrine, which targeted the 1st instar larva. This increased the cost of the pesticide programme and led to more pesticide residues entering the environment.

As in South Africa, chemical control of mealybugs was also reported as a problem in Portugal (Leandro *et al*. 2006). Generally, mealybugs are known to be difficult to control with chemical insecticides. The dense waxy body cover makes contact by the pesticide active ingredient very difficult. However, use of oils and detergents can assist in breaking away this waxy protection layer. This increases the cost of application, although it assisted in controlling mealybug problem in Portugal. However, in some cases, *Protea cynaroides* in particular, mealybugs resided under the involucral bracts, where chemical substances did not reach, since the bracts are tightly closed and have a thick hairy covering, which makes them difficult to wet. This problem of inaccessibility of insecticides has also been reported on mealybugs in South Africa, and also in the case of control of *Orophia ammopleura* (speckled

protea borer) and *Erioderes candezei* (Cerambycidae) (protea long-horned beetle) (Marius Huysamer, pers. comm.).

Because of the non-effectiveness of pesticides, development of insecticide resistance by some of the pests, high pesticide costs, and the need to have environmentally-friendly protea production, alternatives are being sought. Integrated pest management (IPM) is, according to Dent (1991) and Neuenschwander *et al.* (2003), a pest management system which utilises all suitable techniques in as compatible a manner as possible, so as to maintain pest population levels below those causing economic injury. The emphasis is on pest management, not on pest eradication. IPM entails using monitoring systems to assess pest population dynamics, applying thresholds, encouraging biological control, cultural/physical control and minimal use of chemicals (Wright 1995).

4.1.1 Biological control

In South Africa, biological control trials have only been conducted on *E. acerbella*, where the use of entomopathogenic nematodes had been tried *in vitro* and recorded an ≈ 93% borer mortality (Wright *et al.* 1991, Wright 1995). Most of the key troublesome arthropod species in cultivated Proteaceae have not yet been linked to specific natural enemies. *Capys alphaeus* eggs are reported to be attacked by chalcids and no larval parasites have been identified as yet. It is suspected that the pupa may be attacked by ichneumonids (Clark and Dickson 1971). But since a diverse array of arthropods has been recorded in wild Proteaceae, including a large suite of predators and parasitoids (Coetzee 1989), there may be a possibility for biological control, knowing that this approach has limitations for indigenous pests.

In Portugal, biological control using the ladybird *Cryptolaemus montrouzieri* was begun to reduce mealybug (*Paracoccus* spp.) population levels after unsatisfactory control with

pesticides. This became the first ever recorded use of this predator in Proteaceae. Very promising results were found on the *Leucospermum* cultivars, i.e. Scarlet Ribbon and High gold, but not on *P. cynaroides*, where mealybug population levels continued to increase even after the introduction of *C. montrouzieri* (Leandro *et al.* 2006). Possibly, the structural nature of the *P. cynaroides* infructescence made it difficult for the relatively big ladybeetle to reach the mealybug colonies hidden under the involucral bracts compared, to *Leucospermum* cultivars where mealybugs grow on the open stem apex, easily reachable by natural enemies (Matthews 2002, Leandro *et al*. 2006).

Other suggested biological control agents have been the encyrtids, *Leptomastix dactylopii* and *Anagyrus pseudococci* against mealybugs in *P. cynaroides*, since their small size is assumed to allow them to reach the mealybug colonies under the bracts (Leandro *et al*. 2006). Because of concerns over inadequate host specificity in these parasitic wasps, and owing to the complexity of the interactions in the field, laboratory trials were first carried out on *Delottococcus confusus* and *Paracoccus* sp. Average parasitism was 34.5% (± 10.5%) for *A. pseudococci* and 48.9% (± 3.6%) for *L. dactylopii* (Leandro *et al.* 2008). However, parasitoids are typically more selective in their host range than generalist predators, and have been reported to be affected by a defence response from the hosts which encapsulate the parasitoid eggs (Blumberg 1990, 1997a, b, Passarinho 2004, Leandro *et al.* 2008). *Anagyrus pseudococci* and *L. dactylopii* are native species in South Africa and already play a role controlling the vine mealybug *Planococcus ficus* (Walton and Pringle 2004a, b), and may be effective on Proteaceae as well.

Biological control on Proteaceae was also tested on *H. armigera*, one of Portugal`s key protea insect pests. Bt (*Bacillus thurigiensis*) was applied on *Leucadendron* varieties, in particular,

Safari sunset, Blush, Fireglow and Long Tom, where it showed acceptable efficacy, and obviously had no effect on the eggs (as it must be ingested). *Trichogramma* sp. did however, parasitize the eggs of *H. armigera* in Proteaceae plants in Portugal, and plans were made to introduce it as a biological control agent in proteas (Leandro *et al.* 2006). However, field trials for Bt and the rest of the parasitoids used in laboratory experiments in Portugal are still pending.

4.1.2 Cultural and physical control

Wright (unpubl.) emphasised the removal and destruction of infested plants (strict sanitation) for partial control of most insect pests, especially those with no registered insecticides in South Africa. He recommended this on most insect borer pests, especially those which tunnel into the stem or head, where insecticides cannot reach. He also suggested physical control by covering young buds with nylon stockings (to avoid egg laying). However, this method is labour intensive and only suitable for small protea patches.

In this chapter, attention will be given to arthropod pest control on proteas and problems related to control measures, with suggestions for an IPM programme.

4.1.1 Objectives

- To determine the effectiveness of the current spray programme and to ascertain whether it is killing both the beneficial arthropods and pests.
- To make some preliminary suggestions for an integrated pest management (IPM) programme.

In this study, protea is a common collective name for all Proteaceae, while *Protea* refers to members of the genus *Protea*. "Wild" block refers to the remnant fynbos vegetation surrounding the cultivated protea blocks.

4.2 Materials and methods

4.2.1 Study area and sampling period

Arthropod sampling was done in Proteaceae at Molteno Brothers Estate (34° 08 S, 19° 02 E) in Elgin, Western Cape Province, South Africa from September 2007 – July 2008. Sampling was conducted twice every season, i.e. from spring (September and October), summer (December and January), autumn (March and April) and winter (June and July).

4.2.2 Overall sampling-arthropod diversity and abundance, and statistical analysis

Arthropod surveys were conducted in sprayed blocks, of cultivated Susara (S) and Sylvia, with a Susara block being used as the unsprayed control. Other protea blocks (Sheila, King protea, Safari sunset, Seedling and "Wild") were also unsprayed. The abundance and species richness of all arthropods were determined in the seasonal samplings, with special focus on natural enemies and key arthropod pest species. Each sampling block was divided into quadrants. In each block, active collection and active searching methods were employed, which involved collection of inflorescences, infructescences and foliage which were then dissected in the laboratory, and the arthropods retained. Three of each, i.e. inflorescences, infructescences and stems (<15 cm) were sampled per each plant in the quadrant. However, inflorescences and infructescences samples depended on availability, otherwise when absent, they were replaced by stems. Active field collection was limited to 12 plants per quadrant/block, while active searching followed (which involved collection of visibly damaged plant parts), and was conducted for five minutes per quadrant. Arthropods collected were identified as far as possible, with the assistance of taxonomists.

Arthropod data collected was analysed using factorial ANOVA (Statistica 8, StatSoft Inc, USA), looking at species richness or abundance and possible assemblage-influencing

determinants, season, pesticide treatments and Proteaceae block. Post hoc Bonferroni tests (Statistica 8, StatSoft Inc, USA) for arthropod species abundance and richness in the sprayed vs. control blocks were carried out. Significant levels are reported when $p<0.05$.

4.2.3 Key pest species determination

For key Proteaceae pests, mainly crop loss surveys (Mulaa 1995), personal observations from the field and laboratory analysis of plant material, as well as literature (including grey literature form) were used.

Personal interviews were conducted with a group of protea farmers (South African Protea Producers and Exporters - SAPPEX) for the crop loss surveys. The surveys were undertaken simply to determine the types of losses occurring and their main causes (Walker 1987). The plant material (inflorescences, infructescences and <15 cm long stems) collected from the field were closely analysed for any arthropod damage. The damage on the plants was then associated with an arthropod. The numbers of damaged plant material by an arthropod per block were tallied (Appendix 4). The arthropods that affected most plant materials collected from the field were considered key pests. Those that damage the essential plant parts (harvestable product) to the extent that renders them completely unmarketable were designated as “most devastating” pests. Those arthropod species that had instead their numbers (abundant) being a problem and usually not directly affecting the essential plant materials (of phytosanitary importance) were labelled as “less devastating” pests.

4.2.4 Control-Impact method

The aim was to evaluate overall arthropod abundance in the sprayed and unsprayed Susara blocks (which were of equal sizes and adjacent to each other), as well as at a more distant Sylvia (sprayed) block. Focus was mainly on evaluating the key pests and natural enemy

arthropod species between these three blocks, as well as the rest of the other Proteaceae blocks. All the blocks were treated with pesticides in August 2007, a month before systematic sampling began. Then Susara (S) and Sylvia blocks were treated with pesticides from September 2007 (when systematic sampling began) till July 2008 (Table 4.1) using tractor sprays (sprayed at 10 BAR – 2.4 RPM). Fungicides (Dithane, Quadris, Bravo and Chronos) were also applied to the sprayed protea blocks during the sampling period.

Table 4.1. Period and pesticides applied in commercial Proteaceae during the sampling period (September 2007 – July 2008) at Molteno Brothers Estate, Elgin, South Africa.

Spray Date	Pesticide Commercial Name	Active Ingridient	Targeted Pest	ml/100L	g/100L	Crop
Aug-07	Divos	Dichlorovos	LM, Borer	100		*All
Oct-07	Divos	Dichlorovos	LM, Borer	100		Susara (S), Sylvia
Nov-07	Steward	Indixacarb	Borer		15	Sylvia
Jan-08	Divos	Dichlorovos	LM, Borer	100		Susara (S), Sylvia
Feb-08	Mospilan	Acetamiprid	LM		40	Susara (S), Sylvia
Mar-08	Mospilan	Acetamiprid	LM		40	Susara (S), Sylvia
Apr-08	Liriphos	Chlropyrites	LM, MB	100		Susara (S), Sylvia
May-08	Dimet	Dimethoate	LM, Borer	75		Susara (S), Sylvia
Jun-08	Dimet	Dimethoate	LM, Borer	75		Susara (S), Sylvia

*All refers pesticide treatment to all Proteaceae blocks (Sheila, Seedling, Sylvia, "Wild", Susara, Susara (S), Safari sunset and King protea). LM = Leaf miner, MB = Mealybug.

Key pest population percentages in the experimental blocks were estimated using the formula:

Key pest population % = No. of key pest per Proteaceae block/ Total number of the key pest in all (eight) Proteaceae blocks x 100.

Population percentages of natural enemies (predators and parasitoids) in pesticide experimental blocks were estimated using the formula:

Population % of N.E = No. of N.E (abundance/richness) per Proteaceae block/ Total no. of N.E (abundance/richness) in all (eight) Proteaceae blocks x 100, where N.E = Natural Enemies.

4.2.5 Key pest species parasitism incubation experiments

In order to verify parasitism of key pest species by parasitic wasps, incubation experiments were conducted. Nine key pest species (arthropods that cause serious damage to the plant parts and render the flowers unmarketable) used in the experiments were *Phyllocnistis* sp., *O. ammopleura*, *Delottococcus* sp., *C. alphaeus*, *Argyroploce* sp., *G. hottentottus*, *Diaplochelus longipes*, Tortricidae (indet.) and Lepidoptera (indet.). *Epichoristodes acerbella* and Oecophoridae (indet.) were omitted in the incubation experiments because of their low number of individuals. Altogether, fifteen of each larvae/adults of key pest species collected from the field were incubated at room temperature in clear plastic containers (11 cm x 6.5 cm x 5.5 cm) with a snap tight lid to isolate the parasitoids and estimate percentage parasitism. Mealybugs of varying sizes from the field (handled using a fine paint brush) were also incubated in gelatin capsules as well as the finely cut folded sections of leaves affected by the channel leafminer, *Phyllocnistis* sp. The incubation chambers were left to stand for <2 weeks. Sample size for the incubation experiments was limited due to absence and limitation of some pest species at certain times. The incubation experiments ran throughout the sampling period. For each specimen analysed, the number of emerged parasitoids and encapsulated eggs were quantified. Egg encapsulation was determined through the dissection of incubated specimen at the end of the experiment and viewed using a light microscope.

4.3 Results

4.3.1 Sprayed vs. unsprayed blocks

Species abundances

Overall Proteaceae block was found to have a significant effect on overall arthropod abundance ($F = 6.3314$, $df = 7$, $p<0.05$). Compared to the other five different protea blocks which were also sampled, the sprayed blocks had intermediate arthropod abundance relative to the lower abundance in the "Wild", Sheila and Safari sunset blocks, and the higher species abundance in the Seedling, Susara and King protea blocks (Figure 4.1).

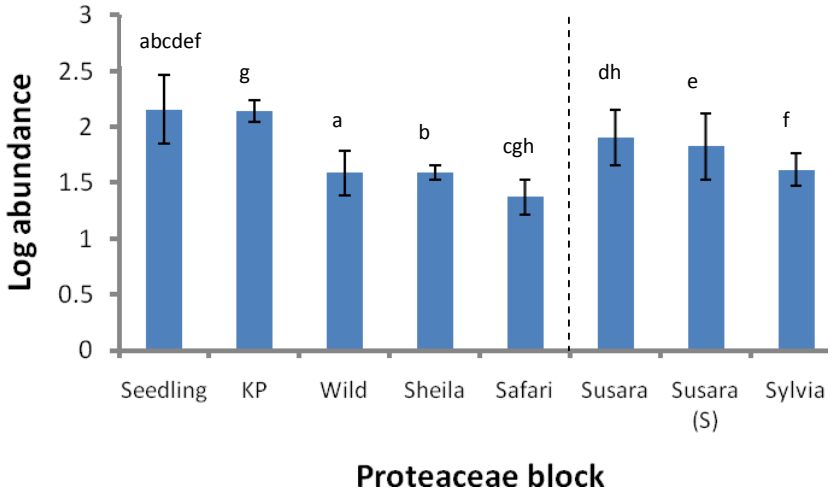

Figure 4.1. Arthropod abundance per Proteaceae block in comparison with the sprayed blocks, Susara (S) and Sylvia. The dashed line demarcates the primary pesticide spray experimental blocks (Susara, Sylvia and Susara (S)) from the rest of the blocks. a, b, c, d, e, f, g, h indicate significant differences. Wild represents the "Wild" block and Susara (S) stands for sprayed Susara block. Error bars denote Standard Error.

However, arthropod abundance between the blocks Susara, Susara (S) and Sylvia were not significantly different ($p>0.05$) after a Bonferroni test. However, the unsprayed Susara block recorded slightly higher abundance over the sprayed blocks, Susara (S) and Sylvia. Between the sprayed blocks, Susara (S) recorded a slightly higher species abundance than Sylvia (Figure 4.2).

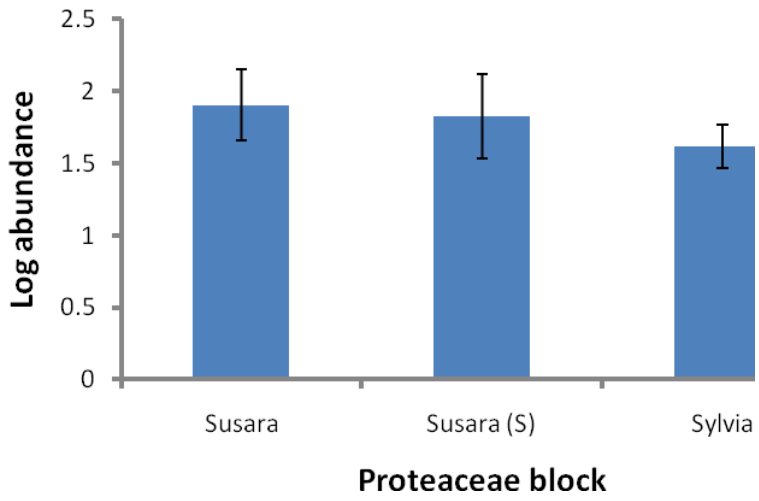

Figure 4.2. Graphical representation of arthropod abundance in sprayed Proteaceae blocks Susara (S) and Sylvia compared to unsprayed (control) Susara block. Susara (S) stands for sprayed Susara block. Error bars denote Standard Error.

Species richness

There was a significant difference in species richness between the sprayed and unsprayed blocks ($F = 15.63$, $p<0.05$). However, this difference between the unsprayed block (control), Susara and the sprayed blocks, Susara (S) and Sylvia was only noted during spring. However, the two sprayed blocks were not significantly different from each other throughout the seasons ($p>0.05$) (Figures 4.3 and 4.4).

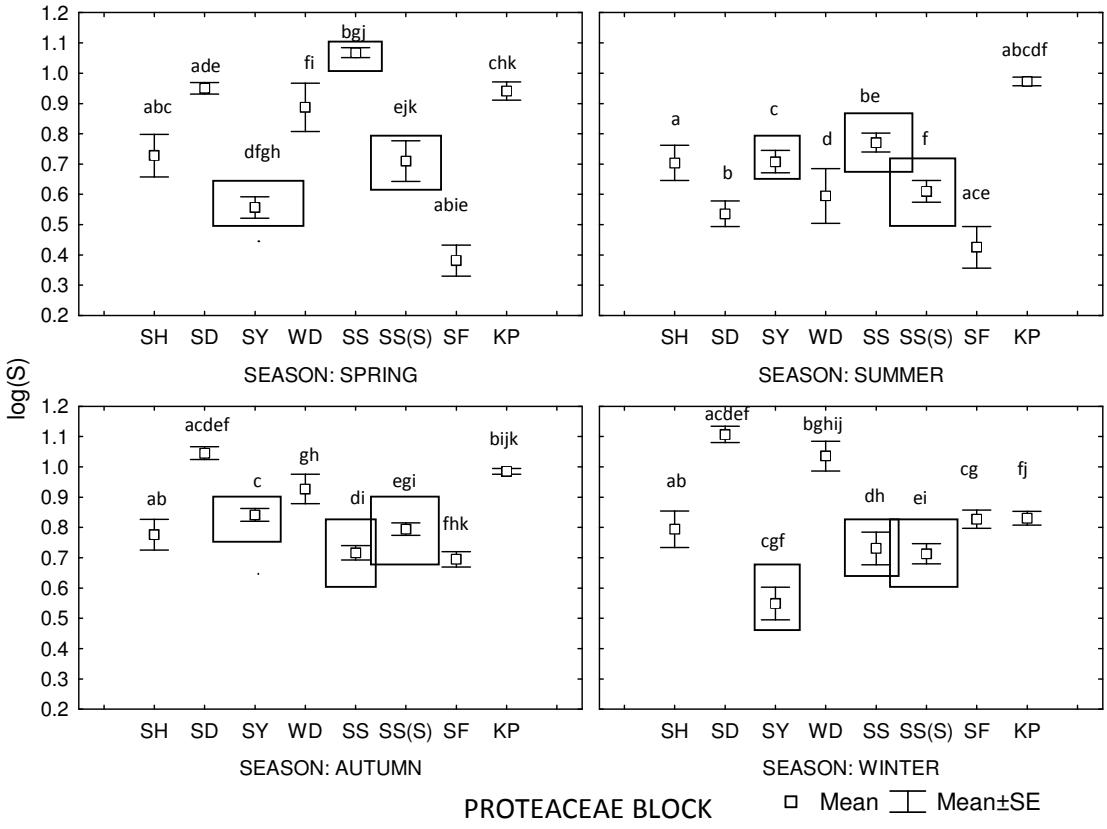

Figure 4.3. Seasonal arthropod species richness in sprayed (Susara (S) and Sylvia), unsprayed (control – Susara) and other, unsprayed protea blocks. ☐ : highlights the sprayed and Susara (immediate control) blocks. log (S) = log of species richness. SH = Sheila, SD = Seedling, SY = Sylvia, WD = "Wild", SS = Susara, SS(S) = sprayed Susara, SF = Safari sunset and KP = King protea. a,b,c,d,e,f,g,h,i,j,k indicate significant differences.

Overall the sprayed blocks, i.e. Susara (S) and Sylvia were also significantly different from the other protea blocks (Figure 4.3 and Appendix 2), and had the lowest species richness (Figure 4.5).

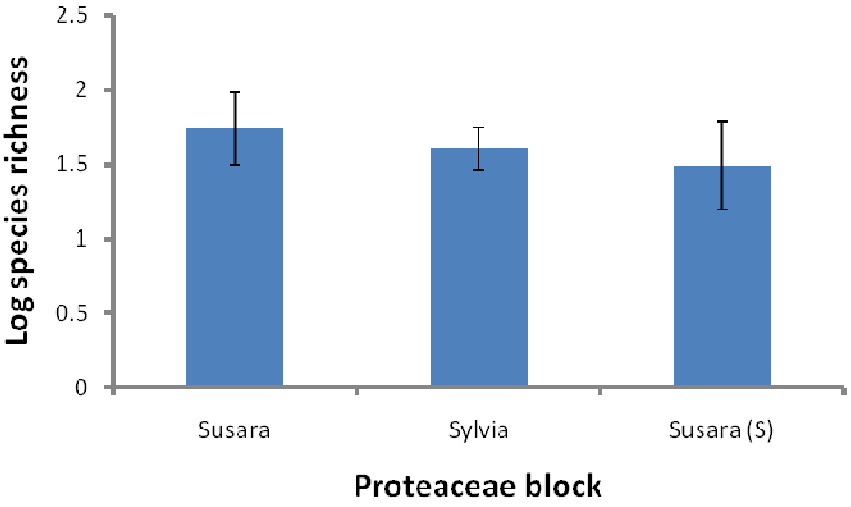

Figure 4.4. Arthropod species richness in the unsprayed (control Susara) block and in sprayed blocks (Susara (S) and Sylvia) over the whole sampling period. Susara (S) stands for sprayed Susara block. Error bars denote Standard Error.

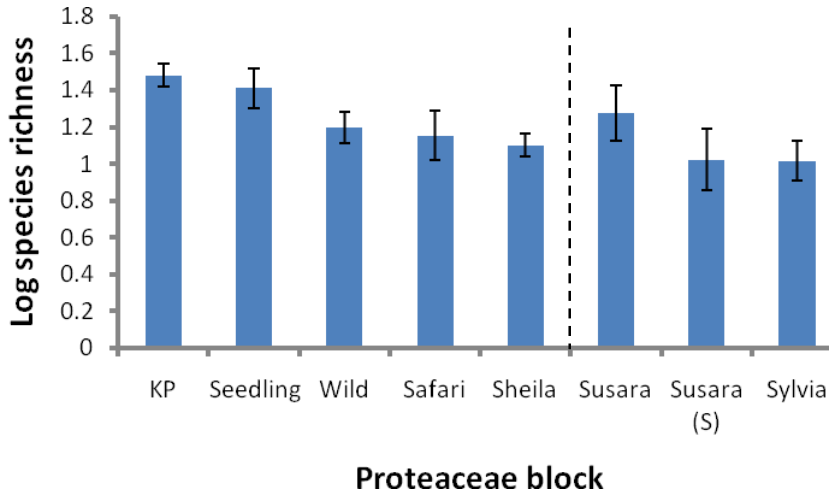

Figure 4.5. Overall species richness in protea blocks for the entire sampling period. The dashed line demarcates the primary pesticide spray experimental blocks (Susara, Sylvia and Susara (S)) from the rest of the blocks. Wild represents the "Wild" block and Susara (S) for sprayed Susara block. Error bars denote Standard Error.

4.3.2 Effects of pesticide application on key pest species and natural enemies

Generally, relatively lower abundance of key pest species was recorded in the sprayed blocks, except in few cases, e.g. where Oecophoridae (indet.), *D. longipes* and *C. alphaeus* had relatively higher abundances in the sprayed than in the unsprayed (control) block. Generally, the sequence of decreasing key pest species richness was: Susara > Susara (S) > Sylvia (Table 4.2).

Table 4.2. Key pest population percentages (% abundance) in sprayed and unsprayed (control) protea blocks (n = 723) at Molteno Brothers Estate, Elgin, South Africa.

Species	Log (N)	Susara %	Susara (S) %	Sylvia %
Diaplochelus longipes	2.99	6.3	9.61	1.34
Phyllocnistis sp.	2.68	42.32	25.47	21.89
Delottococcus sp.	2.28	3.66	2.09	0
Capys alphaeus	2.13	0	0	33.09
Orophia ammopleura	1.92	38.1	21.43	4.76
Tortricidae (indet.)	1.69	6	6	0
Argyroploce sp.	1.48	0	0	0
Genuchus hottentottus	1.34	4.55	0	0
Lepidoptera (indet.)	1.3	20	10	15
Oecophoridae (indet.)	1.11	0	30.77	0

Log (N) = Overall log abundance of the species in all protea blocks
(indet.) = indeterminate species
N.B: *E. acerbella* was omitted on this list due to negligible number of specimens.

In terms of natural enemies, the unsprayed block showed highest abundance and richness, followed by Susara (S) and, then Sylvia recording the least (Table 4.3). However, these blocks were not considerably different from each other, especially in terms of species richness, with some notable differences in abundance.

Table 4.3. Population percentages of natural enemies (predators and parasitoids) in sprayed (Susara (S) and Sylvia) and unsprayed (Susara) control blocks at Molteno Brothers Estate, Elgin, South Africa.

Cultivar/species	Species richness (%)	Abundance (%)
Susara	35.55	21.84
Susara (S)	33.33	13.99
`Sylvia	31.11	8.53

4.3.3 Natural enemies

A diverse array of natural enemies, which comprised of general coleopteran predators, spiders, hymenopteran parasitoids, as well as predatory mites were found associated with Proteaceae. Some natural enemy species had a wide range, i.e. found in almost every Proteaceae block and some were restricted to a single block (Table 4.4). *Clubiona abbajensis* was the only species which was found on all the Proteaceae blocks, followed by *Harmonia axyridis* and *Platysoma capensis* (Histeridae) which were found in 7 out of the 8 sampled Proteaceae blocks. Most spiders e.g. *Echemus* sp., *Synema imitator* occupied 6 out of the 8 blocks together with the predacious mite *Proctolaelaps vandenbergi* (E. Ueckermann, pers. com.) and the common general predator *Hippodamia variegata*. Most parasitic wasps, except for *Pediobius* sp. showed short range occupancy as they were only found in few Proteaceae blocks. Spiders were the most speciose group with 24 different species.

Table 4.4. Natural enemies associated with Proteaceae collected during the sampling period (September 2007 – July 2009) at Molteno Brothers Estate, Elgin, South Africa.

Taxon	SH	SD	SY	WD	SS	SS(S)	SF	KP
Coleopteran predator species								
Coleoptera								
Coccinellidae								
Hippodamia variegata	*	-	*	*	*	-	*	*
Harmonia axyridis	-	*	*	*	*	*	*	*
Cheilomenes lunata	-	-	*	-	-	-	-	-
Cheilomenes propinqua	-	-	*	-	-	-	-	-
Rhyzobius sp.	-	-	-	-	-	*	*	*
Rodolia cardinalis	-	-	-	-	-	-	-	*
Histeridae								
Platysoma capensis	*	*	*	*	*	*	-	*
Parasitoids								
Hymenoptera								
Eulophidae								
Pediobius sp.	*	-	*	*	*	*	-	-
Eulophidae (indet.)	-	-	-	-	*	*	-	*
Elasmidae								
Elasmus sp.	-	-	-	-	-	-	-	*
Encyrtidae								
Anagyrus sp.	-	-	-	-	-	*	*	*
Cerhysiella sp.	-	-	-	*	-	-	-	-
Eucoilidae (indet.)	-	*	-	-	-	-	-	-
Braconidae (indet.)	-	-	*	-	-	-	*	*
Platygastridae (indet.)	-	-	-	-	-	-	*	-
Eurytomidae (indet.)	-	-	-	-	*	-	-	*
Spiders								
Araneae								
Clubionidae								
Clubiona abbajensis	*	*	*	*	*	*	*	*
Armaurobiidae								
Chresiona invalida	*	-	-	-	-	-	-	-
Chresiona sp.2	*	-	-	-	-	*	*	*
Araneidae								
Neoscona subfusca	-	-	*	-	-	*	-	-
Corrinidae								
Trachelas sp.1	*	-	-	-	-	-	-	-
Gnaphosidae								
Echemus sp.1	*	*	*	-	*	*	-	*

Xerophaeus sp.1	-	-	-	*	-	-	-	*
Linyphiidae								
Pelecopsis janus	-	-	*	*	-	-	-	-
Lycosidae								
Pardosa sp.1	-	-	-	-	*	-	-	-
Miturgidae								
Cheiracanthium sp.1	*	-	-	-	-	-	*	*
Philodromidae								
Gephyrota sp.1	-	-	-	-	*	-	-	-
Philodromus sp.1	-	-	-	-	*	-	-	-
Tibellus sp.	-	-	*	-	-	-	-	-
Salticidae								
Baryphus ahenus	-	-	*	-	-	*	*	-
Heliophanus debilis	*	-	-	*	-	-	-	*
Heliophanus insperatus	-	*	-	-	*	-	-	-
Menemerus sp.1	-	-	-	*	-	-	-	*
Massagris regina	-	*	-	-	-	-	-	-
Theridiidae								
Theridion sp.1	*	-	*	*	*	*	*	-
Theridion sp.2	*	-	-	*	-	-	*	-
Euryopis sp.	-	*	*	-	-	-	-	-
Thomisidae								
Synema imitator	*	*	-	-	*	*	*	*
Holopelus almiae	-	-	-	-	-	-	*	-
Theridiostomatidae (indet.)	-	-	*	-	-	-	-	-
Mites								
Acarina								
Ascidae								
Proctolaelaps vandenbergi	-	*	*	*	*	*	-	*
Macrochelidae								
Macrocheles sp.	-	*	-	*	*	-	-	-
TOTAL	**13**	**12**	**15**	**14**	**16**	**14**	**14**	**19**

SH = Sheila, SD = Seedling, SY = Sylvia, WD = "Wild", SS = Susara, SS (S) = sprayed Susara, SF = Safari sunset, KP = King protea.

The numbers of natural enemy species per Proteaceae block were not very different. King protea had the most species, followed by Susara and the lowest number of species was recorded in the Seedling block. The sprayed blocks, Susara (S) and Sylvia both had intermediate numbers of natural enemies.

4.3.4 Natural enemies – key pest species

Some natural enemies were associated with the key pest species. Incubation experiments resulted in emergence of some parasitoid wasps from the key pest species (Figure 4.6). Table 4.5 shows the percentage parasitism results from the incubation experiments. Out of the nine incubated key pest species, only three yielded parasitic wasps (Table 4.5).

Table 4.5. Percentage parasitism between key pest species and associated parasitoids in commercial proteas at Molteno Brothers Estate, Elgin, South Africa.

Species	No. incubated	No. parasitized	Parasitoids	% Parasitism
Delottococcus sp.	15	5	5*	33.33
Orophia ammopleura	15	1	9#	6.67
Phyllocnistis sp.	15	4	4"	26.67

**Anagyrus* sp., #Braconidae, "*Pediobius* sp.

Percentage parasitism was relatively higher in *Delottococcus* sp. where 33.33% of the mealybugs were affected by *Anagyrus* sp. All the *Anagyrus* sp. emerged from relatively big mealybug individuals. *Phyllocnistis* sp. was affected by *Pediobius* sp., with 26.67% parasitism. The least percentage parasitism (6.67%) was recorded in the black moth, *O. ammopleura*, where interestingly, one larva yielded nine braconid parasitoids with two encapsulations (Table 4.5). Even under field conditions, some cases of predator-prey relationships were evident, e.g. mealybug mummies were recorded as well as pre-pupal shells of *Phyllocnistis* sp., and the parasitoid wasp *Pediobius* sp. under the same leaf folds.

Other general predators such as *H. variegata*, *Rhyzobius* sp., *H. axyridis* (newly invasive to South Africa) and arachnid species were also recorded associated with key pest species.

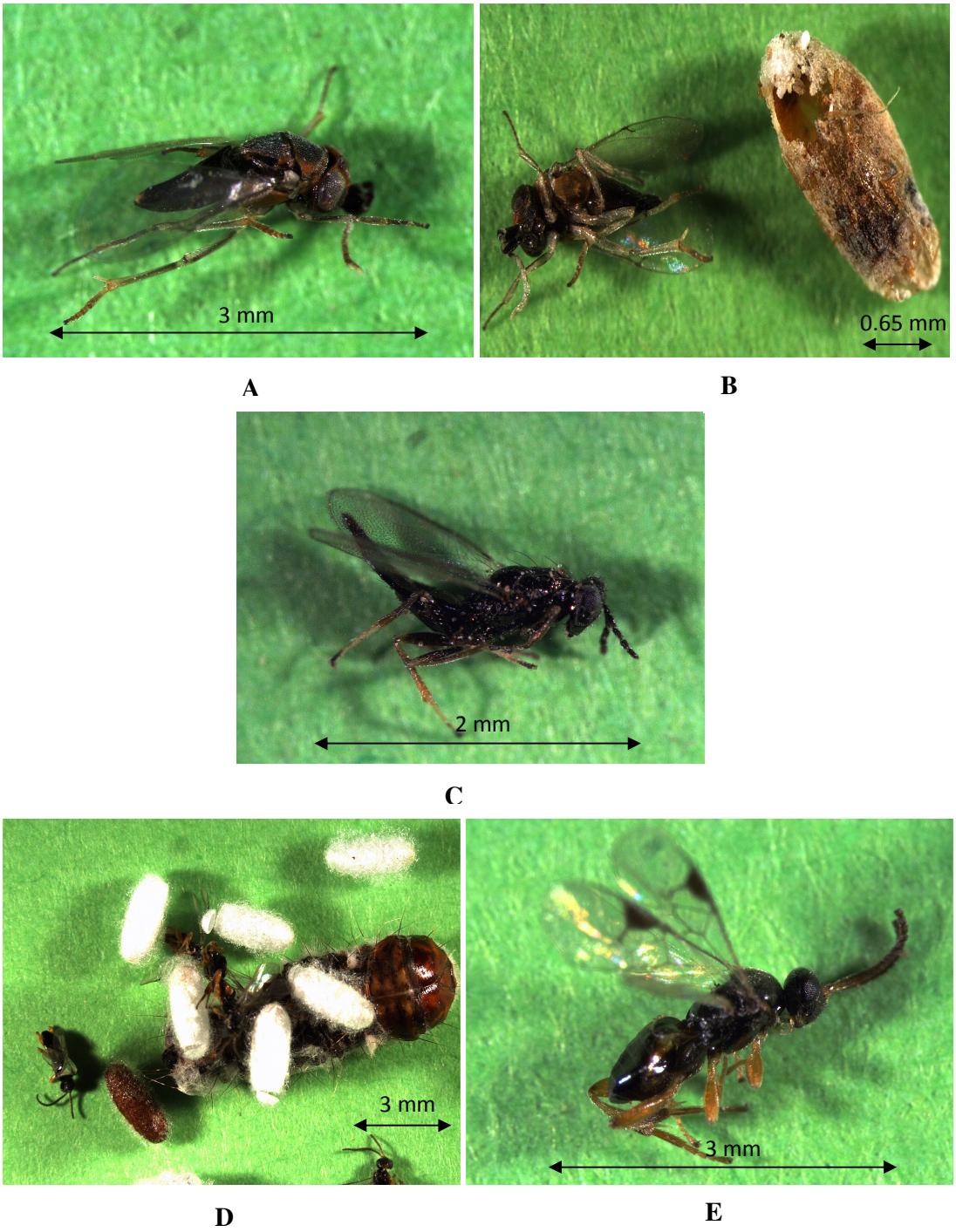

Figure 4.6. Parasitoids associated with key pest species: A & B - *Anagyrus* sp. from a mealy bug mummy (*Delottococcus* sp.), C - *Pediobius* sp. associated with *Phyllocnistis* sp., D & E - Braconidae sp. (indet.) from an *O. ammopleura* larva.

4.4 Discussion

4.4.1 Effects of pesticides application

Even with pesticide sprays, the arthropod species abundances were not significantly different from the unsprayed (control) Susara block ($p>0.05$). Only a slight difference in species abundances was noted between the sprayed, (Susara (S) and Sylvia) and the unsprayed ((control) Susara) block (Figure 4.2). The unsprayed Susara had relatively higher arthropod abundance, reflecting the small impact of pesticides on the blocks. Even among the sprayed blocks themselves, there were slight differences, with Susara (S) having slightly higher arthropod abundance than the Sylvia cultivar. This slight difference is likely to be explained by cultivar type, which has an effect on the abundance of many species of arthropods. Susara (*P. magnifica* x *P. susannae*) is an architecturally complex protea cultivar, which can grow as high as 3 m, while the Sylvia (*P. eximia* x *P. susannae*) cultivar has an upright growth of 1.8-2.4 m, and 1-1.5 m width. The more complex structure may result in pesticides not reaching some plant parts harbouring arthropods. An example of this is the mealybug *Delottococcus* sp., which has been reported to be a problem to control as it occupies areas unreachable by pesticides (Leandro *et al*. 2006).

Furthermore, in terms of the overall relationship of arthropod abundance to the rest of the other blocks, the sprayed blocks were intermediate (Figure 4.1) compared to the "Wild", Sheila and Safari sunset blocks (which had generally lower abundances) and the unsprayed Susara, Seedling and King protea blocks (which had relatively higher abundances). It seems that the plant/habitat complex was playing a role here, with structurally more complex plants/blocks having higher arthropod abundances (Wallner 1987). Even though the King protea is a low bush, its large flower head size (120 mm-300 mm diameter) is home to high numbers of arthropods (the smaller, docile insects have a tendency of hiding deep amongst

the florets (Visser *et al.* 1999, personal observation). The same applies to the Seedling block, which was made up of seven different protea species/cultivars, most of which had complex structures.

Unlike the Seedling block, the "Wild" block, even though it was made up of several different protea species had relatively lower abundance compared with the sprayed blocks. This might, as Coetzee (1986) points out, be a case of an undisturbed natural environment with a dynamic equilibrium between the host plants, the insects that feed on it, and the natural enemies, with overall lower arthropod abundance. This block had different genera and these e.g. *Leucospermum* due to the simple architectural structure are known to have fewer arthropods associated with them (Lawton 1983).

The significant differences in species richness between the sprayed and unsprayed blocks during spring ($p<0.05$) (Figure 4.3) was probably because the pesticides applied were effective at reducing arthropod species diversity in the sprayed protea blocks. This is further supported by the lack of significant differences among the sprayed blocks themselves in spring, as they might be reflecting the same impact of pesticides on the species (Figures 4.3 and 4.4). Also, compared to the rest of the blocks, overall the sprayed, Susara (S) and Sylvia blocks had the lowest species richness (Figure 4.5), which supports the assumption that pesticides impact species richness. However, the lack of significant differences during the other seasons likely reflects the overall ineffectiveness of the pesticides used, with pesticides being effective in spring but not effective the rest of the year (Figure 4.3).

Also, the presence or lack of significant differences on species richness might have been influenced by other factors, such as season (see also Chapter 3). Since season has been found to have an effect on species richness ($p<0.05$), it may mean that some species which were

recorded during the moderate weather conditions of spring were absent during the hot and dry weather of summer and so on (and hence no significant differences). Indeed, there were several minor (rare) species, which were recorded during spring in unsprayed Susara, but not in any other season (e.g. *Conimus* sp. (Lathridiidae), *Spermophagus* sp. (Bruchidae), *Trichostetha fascicularis* (Scarabaeidae), *Linepithema humile*, *Meligethus* sp. (Chrysomelidae), *Gephyrota* sp.1 (Philodromidae), Acaroidea (indet.) and Empididae (indet.)). These species might have been present in the sprayed blocks (most probably in Susara (S) since it was similar to Susara) but was affected by the pesticides sprays. It is highly likely that rare species are readily affected by pesticides, since they are not normally exposed to pesticides and are highly sensitive to them.

Even though there were no significant differences in arthropod abundance between the sprayed and control blocks, the results however (Table 4.2), did show some small differences, with the sprayed blocks having reduced numbers compared to the unsprayed (almost to 1:2 ratio in the Susara-Susara (S) case), with the trend: Susara > Susara (S) > Sylvia. However, the impact of cultivar still cannot be ruled out, especially among the sprayed blocks.

Given that the same pesticides were used almost on a monthly basis (see Table 4.1) and yet a lack of significant differences between the sprayed and control blocks was observed, there is the possibility that the pests could have developed tolerance or resistance to the pesticides. Almost the same species (regular species) appeared in most seasons and this gave them much exposure to the pesticides, and hence a chance to develop resistance to the pesticides. This included even the targeted key pest species such as the mealybug *Delottococcus* sp., borers (e.g. *O. ammopleura*) and leafminers (e.g. *Phyllocnistis* sp.). Although possibly the most important factor was that some of these pest species occupy areas which cannot be easily

reached by pesticides. For example, Leandro *et al*. (2006) found that mealybugs are difficult to control using pesticides as they occur under the involucral bracts.

In some cases e.g. Oecophoridae (indet.), the high percentages in the Susara (S) blocks and nothing in the other blocks might have been due to competing species being more susceptible to pesticides, leaving Oecophoridae (indet.) without competitors and hence more successful. Absence of competitors may mean no competition for space (habitats) and resources (food). However, its absence in Sylvia (another sprayed block) might be the effect of cultivar on species richness, Sylvia might not be the plant of choice for Oecophoridae. This might also explain the presence of the relative high numbers of *C. alphaeus* in Sylvia.

In the case of *D. longipes*, the difference is too small, which could be accounted for by chance, or this might be a problem of the pesticides not reaching plant recesses where the pest is present. *D. longipes* usually inhabits the inside of inflorescences (and under involucral bracts in the case of King protea), where this pest causes serious phytosanitary problems. Looking at other blocks, about every one in four King protea heads were affected by *D. longipes*. In the case of *Argyroploce* sp., it is highly likely that this species does not prefer the selected blocks, as it was not even recorded in the unsprayed block. Moreover, its overall abundance in all proteas was generally low throughout the Proteaceae blocks (mean log abundance = 1.11).

Even though the differences were not statistically significant, natural enemies still followed the same trend (Susara > Susara (S) > Sylvia) as that of key pest species, where a relatively higher abundance was recorded in the unsprayed block than in the sprayed blocks (Table 4.2). The species maintained the 1:2 ratio of sprayed to unsprayed blocks, as was observed for the key pest species percentage abundances (Table 4.2). This further reflects the possible

negligible impact of the pesticides, and suggests that pesticides had the same effect on both the key pest species and natural enemies.

Since a diverse array of natural enemies, i.e. general predators (coccinellids, spiders and predatory mites) and parasitoids were found, these might also be playing a major role in suppressing pest species in these proteas. Parasitoids besides being more specialist than predators, were also associated with fewer Proteaceae blocks (Table 4.4). Interestingly, some parasitoids were even associated with specific key pest species, e.g. *Pediobius* sp. was closely associated with *Phyllocnistis* sp., *Anagyrus* sp. closely linked with the mealybug, *Delottococcus* sp., and Braconidae (indet.) associated with *O. ammopleura*.

Anagyrus sp. parasitized about 33.3% of the mealybug (*Delottococcus* sp.) population and appeared to prefer large specimens. This is not very different from what has been recorded in biological control trials in commercial proteas carried out in Portugal, where percentage parasitism by *Anagyrus* sp. was recorded at 34.5% (Leandro *et al*. 2008). However, unlike in Portugal, no records of hyper-parasitism or encapsulation were recorded here for this *Anagyrus* sp.. According to Blumberg (1997a), the low levels of hyper-parasitism and of encapsulation suggest a high physiological adaptability of parasitoids to their host. This, together with the values of the parasitism rate, indicates that *Anagyrus* sp. has much potential as biological control agent for suppression of the mealybug. Even in the field, mealybug mummies are relatively common. *Anagyrus* sp. has also been reported to be a successful biological agent in the control of vine mealybug (*Planococcus ficus*) in the Western Cape, South Africa (e.g. Walton and Pringle 2004a, Mgocheki and Addison 2009), as well as in some other parts of world (e.g. Gülec *et al*. 2007).

Channel leafminer, *Phyllocnistis* sp. and black moth, *O. ammopleura* larva were found to be parasitized by *Pediobius* sp. and an unidentified braconid wasp (Braconidae indet.) respectively. Percentage parasitism of *Phyllocnistis* sp. by *Pediobius* sp. was found to be 26.67%, and is the first time that this association has been reported in proteas. However, one drawback of this parasitic wasp is that it appears to affect the leafminer after the damage has been already done to the foliage. This appeared so because most of the parasitoids emerged from the leaf folds made by the leaf miner for pupating. However, there is still the general advantage that one *Pediobius* sp. instead of a leaf miner, results in one less pest adult that would have laid more eggs and increase the pest population.

The parasitoid associated with *O. ammopleura* could not be identified further than the family level. Percentage parasitism was found to be low, 6.67% (Table 4.5). Interestingly, one black moth larva yielded about nine Braconid (indet.) parasitic wasps and two encapsulated eggs. The low parasitism of this pest was likely because of the location it inhabits (it tunnels into stems or infructescences) making it difficult for the parasitic wasps to reach (this makes sanitation an important action in controlling this pest in proteas). Moreover, Dent (1991) urged that the use of natural enemies for the control of low threshold pests is generally not feasible.

It was interesting to note that the newly discovered invasive ladybeetle species to South Africa, *H. axyridis* had a slightly wider range of occupancy than the common and naturalised (well established) *H. variegata*. Moreover, these coccinellids species dominated by far the other coccinellids, *Cheilomenes lunata* and *Cheilomenes propinqua*. These last two species had narrow host preferences, i.e. in the number of protea blocks they were associated with. It also appears as if the highly invasive *H. axyridis* is outcompeting the other two species. In

other countries, where *H. axyridis* has invaded or been deliberately introduced, there are reports of displacement and threats to the native coccinellid species. Cottrell and Yeargan (1998) and Cottrell (2005) found that *H. axyridis* larva even preyed on native coccinellid species (feeding on eggs and larvae) and moreover they are more aggressive and have a size advantage over the native species. Also, Soares and Serpa (2007) concluded that if re-introduced to the Azores, *H. axyridis* would present a risk to the native species.

In a risk assessment of 31 exotic natural enemies of pest species used in biological control in Europe, *H. axyridis* had the second highest environmental risk index. This was founded on its wide host range (i.e. multiple prey species), ability to establish and disperse, and direct and indirect effects on non-target species (van Lenteren *et al*. 2003). According to van Lenteren *et al*. (2007) there is no easy way to mitigate or reduce the risk of *H. axyridis*.

However, *H. axyridis* is known to be an effective predatory species, especially for aphid species in areas where it is established (e.g. Brown *et al*. 2008). Since, there were negligible numbers of aphids found in this study, this might mean this coccinellid was most likely targeting other prey in proteas. But since it is already linked with soft bodied prey, they were mostly associated with blocks with relatively high mealybug infestations, they were perhaps impacting on this host.

Unlike the other coccinellids, *H. axyridis* was the only coccinellid in both sprayed blocks, Susara (S) and Sylvia. This may mean that it has some degree of resistance to pesticides, in which case it will increase its environmental risk status. Nonetheless, there is the need to know more about this predator, especially on issues like its preferred and alternative prey in proteas. *H. axyridis*, being an effective predator, seems to be good news to the protea farmer, but it appears to threaten biodiversity as a whole. This might also lead to secondary pests

outbreaks as those pest species which were being suppressed by other coccinellids, and the non-preferred prey of *H. axyridis* may increase.

Overall species richness associated with the King protea seems to extend to high species richness of natural enemies as well. Indeed, most key pest species were recorded on King protea (see Chapter 2). However, the Seedling block, besides having relatively high overall species richness, yielded relatively lower numbers of natural enemy species. This may have been partly due to this block being largely dominated by coleopteran species e.g. *Phloenomus* sp., which are rarely associated with certain natural enemies guilds such as parasitoids. This however could explain the high presence of *P. capensis* (general coleopteran predator), mainly in the inflorescences of the Seedling block. This general predator could have been preying on the other abundant coleopteran species occurring in the Seedling block.

4.5 Conclusions

Overall, pesticides had no significant impact on species abundances at all trophic levels. However, pesticides had some effect on species richness, with rare species being most affected, possibly being sensitive though lack of prior exposure. The lack of significant differences in abundance of most species emphasizes the ineffectiveness of the pesticides, despite the fact that they had been applied on a monthly basis (Table 4.1). This is an economically and environmentally unacceptable approach. Furthermore, chemical resistance may already have developed. This calls for an implementation of an IPM programme in commercial proteas. Furthermore, fungicides were applied, which may have affected the fungi on which various species such as mites, some beetles and bugs depend on.

Low levels of encapsulation and no records of hyper-parasitism in the recorded parasitoids suggest a high physiological adaptability to hosts. This together with the values of the parasitism rate (especially that of *Anagyrus* sp.) indicates that the parasitoids have a high potential as biological control agents for use in the suppression of the pest populations in the proteas. However, these species must be extensively evaluated under field production conditions, i.e. the number of pests to be incubated for parasitism assessments. Even though mealybugs collected under the involucral bracts of *P. cynaroides* were parasitized, it is extremely important to determine how effective the parasitoids are in locating and parasitizing the mealybugs underneath these flower bracts. Overall, the presence of a diverse array of natural enemies showed the potential of alternative pest management in proteas.

4.6 Recommendations

4.6.1 Preliminary suggestions for IPM

As this study shows that the current pesticides applications are not effective in controlling the pests, and yet also have a negative impact on the natural enemies, there is need to integrate pest control methods so as to effectively reduce the pests numbers to below the economic injury levels in an environmentally sensitive way. IPM involves use of different approaches to control pests in agroecosystems, and these involve implementation of a monitoring system, applying thresholds, and encouraging biological control, as well as cultural/physical and chemical control (Dent 1991). Since a diversity of natural enemies was recorded here associated with commercial proteas, biological control can be considered. Also, there is need to revise and screen the pesticides used, for instance, opting for "soft" pesticides and apply them at appropriate times of the year. Also, there is a need to assess cultural and physical measures which facilitate pest reduction.

In South Africa, Wright (1995) established some preliminary IPM procedures for proteas, some of which are expanded upon here.

4.6.1.1 Monitoring

Monitoring is very important for determining the pest status in the field. There is a need to check for pest signs, e.g. eggs, damage on the more vulnerable structures such as new flushes and flower buds from time to time. Early detection of pests will result in action being taken before serious and economic damage has been done. Early detection of pests may reduce inappropriately timed pesticides applications.

To have an effective monitoring system, efficient monitoring methods and devices must be put in place, i.e. sampling methods. According to Binns *et al.* (2000), efficient field sampling

is a corner stone of pest management. Sampling methods can be divided into absolute and relative methods as well as population indices (Romoser and Stoffolano 1998, De Villiers 2006). Absolute sampling methods provide information on pest population levels per unit habitat (Romoser and Stoffolano 1998, De Villiers 2006, Pringle unpubl.) like the number of borer pests per new flush. Relative sampling methods relate pest activity to the particular sampling method used, and not to a unit of the habitat within which the sampling is being conducted, e.g. use of traps counts. Population indices involve looking at the effects of arthropod activity, such as plant damage (Romoser and Stoffolano 1998, De Villiers 2006).

Combination methods, for instance making use of absolute methods and population indices, can be applied simultaneously for pest monitoring (Table 4.6A). However, considering that proteas are being grown in their natural environment where a number of the pests are endemic and occur in the natural environment as well, use of relative sampling methods can be a problem. The traps may attract pests from the surrounding natural habitat, making it difficult to tell whether the arthropods trapped are from the commercial fields or from the wild vegetation.

Table 4.6A. Suitable sampling methods, approximate infestation % and proposed time for monitoring of key pest species in Proteaceae.

Pest	Sampling method	≈High infestation %	Peak months	Proposed monitoring T	Most preferred cultivar
Phyllocnistis sp.	AS/PI	>90	January-March	When new flushes begin	Susara
C. alphaeus	AS/PI	25	October-December	September - AYR	KP
Delottococcus sp.	AS	25	January-March	September - AYR	KP/Safari sunset
O. ammopleura	AS/PI	33	December-January	When new flushes begin - AYR	Susara
Argyroploce sp.	AS	8	January-March	October & June - AYR	KP
**E. acerbella*	PI	N/A	June-July	April-May	Safari sunset

PI = Population indices, AS = Absolute sampling
*negligible number of *E. acerbella* recorded but exhibited severe plant damage.
AYR = All Year Round
T = Time

Table 4.6B. Stages to look for during monitoring, most preferred positions on plants and the signs of key pest species presence.

Pest	Stages to search	Position preferred	Signs of pest presence
Phyllocnistis sp.	Pre-pupa (bright yellow)	New flush leaves	Characteristic tunnels and folded leaves
C. alphaeus	Eggs (dull white & dome shaped)	Lower side of flower bud	Excreta on infructescence
Delottococcus sp.	Egg sacs/Crawlers/Adults	Under involucral bracts leaves	Sometimes honey dew visible on bracts
O. ammopleura	Eggs/Larva (pink red eggs/whitish larva)	New flush stems/leaves & buds	Wilting shoot tips & pin sized hole on young stem
Argyroploce sp.	Eggs/Larva (flat whitish eggs/cream larva)	Young buds/stems	Wilting shoot tips & stems
**E. acerbella*	Larva/Adults	New flush leaves/stems	Damaged young leaves and stems

Information on biology and seasonal occurrence of pests (Chapter 3) plays a significant role in pest monitoring. Sometimes it will not be economical to apply pesticides on first detection of pests. There are levels (economic thresholds) at which action must be taken, and this information is all gathered through monitoring. Table 4.6B provides additional information

which might be useful in monitoring of key pest species in Proteaceae. It must also be emphasized that monitoring of some of the key pest species be conducted throughout the year as they are multivoltine.

4.6.1.2 Thresholds

Thresholds are defined as levels of pest damage which warrant the use of plant protection measures, usually an application of a pesticide. There are three types of thresholds which are relevant to decision making in pest management, i.e. economic damage (ED), economic injury level (EIL) and economic threshold (ET). The ED is defined as the amount of damage that justifies economic control, and is caused by arthropod population which exceeds the EIL. EIL is the lowest population density that will cause ED. The ET is the level at which control measures should be implemented to prevent an increasing pest population from reaching the EIL (Dent 1991).

According to Wright (1995), crop loss to borers in proteas can be determined and so can the determination of thresholds. For instance, each bud or stem which is attacked may be considered lost. Percentage infestation could be estimated as number of buds/stems in a sample of 100 stems infested with eggs of bud/stem borers. The cost of crop loss is simply a percentage of the estimated yield per hectare lost to pests. Spraying costs are easily calculated (e.g. amount of pesticide applied per hectare and operating costs) and then determination can be made of what percentage of infestation requires the application of an economically viable and suitable control measure. At lower infestation levels, the cost of insect control exceeds the value of the crop lost and financial losses can be incurred. N.B. calculations could not be done here due to lack of operating data. It must also be noted that most of the borer species are low threshold pests, i.e. they can cause economic damage at very low population levels.

4.6.1.3 Biological control

A number of key pest species were found directly associated with their natural enemies in this study (Table 4.5). Channel leafminer, *Phyllocnistis* sp., was associated with the eulophid parasitic wasp, *Pediobius* sp.; mealybug, *Delottococcus* sp. was parasitized by *Anagyrus* sp.; *O. ammopleura* by a braconid parasitoid. *Capys alphaeus* eggs have been reported to be attacked by chalcids, although no larval parasites have yet been identified. It is suspected that the pupa may be attacked by certain ichneumonids (Clark and Dickson 1971). *Epichoristodes acerbella* was reported to be attacked by an unidentified parasitoid in the field, with a percentage parasitism of approximately 35% (Wright 1995). In summary, this makes *Argyroploce* sp. the only "most devastating" key pest species of proteas with no recorded specific natural enemy in the field. In addition, there was a large suite of other parasitoids which could not be directly linked to specific pests, as well as other general predators (e.g. a large number of spiders and coccinellids).

The large number of natural enemies in these proteas illustrates the potential of biological control as a pest management tool in the commercial cultivation of these plants. Percentage parasitism for some of these natural enemies is relatively high (Table 4.5), considering that pesticides were also applied. Wright (1995) pointed out the challenge faced by predators and parasites in monocultures where pesticides are used. Pesticides tend to lead to pest outbreaks, including that of secondary pests. Rearing the natural enemies here is a challenge. Furthermore, introducing large populations of parasitoids and predators may lead to disruption of ecological processes in the neighbouring natural vegetation.

What is needed now are methods that promote natural enemy population development in commercial protea fields. It can be started by judicious use of insecticides to conserve the predators and parasitoids. With the knowledge of seasonal occurrence and use of monitoring

of key pest species, it could be easier to know when to apply pesticides (especially making use of "softer" pesticides). Natural enemy populations can also be boosted by creating an environment that provides them with refuge, i.e. environmental manipulation to suit the environment favoured by natural enemies.

However, the most promising avenue of IPM in commercial proteas is the use of entomopathogenic nematodes (Wright 1995). Actually, Wright (1991) found from laboratory experiments that entomopathogenic nematodes are effective in borer species causing about 93% borer mortality in proteas. The applications of nematodes are spatially explicit in the target fields, their impact on surrounding natural biodiversity is likely to be minimal.

4.6.1.4 Cultural control

Cultural control is the use of agricultural practices which makes plants within the agro-ecosystem less susceptible to attack by pests (Dent 1991). However, many cultural practices such as polycropping and intercropping have not yet been tested in proteas. The aim is to increase plant diversity in the monocultures to promote a higher density of predators and parasitoids (Altieri and Nicholls 2004, Swallow *et al*. 2006). The high levels of natural enemies are brought about by an improvement in conditions for their survival and reproduction. For example, certain flowering plants are known to provide greater temporal and spatial distribution of nectar and pollen sources, which can increase parasitoid reproductive potential and abundance of alternative hosts/prey when the pest species are scarce or at an inappropriate stage (Dent 1991, Altieri 1994). There is a need to find out which plants are favoured by the parasitoids, as well as carrying out polycropping and intercropping experiments to find out how the parasitoids react.

There is need to include plants that do not compete directly with the protea plants, otherwise the flower yields will be affected in another way besides that of pests. Use of trap plants is a possibility and can be recommended in commercial proteas since they are grown in their natural environment with many local (endemic) pests. Plants which are known to be highly preferred by the pestiferous species would be grown either at the field edge or among protea rows to attract the pests, leaving the commercial proteas less exposed and incur less damage (Cook *et al*. 2007). There are some other natural enemy conservation methods that have not yet been applied to proteas, which have yielded positive results elsewhere, e.g. use of conservation headlands (e.g. Dover 1997), beetle banks (e.g. Wäckers *et al*. 2005) and agri-environmental schemes (so far exclusive to Europe) (e.g. Kleijn and Sutherland 2003).

Changes in physical environment resulting in crop manipulation can also be used as a means of cultural control, e.g. irrigation may reduce pest population development (Dent 1991, Charlet *et al*. 2007) and pest control (Opit *et al*. 2006). Wright (1995) recommended that the plants must always be in good health, as healthy plants have higher tolerance levels for pests. Wright (1995) also urged the need to find out if certain protea species/cultivars are more susceptible under certain habitat or climatic conditions, so that careful choices of what species/cultivars are to be grown in which localities can be made.

4.6.1.5 Physical control

Sanitation in the protea stands is an important key aspect in managing their pests. All old and infected inflorescences and infructescences, as well as infected stems, must be removed from the fields, as they may remain as sources of pest reinfestations (Coetzee *et al*. 1988, Wright 1995). Like the case presented in Chapter 2, *G. hottentottus* (a protea seed eater) was found abundant in the "Wild" block where seed heads were not harvested throughout the year,

thereby acting as reservoirs for the borers. Another possible way of avoiding extensive damage on proteas (though rather expensive) is growing the plants under glass. Besides keeping the plants away from direct contact with a number of arthropods, the physical environment can be controlled (also good for cultural control (Dent 1991)) resulting in disruptions of the biology of those pest species which manage to pass through the barrier. However, under glass, several pathogenic diseases are likely to be a problem due to the confined environment (Dent 1995).

Covering developing infructescences with nylon cloth is another physical method some farmers in South Africa have been using to protect them from pest damage. However this method is labour intensive and only suitable for small-scale protea producers.

4.6.1.6 Chemical control

The chemical control component of IPM aims to reduce the overdependence on chemical use. With the use of monitoring and threshold information, pesticides must only be applied when absolutely necessary, i.e. target specific times of emergence or when pests are reaching the ET. In the case of borers, timing is vital, e.g. many borers became difficult to control using pesticides when they inhabit inaccessible microhabitats inside inflorescences, infructescences and stems. Considering that low threshold pests that affect proteas are difficult to control using biological control (Dent 1991), judicious application of pesticides is crucial. New pesticides trials must be conducted in the South African Proteaceae industry to find better and effective pesticides. Moreover, there is a need for registration of these pesticides once found and urging the farmers to practice IPM techniques to avoid overdependence on chemicals.

Use of “soft” pesticides, e.g. botanic derived pesticides such as azadirachtin, as well as other biopesticides (e.g. Bt (*Bacillus thuringiensis*)), are recommended, as they do not leave

harmful residues in the environment. *Bt* has been tested against borers in Portugal and showed some acceptable efficiency, even though of course it did not affect the eggs (as it must be ingested), which later hatched and led to a second outbreak (Leandro *et al*. 2006). But when used in combination with other control measures such as biological control can be effective. For example, when used with *Trichogramma* sp. in the control of *H. armigera*, in proteas in Portugal the borer numbers were significantly reduced (Leandro *et al*. 2006). Use of silicon has been found to be useful in pest control, especially in sugar plantations. Silicon is considered to have a catalytic role in the expression of physiological resistance through the production of tannic and phenolic compounds, among other chemicals. Phenolic and tannic compounds have already been reported to reduce leaf herbivory in proteas (Wright and Giliomee 1992, Coetzee *et al*. 1997). Nevertheless, their impact on reducing herbivory on other structures e.g. stems and flowering structures for borers is unknown. Silicon addition to proteas may however increase the resistance compounds to all the other plant structures, and thereby reduce pest damage.

Tannic and phenolic compounds are known to function by reducing the nutritional value of the plant material, as they form a protein precipitate in the arthropod gut (Wright and Giliomee 1992). A diet containing as low as 0.5% tannic acid can lead to significant growth reduction of caterpillars (Karowe 1989) and higher levels (through silicon addition to plants) may increase the toxicity. Silicon application in pest control has the advantage that it leaves no pesticide residues in food or in the environment. Moreover, it can be integrated with other pest control management practices such as biological control (Laing *et al*. 2006).

It is also timely to start breeding cultivars (varieties) that are both visually attractive, yet with a resistance to arthropod damage. This can be achieved through increasing plant resistance

using genetics. Plants in the wild might have the traits of pest resistance and these may be transferred to cultivars.

4.6.2 Problems regarding the application of IPM to commercial Proteaceae in South Africa

The fact that proteas are being grown in their natural environment with their natural community of arthropods is a huge problem. Furthermore, the surrounding natural vegetation remains as a source of reinfestation for the commercial fields (Coetzee1986). Other pest control programmes are unlikely because they end up affecting those species in the natural environment as well, e.g. area-wide IPM is practically not feasible in commercial proteas. To avoid ecological disruptions in the natural environment, only methods that affect those species in the commercial fields must be applied.

The other challenge of implementing an IPM programme in ornamentals is the presence of numerous species and cultivars which are usually affected by different arthropod pest complexes. Moreover, there is zero-tolerance for plant damage (as it is usually the whole flower stem which is marketed) and arthropod presence for export material (Dent 1995).

It is highly likely that the farmers may be reluctant to implement IPM if they are not convinced by the economic benefit of the programme. Only when the IPM method is perceived to be better than conventional methods will it be adopted by growers (Dent 1995). Yet the fact that the current pesticides are not effective, in addition to the problem of pesticide registration in this industry, particularly in South Africa (Wright 1995) appears to leave the growers with little choice but to implement an IPM programme.

There is not much hope for cultivating export-quality proteas commercially in their natural habitat unless arthropod control measures are developed. For this reason development of an IPM programme is of the utmost importance (Coetzee 1986). Further work on IPM in proteas is recommended, for a start by finding out the threshold values and monitoring of the key pest species.

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Chapter 5

General discussion

5.1 General synthesis

Even though the proteas are here cultivated in commercial blocks, they are still surrounded by natural vegetation, including wild protea plants, with their associated arthropods. This means the natural vegetation may act as reservoirs and sources of reinfestation of arthropod pests in commercial blocks. There are a large number of arthropods associated with cultivated Proteaceae. They range in size from the large long-horned beetles to tiny species which can be hardly seen without an aided eye, e.g. mites and thrips. Among these arthropods are a number of pest species which threaten the commercial cultivation of proteas.

In all protea-growing regions and on all cultivars, control of e.g. lepidopteran borers is the main challenge. However, in Portugal, *Helicoverpa armigera* (Noctuidae), *Sesamia nonagrioides* (Noctuidae) and *Cacoecimorpha pronubana* (Tortricidae) were the main pests of cultivated proteas (Leandro *et al*. 2003). In the study here, four major lepidopteran borers *Capys alphaeus* (Lycaenidae), *Orophia ammopleura* (Oecophoridae), *Argyroploce* sp. (Tortricidae) and *Epichoristodes acerbella* (Tortricidae) were the most important pests. This concords with findings on wild proteas (e.g. Myburgh *et al*. 1975, Coetzee and Giliomee 1987). In addition to these lepidopteran borers, *Phyllocnistis* sp. (micro-lepidopteran leaf miner) is also a major challenge. The reason why lepidopterans favour protea plants is not clear, especially considering that these plants have been reported to have low arthropod nutritional value (Wright and Giliomee 1992).

However, even though these pests belong to the same taxonomic order, they are not closely related, i.e. the lepidopteran pests in South Africa are almost entirely of different families compared to those other countries, especially Portugal. Only *C. pronubana* and *E. acerbella*

are of the same family, Tortricidae, and have the same effect on the plants, i.e. making a web around young leaves joining them together and feeding within this nest (carnation worms). The larvae prefer mostly *Leucadendron* varieties in both areas.

The mealybug *Delottococcus* sp. was among the key pests in South African commercial proteas. Furthermore, pesticide spray programmes against it are ineffective, expensive and environmentally unacceptable. This mealybug occurs under the involucral bracts, where pesticide sprays cannot easily reach, and making control difficult. This situation is unlike in Portugal, where mealybug, *Paracoccus* sp. was controlled by pesticides because this insect was on exposed structures (Leandro *et al*. 2006). In contrast, *Delottococcus* sp. in South Africa is probably well adapted to protea species since both are confined to this region. The mealybug might have been selected to survive in the most favourable microhabitats (underneath the bracts), as a survival tactic from attack by natural enemies. Protection from pesticides is a side effect of this strategy.

Plant`s structural architecture provides a number of microhabitats that are suitable for a variety of species. For example, greatest arthropod species richness was recorded also in other studies especially from the genus *Protea*. This is likely attributed to the structurally more complex nature of these plants compared to the simpler architecture of the other common genera such as, *Leucadendron* and *Leucospermum*. Furthermore, the size of most *Protea* species, be it inflorescences, infructescences, leaves or stems, are generally twice (and much more in the case of *P. cynaroides*) the size of either a typical *Leucadendron* or *Leucospermum.* In other words, the more complex the plant and the larger the infructescences, the more microhabitats are available for a greater variety of arthropods.

It also appeared that a combination of protea cultivar/species and season determines the arthropod species. As the season changes, so is the change in plant`s development. Plants develop structures such as new flush leaves, inflorescences and infructescences as the seasons change. This change in plant structure was found to affect the arthropod species to be found on a protea cultivar/species, because this could result in either increase or decrease in habitat or food sources availability. Those plants which becomes more structurally complex were found to inhabit more arthropod species. Host plant size, growth form and variety of resources were also found to be the determinants of species abundances on protea.

Carnation worm *Epichoristodes acerbella* and eucalyptus longhorned borer *Phoracantha semipunctata* were the only major arthropod pests also affecting other non-protea crops. They were however found in low abundance probably due to the poor nutritional content of proteas (Wright and Giliomee 1992). For many species that are pests on other crops the low nutritional status and anti-herbivory defence mechanisms of proteas may be inhibitions to colonization. There is a possibility that some arthropods on proteas might only find it as a suitable habitat, since it provides a diversity of habitats, with some arthropods only coming to feed on abundant nectar and pollen. This could also further explain the high numbers of species in the flower visiting/free living guild.

Even though this study contributes to the arthropod ecological data of the fynbos and pest management in proteas, poor identification of arthropods could hinder continuing progress in the field. There is need for reliable identification of the pest species which is an important prerequisite for effective control and quarantine measures, especially if IPM or biocontrol is applied. More sampling and taxonomic identification of fynbos and commercial plant species are required, because as Parrella and Keil (1984) pointed out, taxonomic confusion is a major

problem for pest control. This is because closely-related species may have a different lifestyle and different host preferences. Agromyzids for example, are difficult to identify because of their morphological uniformity and small body sizes, and several, similar species may occur together.

5.1.1 Other notable findings in proteas

There is concern here that the significant invasive species, the ant *Linepithema humile* and the coccinellid *Harmonia axyridis* were recorded. Presence of *L. humile* is not surprising as it is a major invader of disturbed fynbos (e.g., De Kock and Giliomee 1989, Luruli 2007) and it is not surprising that it was recorded in these effectively disturbed protea patches. Presence of *H. axyridis* is of great concern as it is known to have a major impact on ecosystems (Michaud 2002, Cottrell 2005, Roy *et al*. 2006), with the possibility of having a severe impact on fynbos insects at various trophic levels.

5.1.2 Climate change and arthropods

There is need to determine the potential impacts of climate change on arthropods of fynbos and pest complexes. Temperature is one of the driving forces affecting survival, development and movement of arthropods (Fraser 2006). An increase in temperature due to climate change could affect arthropod development, which includes pest species and natural enemies. There is also the possibility that some insects that are normally secondary pests might become serious pests (Thomson *et al*. 2010).

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Appendix 1. Rank-log abundance of Proteaceae-associated arthropod species recorded from Molteno Brothers Estate, Grabouw, Western Cape (indet. = indeterminate species, meaning inconclusive, undetermined to at least genus level).

SPECIES	RANK	LOG ABUNDANCE
MAJOR (ABUNDANT) SPECIES		
Phloenomus sp.	1	3.45
Diaplochelus longipes	2	2.99
Chirodica sp.1	3	2.96
Staphylinidae sp. (indet.) (larva)	4	2.76
Phyllocnistis sp.	5	2.68
Phyconomus tricolor	6	2.46
Technomyrmex albipes	6	2.46
Platysoma capensis	7	2.42
Pria cinerascens	8	2.41
Agromyzidae sp. (indet.) (pupa)	9	2.36
Delottococcus sp.	10	2.28
Diptera sp.1 (indet.) (larva)	11	2.2
Capys alphaeus	12	2.13
Orophia ammopleura	13	1.92
Psocoptera sp. (indet.) (booklice)	14	1.77
Drosophila sp.	15	1.72
Histiostoma feroniarum	15	1.72
Clubiona abbajensis	16	1.7
Tortricidae sp. (indet.)	17	1.69
Pediobius sp.	18	1.64
Oxycarenus maculatus	19	1.6
Argyroploce sp.	20	1.48
Theridion sp.1	20	1.48
Hippodamia variegata	20	1.48
Acaroidea sp. (indet.)(deutro nymph)	21	1.38
Haplothrips bagnali	22	1.36
Genuchus hottentottus	23	1.34
Diplopoda sp. (indet.) (millipede)	24	1.32
Synaptothrips gezinae	25	1.3
Lepidoptera sp. (indet.)	25	1.3
Cryptophagus milleri	26	1.28
Antestia astrosignata	26	1.28
Harmonia axyridis	27	1.26
Braconidae sp. (indet.)	28	1.2

Carabidae sp. (indet.)	28	1.2
Collembola sp. (indet.) (springtails)	29	1.18
Macrocheles sp.	30	1.15
Oecophoridae sp. (indet.)	31	1.11
Diptera sp.2 (indet.)	32	1.04
Formicomus coeruleus	33	1
Xerophaeus sp.1	33	1
Ameroseius sp.	33	1
Acarus sp. (cf *immobilis*)	33	1
MINOR (RARE) SPECIES		
Echemus sp.1	34	0.95
Heliophanus debilis	34	0.95
Cheiracanthium sp.1	34	0.95
Chresiona sp.2	34	0.95
Rhyzobius sp.	34	0.95
Apis mellifera capensis	34	0.95
Glycyphagus sp.	34	0.95
Empididae sp. (indet.)	34	0.95
Synema imitator	35	0.9
Porcelia sp.	35	0.9
Nysius sp.	35	0.9
Diplogyniidea sp. (indet.)	36	0.85
Baryphus sp.	36	0.85
Nitidulidae sp. (indet.)	36	0.85
Eulophidae sp. (indet.)	36	0.85
Pheidole sp.1	36	0.85
Theridion sp.2	37	0.78
Lepisiota sp.1	37	0.78
Tyrophagus putrescentiae	37	0.78
Sciaridae sp. (indet.)	37	0.78
Macrosiphum euphorbiae	37	0.78
Psyllidae sp. (indet.)	37	0.78
Olethreutidae sp. (indet.)	37	0.78
Araneae sp. (indet.)	37	0.78
Phlegra bresnieri	38	0.7
Linepithema humile	38	0.7
Anthophoridae sp. (indet.) (scale insect)	38	0.7
Formicidae sp. (indet.)	38	0.7
Anagyrus sp.	38	0.7
Pelecopsis janus	39	0.6
Euryopis sp.	39	0.6

Monomorium sp.	39	0.6
Conimus sp.	39	0.6
Trichostetha fascularis	39	0.6
Polistes sp.	39	0.6
Orius sp.	39	0.6
Aphididae sp. (indet.)	39	0.6
Menemerus sp.1	40	0.48
Trachelas sp.1	40	0.48
Neoscona subfusca	40	0.48
Pheidole sp.3	40	0.48
Nezara viridula	40	0.48
Vitticatantops humeralis	40	0.48
Phlaeothripidae sp. (indet.)	40	0.48
Stictopleurus scutellaris	40	0.48
Pyrallidae sp. (indet.)	40	0.48
Hymenoptera sp. (indet.)	41	0.3
Heliophanus insperatus	41	0.3
Holopelus almiae	41	0.3
Meranoplus peringueyi	41	0.3
Sphenoptera cupreosplendens	41	0.3
Xenoomorphus sp.	41	0.3
Euderes lineicollis	41	0.3
Heteroderes sp.1	41	0.3
Chirodica sp.2	41	0.3
Spermophagous sp.	41	0.3
Orthoschizops reticulata	41	0.3
Tulipidae sp. (indet.)	41	0.3
Bactrothrips sp.	41	0.3
Haplothrips avaneae	41	0.3
Cecidomyiidae sp. (indet.)	41	0.3
Elasmus sp.	41	0.3
Cerhysiella sp.	41	0.3
Blaberidae sp. (indet.)	41	0.3
Mantodea sp. (indet.)	41	0.3
Philodromous sp.1	42	0
Thyene sp.1	42	0
Tibellus sp.	42	0
Gephyrota sp.1	42	0
Pardosa sp. 1	42	0
Massagris regina	42	0
Chresiona invalida	42	0
Theridiosomatid sp. (indet.)	42	0

Camponotus sp. 1	42	0
Plagiolepis sp.1	42	0
Camponotus sp.2	42	0
Pheidole sp.2	42	0
Cheilomenes propinqua	42	0
Sibinia cervina	42	0
Isorhynchus sp.1	42	0
Meligethus sp.	42	0
Cheilomenes lunata	42	0
Epichoristodes acerbella	42	0
Rodolia cardinalis	42	0
Sitophilus sp.	42	0
Platygastridae sp. (indet.)	42	0
Eurytomidae sp. (indet.)	42	0
Eucoilidae sp. (indet.)	42	0
Lasioglossum sp.	42	0
Bethylidae sp. (indet.)	42	0
Agraphosus sp.	42	0
Pemphigus sp.	42	0
Phoracantha semipunctata	42	0
Dermaptera sp. (indet.)	42	0
Chilopoda sp. (indet.)	42	0
Tenebrionidae sp. (indet.)	42	0
Acanthacris ruficormis	42	0
****Proctolaelaps vandenbergi*		TNTC
****Stylommatophora (snails)		0.6

*** = *too numerous to count individuals singly*

****= *non-arthropod species*

TNTC = *too numerous to count*

Appendix 2. Test for significant differences between the species richness of arthropods associated with various Proteaceae blocks per season (post hoc Bonferroni) on Molteno Brothers Estate, Elgin. Bonferroni test; variable: species richness. Probabilities for Post Hoc Tests. Error: Between MS = 0.05449, df=1340.0

CELL	SEASON	CULTIVAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	SPRING	SHEILA		0.012353	1.000000	1.000000	0.000000	1.000000	0.000736	0.036213	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.012893	0.001359	1.000000	0.000000	1.000000	0.212583	1.000000	1.000000	1.000000	0.000336	1.000000	0.000000	1.000000	0.000011	1.000000	1.000000	1.000000	1.000000
2	SPRING	SEEDLING	0.012353		0.000000	1.000000	0.965281	0.002596	0.000000	1.000000	0.001120	0.000000	0.000357	0.000001	0.049371	0.000000	0.000000	1.000000	0.209524	1.000000	1.000000	1.000000	0.000364	0.243492	0.000054	1.000000	0.861374	0.024414	0.000000	1.000000	0.008408	0.000590	1.000000	1.000000
3	SPRING	SYLVIA	1.000000	0.000000		0.000043	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	1.000000	1.000000	0.101056	1.000000	1.000000	0.000000	0.131333	0.000000	0.000150	0.000000	1.000000	0.012224	1.000000	0.000000	0.044454	0.000000	1.000000	0.000000	1.000000	1.000000	0.000897	0.000487
4	SPRING	WILD	1.000000	1.000000	0.000043		0.110212	1.000000	0.000000	1.000000	1.000000	0.000019	0.925349	0.006686	1.000000	0.001904	0.000000	1.000000	1.000000	0.720695	1.000000	1.000000	1.000000	1.000000	0.364711	1.000000	1.000000	0.004363	0.000116	1.000000	1.000000	1.000000	1.000000	1.000000
5	SPRING	SUSARA	0.000000	0.965281	0.000000	0.110212		0.000000	0.000000	0.644567	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000	0.000000	1.000000	0.000018	0.566458	0.000000	0.000000	0.000000	1.000000	0.000006	1.000000	0.000000	1.000000	0.000000	0.000010	0.000006
6	SPRING	SUSARA (S)	1.000000	0.002596	1.000000	1.000000	0.000000		0.002475	0.008485	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.037627	0.000241	1.000000	0.000000	1.000000	0.061295	1.000000	1.000000	1.000000	0.000054	1.000000	0.000000	1.000000	0.000002	1.000000	1.000000	1.000000	1.000000
7	SPRING	SAFARI	0.000736	0.000000	1.000000	0.000000	0.000000	0.002475		0.000000	0.003226	1.000000	0.001197	1.000000	0.000004	0.628018	1.000000	0.000000	0.000007	0.000000	0.000000	0.000000	0.000430	0.000000	0.002405	0.000000	0.000002	0.000000	1.000000	0.000000	0.000369	0.000730	0.000000	0.000000
8	SPRING	KP	0.036213	1.000000	0.000000	1.000000	0.644567	0.008485	0.000000		0.003954	0.000000	0.001527	0.000006	0.156021	0.000000	0.000000	1.000000	0.536269	1.000000	1.000000	1.000000	0.001666	0.694515	0.000276	1.000000	1.000000	0.017015	0.000000	1.000000	0.026623	0.002123	1.000000	1.000000
9	SUMMER	SHEILA	1.000000	0.001120	1.000000	1.000000	0.000000	1.000000	0.003226	0.003954		1.000000	1.000000	1.000000	1.000000	1.000000	0.048297	0.000092	1.000000	0.000000	1.000000	0.032835	1.000000	1.000000	1.000000	0.000019	1.000000	0.000000	1.000000	0.000001	1.000000	1.000000	1.000000	1.000000
10	SUMMER	SEEDLING	1.000000	0.000000	1.000000	0.000019	0.000000	1.000000	1.000000	0.000000	1.000000		1.000000	1.000000	0.043940	1.000000	1.000000	0.000000	0.058017	0.000000	0.000066	0.000000	1.000000	0.005233	1.000000	0.000000	0.019421	0.000000	1.000000	0.000000	1.000000	1.000000	0.000387	0.000212
11	SUMMER	SYLVIA	1.000000	0.000357	1.000000	0.925349	0.000000	1.000000	0.001197	0.001527	1.000000	1.000000		1.000000	1.000000	1.000000	0.022024	0.000021	1.000000	0.000000	1.000000	0.017463	1.000000	1.000000	1.000000	0.000004	1.000000	0.000000	1.000000	0.000000	1.000000	1.000000	1.000000	1.000000
12	SUMMER	WILD	1.000000	0.000001	1.000000	0.006686	0.000000	1.000000	1.000000	0.000006	1.000000	1.000000	1.000000		1.000000	1.000000	1.000000	0.000000	1.000000	0.000000	0.030917	0.000074	1.000000	0.666248	1.000000	0.000000	1.000000	0.000000	1.000000	0.000000	1.000000	0.100155	0.069620
13	SUMMER	SUSARA	1.000000	0.049371	0.101056	1.000000	0.000000	1.000000	0.000004	0.156021	1.000000	0.043940	1.000000	1.000000		1.000000	0.000146	0.004490	1.000000	0.000001	1.000000	0.964192	1.000000	1.000000	1.000000	0.000949	1.000000	0.000000	0.156863	0.000027	1.000000	1.000000	1.000000	1.000000
14	SUMMER	SUSARA (S)	1.000000	0.000000	1.000000	0.001904	0.000000	1.000000	0.628018	0.000000	1.000000	1.000000	1.000000	1.000000	1.000000		1.000000	0.000000	1.000000	0.000000	0.008049	0.000006	1.000000	0.351617	1.000000	0.000000	0.874133	0.000000	1.000000	0.000000	1.000000	1.000000	0.036360	0.022256
15	SUMMER	SAFARI	0.012893	0.000000	1.000000	0.000000	0.000000	0.037627	1.000000	0.000000	0.048297	1.000000	0.022024	1.000000	0.000146	1.000000		0.000000	0.000227	0.000000	0.000000	0.000000	0.009384	0.000013	0.041589	0.000000	0.000067	0.000000	1.000000	0.000000	0.007362	0.014426	0.000001	0.000000
16	SUMMER	KP	0.001359	1.000000	0.000000	1.000000	1.000000	0.000241	0.000000	1.000000	0.000092	0.000000	0.000021	0.000000	0.004490	0.000000	0.000000		0.027751	1.000000	1.000000	1.000000	0.000019	0.025518	0.000002	1.000000	0.142646	0.194773	0.000000	1.000000	0.000806	0.000030	0.505874	0.475023
17	AUTUMN	SHEILA	1.000000	0.209524	0.131333	1.000000	0.000000	1.000000	0.000007	0.536269	1.000000	0.058017	1.000000	1.000000	1.000000	1.000000	0.000227	0.027751		0.000012	1.000000	1.000000	1.000000	1.000000	1.000000	0.007552	1.000000	0.000000	0.189641	0.000268	1.000000	1.000000	1.000000	1.000000
18	AUTUMN	SEEDLING	0.000000	1.000000	0.000000	0.720695	1.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000	0.000001	0.000000	0.000000	1.000000	0.000012		0.000576	1.000000	0.000000	0.000004	0.000000	1.000000	0.000127	1.000000	0.000000	1.000000	0.000000	0.000000	0.000292	0.000209
19	AUTUMN	SYLVIA	1.000000	1.000000	0.000150	1.000000	0.000018	1.000000	0.000000	1.000000	1.000000	0.000056	1.000000	0.030917	1.000000	0.008049	0.000000	1.000000	1.000000	0.000576		1.000000	1.000000	1.000000	1.000000	0.307889	1.000000	0.000000	0.000470	0.011564	1.000000	1.000000	1.000000	1.000000
20	AUTUMN	WILD	0.212683	1.000000	0.000000	1.000000	0.566458	0.061295	0.000000	1.000000	0.032835	0.000000	0.017463	0.000074	0.964192	0.000006	0.000000	1.000000	1.000000	1.000000	1.000000		0.020907	1.000000	0.004363	1.000000	1.000000	0.020207	0.000000	1.000000	0.176881	0.023721	1.000000	1.000000
21	AUTUMN	SUSARA	1.000000	0.000364	1.000000	1.000000	0.000000	1.000000	0.000430	0.001666	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.009384	0.000019	1.000000	0.000000	1.000000	0.020907		1.000000	1.000000	0.000003	1.000000	0.000000	1.000000	0.000000	1.000000	1.000000	1.000000	1.000000
22	AUTUMN	SUSARA (S)	1.000000	0.243492	0.012224	1.000000	0.000000	1.000000	0.000000	0.694515	1.000000	0.005233	1.000000	0.666248	1.000000	0.351617	0.000013	0.025518	1.000000	0.000004	1.000000	1.000000	1.000000		1.000000	0.005818	1.000000	0.000000	0.023735	0.000169	1.000000	1.000000	1.000000	1.000000
23	AUTUMN	SAFARI	1.000000	0.000054	1.000000	0.364711	0.000000	1.000000	0.002405	0.000276	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.041589	0.000002	1.000000	0.000000	1.000000	0.004363	1.000000	1.000000		0.000000	1.000000	0.000000	1.000000	0.000000	1.000000	1.000000	1.000000	1.000000
24	AUTUMN	KP	0.000336	1.000000	0.000000	1.000000	1.000000	0.000054	0.000000	1.000000	0.000019	0.000000	0.000004	0.000000	0.000949	0.000000	0.000000	1.000000	0.007552	1.000000	0.307889	1.000000	0.000003	0.005818	0.000000		0.044638	0.561022	0.000000	1.000000	0.000182	0.000005	0.152339	0.137159
25	WINTER	SHEILA	1.000000	0.861374	0.044454	1.000000	0.000006	1.000000	0.000002	1.000000	1.000000	0.019421	1.000000	1.000000	1.000000	0.874133	0.000067	0.142646	1.000000	0.000127	1.000000	1.000000	1.000000	1.000000	1.000000	0.044638		0.000000	0.069456	0.001840	1.000000	1.000000	1.000000	1.000000
26	WINTER	SEEDLING	0.000000	0.024414	0.000000	0.004363	1.000000	0.000000	0.000000	0.017015	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.194773	0.000000	1.000000	0.000000	0.020207	0.000000	0.000000	0.000000	0.561022	0.000000		0.000000	1.000000	0.000000	0.000000	0.000000	0.000000
27	WINTER	SYLVIA	1.000000	0.000000	1.000000	0.000116	0.000000	1.000000	1.000000	0.000000	1.000000	1.000000	1.000000	1.000000	0.156863	1.000000	1.000000	0.000000	0.189641	0.000000	0.000470	0.000000	1.000000	0.023735	1.000000	0.000000	0.069456	0.000000		0.000000	1.000000	1.000000	0.002224	0.001327
28	WINTER	WILD	0.000011	1.000000	0.000000	1.000000	1.000000	0.000002	0.000000	1.000000	0.000001	0.000000	0.000000	0.000000	0.000027	0.000000	0.000000	1.000000	0.000268	1.000000	0.011564	1.000000	0.000000	0.000169	0.000000	1.000000	0.001840	1.000000	0.000000		0.000006	0.000000	0.005716	0.004860
29	WINTER	SUSARA	1.000000	0.008408	1.000000	1.000000	0.000000	1.000000	0.000369	0.026623	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.007362	0.000806	1.000000	0.000000	1.000000	0.176881	1.000000	1.000000	1.000000	0.000182	1.000000	0.000000	1.000000	0.000006		1.000000	1.000000	1.000000
30	WINTER	SUSARA (S)	1.000000	0.000500	1.000000	1.000000	0.000000	1.000000	0.000730	0.002123	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.014426	0.000030	1.000000	0.000000	1.000000	0.023721	1.000000	1.000000	1.000000	0.000005	1.000000	0.000000	1.000000	0.000000	1.000000		1.000000	1.000000
31	WINTER	SAFARI	1.000000	1.000000	0.000897	1.000000	0.000010	1.000000	0.000000	1.000000	1.000000	0.000387	1.000000	0.100155	1.000000	0.036360	0.000001	0.505874	1.000000	0.000292	1.000000	1.000000	1.000000	1.000000	1.000000	0.152339	1.000000	0.000000	0.002224	0.005716	1.000000	1.000000		1.000000
32	WINTER	KP	1.000000	1.000000	0.000487	1.000000	0.000006	1.000000	0.000000	1.000000	1.000000	0.000212	1.000000	0.069620	1.000000	0.022256	0.000000	0.475023	1.000000	0.000209	1.000000	1.000000	1.000000	1.000000	1.000000	0.137159	1.000000	0.000000	0.001327	0.004860	1.000000	1.000000	1.000000	

N.B: Red highlighted figures indicate significant values: p<0.05

Appendix 3. Abbreviations used and full species names of Proteaceae-associated arthropod species recorded at Molteno Brothers Estate, Grabouw, Western Cape (indet. = indeterminate species, meaning inconclusive, undetermined to at least genus level).

Aca	*Acanthacris ruficormis*
Acr	Acaroidea sp. (indet.) (deutro nymph)
Acu	*Acarus* sp. (cf *immobilis*)
Agr	*Agraphosus* sp.
Agz	Agromyzidae sp.(indet.) (pupa)
Ame	*Ameroseius* sp.
Ana	*Anagyrus* sp.
Aas	*Antestia astrosignata*
Ant	Anthophoridae sp. (indet.)(scale insect)
Aph	Aphididae sp. (indet.)
Amc	*Apis mellifera capensis*
Ara	Araneae sp. (indet.)
Arg	*Argyroploce* sp.
Bac	*Bactrothrips* sp.
Bah	*Baryphus ahenus*
Bet	Bethylidae sp. (indet.)
Bla	Blaberidae sp. (indet.)
Bra	Braconidae sp. (indet.)
CaA	*Camponotus* sp. 1
Cam	*Camponotus* sp.2
Cal	*Capys alphaeus*
Car	Carabidae sp. (indet.)
Cec	Cecidomyiidae sp. (indet.)
Cer	*Cerhysiella* sp.
Clu	*Cheilomenes lunata*
Cpr	*Cheilomenes propinqua*
Che	*Cheiracanthium* sp.1
Chl	Chilopoda sp. (indet.)
Cfu	*Chirodica* sp.1
Cfu	*Chirodica* sp.2
Cin	*Chresiona invalida*
Csp	*Chresiona* sp.2
Cab	*Clubiona abbajensis*
Col	Collembola sp. (indet.)(springtails)
Con.	*Conimus* sp.
Cmi	*Cryptophagus milleri*
Del	*Delottococcus* sp.

Der	Dermaptera sp. (indet.)
Dlo	*Diaplochelus longipes*
Dip	Diplogyniidea sp. (indet.)
Dda	Diplopoda sp. (indet.)(millipede)
Dp1	Diptera sp. 1 (indet.)(larva)
Dp2	Diptera sp.2 (indet.)(larva)
Dro	*Drosophila* sp.
Ech	*Echemus* sp.1
Elu	*Elasmus* sp.
Emp	Empididae sp. (indet.)
Eac	*Epichoristodes acerbella*
Euc	Eucoilidae sp. (indet.)
Eli	*Euderes lineicollis*
Eul	Eulophidae sp. (indet.)
Ery	*Euryopis* sp.
Eur	Eurytomidae sp. (indet.)
For	Formicidae sp. (indet.)
Fco	*Formicomus coeruleus*
Gho	*Genuchus hottentottus*
Gep	*Gephyrota* sp.1
Gly	*Glycyphagus* sp.
Hav	*Haplothrips avaneae*
Hba	*Haplothrips bagnali*
Hax	*Harmonia axyridis*
Hde	*Heliophanus debilis*
Hin	*Heliophanus insperatus*
Het	*Heteroderes* sp.1
Hva	*Hippodamia variegata*
Hfe	*Histiostoma feroniarum*
Hal	*Holopelus almiae*
Hym	Hymenoptera sp. (indet.)
Iso	*Isorhynchus* sp.1
Las	*Lasioglossum* sp.
Lep	Lepidoptera sp. (indet.)
Lta	*Lepisiota* sp.1
Lhu	*Linepithema humile*
Mac	*Macrocheles* sp.
Meu	*Macrosiphum euphorbiae*
Man	Mantodea sp. (indet.)
Mre	*Massagris regina*
Mel	*Meligethus* sp.
Men	*Menemerus* sp.1
Mpe	*Meranoplus peringueyi*
Mon	*Monomorium* sp.

Nsu	*Neoscona subfusca*
Nvi	*Nezara viridula*
Nit	Nitidulidae sp. (indet.)
Nau	*Nysius* sp.
Oec	Oecophoridae sp. (indet.)
Ole	Olethreutidae sp. (indet.)
Ori	*Orius* sp.
Oam	*Orophia ammopleura*
Ore	*Orthoschizops reticulata*
Oma	*Oxycarenus maculatus*
Par	*Pardosa* sp. 1
Ped	*Pediobius* sp.
Pja	*Pelecopsis janus*
Pem	*Pemphigus* sp.
Phe	*Pheidole* sp.1
P10	*Pheidole* sp.2
P12	*Pheidole* sp.3
Phil	*Philodromous* sp.1
Phl	Phlaeothripidae sp. (indet.)
Pbr	*Phlegra bresnieri*
Psp.	*Phloenomus* sp.
Pse	*Phoracantha semipunctata*
Ptr	*Phyconomus tricolor*
Phy	*Phyllocnistis* sp.
Pla	*Plagiolepis* sp.1
Pty	Platygastridae sp. (indet.)
Pca	*Platysoma capense*
Pol	*Polistes* sp.
Por	*Porcelia* sp.
Pci	*Pria cinerascens*
Pso	Psocoptera sp. (indet.) (booklice)
Psy	Psyllidae sp. (indet.)
Pyr	Pyrallidae sp. (indet.)
Rhy	*Rhyzobius* sp.
Rca	*Rodolia cardinalis*
Sci	Sciaridae sp. (indet.)
Sce	*Sibinia cervina*
Sit	*Sitophilus* sp.
Spe	*Spermophagous* sp.
Scu	*Sphenoptera cupreosplendeus*
Sta	Staphylinidae sp. (indet.) (larva)
Ssc	*Stictopleurus scutellaris*
Sge	*Synaptothrips gezinae*
Sim	*Synema imitator*

Tec	*Technomyrmex albipes*
Ten	Tenebrionidae sp. (indet.)
The	*Theridion* sp.1
Tsp	*Theridion* sp.2
Tsp2	Theridiosomatid sp. (indet.)
Thy	*Thyene* sp.1
Tib	*Tibellus* sp.
Tor	Tortricidae sp. (indet.)
Tra	*Trachelas* sp.1
Tfa	*Trichostetha fascularis*
Tul	Tulipidae sp. (indet.)
Tpu	*Tyrophagus putrescentiae*
Egg	Unidentified eggs
Vhu	*Vitticatantops humeralis*
Xen	*Xenoomorphus* sp.
Xer	*Xerophaeus* sp.1

Appendix 4. Approximate percentages of the plant parts (inflorescences, infructescences and <15 cm long stems) collected from the field damaged by the arthropod species. N (total number of plant parts collected from the field) = 27 648.

Arthropod Species	Number of Plant Parts Damaged	% of Plant Parts Damaged
Phyllocnistis sp.	7658	27.7
Epichoristodes acerbella	2059	7.45
Orophia ammopleura	1980	7.16
Genuchus hottentottus	1692	6.12
Lepidoptera (indet.)	1684	6.09
Capys alphaeus	1324	4.79
Argyroploce sp.	846	3.06
Diaplochelus longipes	718	2.6
Delottococcus sp.	639	2.31
Oecophoridae (indet.)	404	1.46
Tortricidae (indet.)	288	1.04
Vitticatantops humeralis	88	0.32
Acanthacris ruficornis	69	0.25
*Others	122	0.44
TOTAL	19571	70.79

indet. = undetermined species.
* Others = Plant parts damage that could not be associated to any specific arthropod species. N.B.: After consulting with a group of protea farmers (SAPPEX), species that contributed at least 1% of the plant damage were considered as key protea pests.