DEVELOPING MULTI-LAYERED, FLOWERING MEDITERRANEAN PLANT COMMUNITIES USING SOUTH AFRICAN FLORA

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Abstract

The aim of this study was to create sown multi-layered communities of Mediterranean South African plants based on Fynbos and Renosterveld species. These communities were designed to test naturalistic design principles as to achieve long flowering designed plantings involving three canopy heights (tall, medium and low). Competition between shrubs/forbs/succulents and geophytes by using microcosm experiments mirrors the form of actual designed vegetation in practice. The experiments prior to the competition experiment provided the understanding of germination, winter cold and summer wetness tolerance of a large number of SA species (over 300 species) from Western Cape. All winter growing and summer dormant geophyte species had the capacity to emerge from autumn sowings, and some were able to do the same from spring sowing. Smoke treatment prior to sowing is effective on many forb and small shrub species from Fynbos and Renosterveld, but much less useful (or necessary) on geophyte species. Species such as *Gladiolus carneus, Gladiolus tristis* and *Ixia curvata* tolerated -8°C in winter 2010/11, and many more species survived -5°C in winter 2011/12. *Bulbinella elata, Bulbinella elegans, Bulbinella nutans, Moraea tripetala, Kniphofia uvaria, Romulea atrandra* and *Romulea sabulosa* suffered no loss at -5°C and no loss over summer 2012 (historically the wettest summer in the UK since 1910). Altitude and the resulting number frost days which individuals experience at the collection locations were critical factors influencing their winter mortality in Northern England. Habitat soil conditions and other environment factors are important in relation to their summer mortality. Species naturally occuring in Renosterveld and seasonally wet habitats are typically more wet tolerant response in Uk summers (i.e. many *Bulbinella, Kniphofia, Gazania* and *Romulea* species). Specific geographical provenances were explored to find more useful genotypes that can survive well in the UK. Species collected from the inland Roggeveld region, including the provenances Sutherland, Rooiwal, Groot Swartberg mountains, and the Komsberg, were the most successful species in response to winter cold in Sheffield. Fifteen plant community types were designed to access competition amongst 30 selected species in terms of mortality and biomass production within the studies main microcosm experiment. The most successful communities were generally those composed of tall canopy layer geophytes and forbs/shrubs.

Geophytes suffered less mortality than shrub/forb/succulent species but contributed less biomass in the first two years, particularly in low height geophytes. Medium height geophytes formed a more extensive canopy and had higher competition capacity to increase their coverage and biomass in communities from the third year on. Species that did this included *Watsonia* ‘Tresco Dwarf Pink’, *Gladiolus cardinalis* and *Watsonia schlechteri*. Some small Fynbos and Renosterveld geophytes tested in the combinations demonstrated a degree of shade tolerance, as in *Romulea komsbergensis, Ixia* and *Hesperantha* species. These communities were managed by annual cutting in late summer-early autumn.

Declaration

No portion of this work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or institute of learning.

Preface and Acknowledgements

This is a wonderful personal experience that in the past 7 years I met my supervisor Professor James Hitchmough in Sheffield. James is a special person with great passion on herbaceous plants since his twenties. When I came to the UK as anoversea postgraduate student, I first time attended his lectures and went out on field trips with him. He is very knowledgeable on plants and planting design, which inspired me a lot.During the 2 years' master course, his passion on planting gradually transferred to me. Therefore, I chose 'Renosterveld as a model for New Naturalistic planting' as my master dissertation research direction, and spent a year in 2010 doing the research on 21 winter-growing bulbous species from Western Cape Region of South Africa. With the booming interests in this idea, I decided to continue and deepen the research to realise this Mediterranean type of planting community in Western Europe. By three years' experiment observations in the Sheffield Botanical Garden and a west South African fieldtrip, the understanding of their biological characteristics, phenology characteristics, geographic distribution and ecological characteristics were built up progressively. Here, I give my biggest thanks to James for his always support on research and life.

Here I would like to thank my parents for suggesting landscape as my career and inspiring me in exploring planting design as my further research direction. Without their constant love, support and encouragement, this thesis wouldn't have been possible. A special note of appreciation to Jingyu, for the continuous support on my experiments and life with love.

Thanks to Rachel Saunders and her husband Rod Saunders from Silverhill Seeds nursery, a company specializing in South African seeds and bulbs in Cape Town, South Africa. Finally, thanks to South African photographer Colin-Paterson Jones's wife for offering me the right to use some of Paterson's pictures in this thesis from his personal website. Thanks to James Hitchmough, John Manning and Peter Goldblatt for their permission of using their pictures in this thesis.

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CHAPTER 1: CONTEXTUAL BACKGROUND

1.1 Research Context

1.1.1 New challenges and creative opportunities

Climate change is predicted to have a significant effect on the climate of Western Europe (Bakkenes et al., 2002) and Britain in particular (Broadmeadow et al., 2005; Wilby and Perry, 2006), with current estimates suggesting that London will experience a semi-Mediterranean climate by 2050 (UK CIP, 2009). The current climate experienced by Bordeaux on the Atlantic coast of Southwest France is considered to be a good approximation to London in 2050 (Broadmeadow et al., 2005; Hitchmough, 2011). Even in the present day most British cities already have heavily modified thermal climates, due to conventional heat island effects (Smale, 2006). When heat island process combined with global warming (IPCC, 2001), particularly in Southern England (Hulme et al., 2002), a more Mediterranean climate will emerge. In the UK, climate change is also expected to affect annual rainfall distribution patterns which will results in extended dry periods interspersed with excessively wet periods. The decline in summer rainfall in Southern England (Hulme et al., 2002; Broadmeadow et al., 2005) will have profound influences on landscape design and management (Bisgrove and Hadley, 2002); the staple cover in urban greenspace, un-irrigated mown grass, will become increasingly unsatisfactory because it will be brown for much of the summer. The current fitness of both native and non-native species will change with the anticipated climate shifts (Bakkenes et al., 2002; Broadmeadow et al., 2003; Hitchmough, 2011).

There will be both opportunities for, and a necessity for new creative and low cost vegetation types (Kingsbury, 2009), and particularly those which can be easily established in-situ and managed. With demands upon urban vegetation increasing while the resources (water, nutrients, etc.) are in shorter supply, designing urban vegetation as communities is therefore possibly one of the most promising ways to interpret an ecological approach in relation to horticulture

(Hitchmough, 2013) and to develop an ecologically based landscape. Unlike conventional plantings with a clear beginning and end, necessitating complete replanting after a number of years, designed communities are designed to continue to evolve over long periods of time, given appropriate maintenance. In horticulture, striking plants have always been cultivated by providing additional nutrient, water and rigorous weed control to ensure the supra-optimal phenotype. However, the focus of designed planting community has shifted to view the entire appearance as a whole rather than any individuals in the community. These communities commonly behaves in a similar way to plants in spontaneous or “semi-natural” communities (Hitchmough, 2013). Depending on the situation and the needs, the plants can be either native or non-native, or a mix, drawn from parts of the world with drier summer climates. Each species in the community has to be compatible with other plants, which is the core in community design (Hitchmough, 2013).

Climate change will not however be a uniform process. Britain experienced very mild almost frost free winters in the early 2000’s, however there was a return to much colder winters from 2008 to 2011. In Sheffield, a Northern city at approximately 53° N, the minimum screen temperature recorded in the winter 2010-11, itself the coldest for 30 years, was -8.7° C (data recorded at the Weston Park Weather Station, central Sheffield). Temperatures as low as -20° C were experienced in some rural landscapes within a 100km radius of Sheffield (Anon 1). This milder urban climate provides the opportunity to developing Mediterranean-like plant communities, particularly in Southern England.

1.1.2 The use of typical Mediterranean plant communities as models

Most Mediterranean species naturally commence growth in autumn and flower between late winter and early summer (Dallman, 1998), the time of minimal moisture stress but when temperatures are still high enough to permit some growth and flowering. Mediterranean species from Southern Europe are currently widely cultivated in the UK, however their use in ecologically based designed communities has not yet to be investigated. Species from other Mediterranean climatic regions of the world (see Fig. 1.1 below) are much less known and understood, but are sometimes even more attractive.

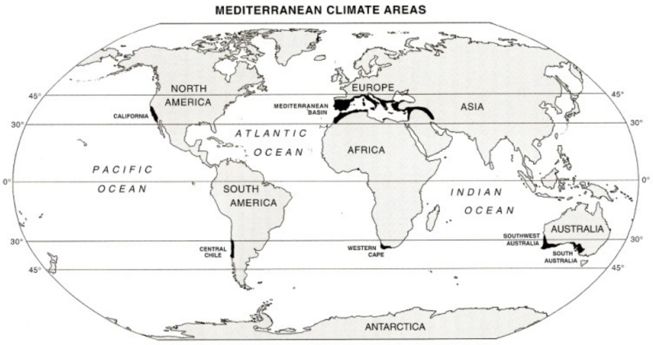

Fig. 1.1 Map of the world with Mediterranean climate areas shown in black. All Mediterranean climate areas lie between 30^{o}and 45^o of latitude. They are all near the coast on the western edge of continents. (adapted from DiCastri et al., 1981)

Among the Mediterranean biomes of North Africa, California, Chile, Western Mexico, Southern and Western Australia, South Africa (hereafter SA) is one of the most interesting for it has the highest species richness of all of these regions, with an average of 94 species/km^2, compared with 12 species/km^2 for California, and less than 2.5 species/km^2 for the flora of Europe (Dallman, 1998). This diversity is composed of a variety of lifeforms, shrubs, sub-shrubs, forbs, graminoids and, more especially, geophytes (plants with either a corm, bulb, tuber or rhizome) which are considered to be the most significant component in the Cape Floral Region of SA (Manning et al., 2002; Proches et al., 2006; Duncan, 2010). Taking *Gladiolus* as an example, there are 165 species in SA, 110 in the Cape (Manning et al., 2002), compared with several native to Europe. Although these plants started to enrich the gardens of Europe four centuries ago (Huntley, 2012), for instance *Protea neriifolia* and *Haemanthus coccineus* were the first two species introduced to Europe in 1597 and 1603 respectively, the presently cultivated South African bulbous plants in gardens are only a fraction of the geophyte richness of the Cape Flora (Manning et al., 2002). The detailed explanations described in Chapter 2 reveal that there is huge design and horticultural potential in this flora that in the past has not been exploited in Western Europe because winter temperatures were too low for survival. However, with global warming, winter cold damage (Broadmeadow et al., 2003) to these geophytes will become less problematic, especially in large cities with marked urban heat islands (Smale, 2006). There are also very cold distributions of these species in the mountains regions of southwest SA that can be utilised (Hitchmough and Cummins, 2011).

Nature-like vegetation communities can be created by only native species, both native and non-native species (Dunnett and Hitchmough, 2004), or entirely non-native species, and can be attractive to both people and invertebrates (Kingsbury, 2004; Hitchmough, 2011). The aim of this research is to explore the development of naturalistic, designed vegetation communities entirely based on non-native species from SA winter rainfall areas with a multi-layered appearance, which are functional and dramatic in terms of flowering display characteristics.

1.2 Research Aims and Objectives

The main aim of the research is to understand the ecological, design and horticultural issues in developing multi-layered, long-flowering communities of South African species from seed sown in-situ, and provide further understanding of the mechanisms involved in long-term management.

1.2.1 Research questions

To achieve the main aim, the following more specific research questions were proposed:

I. Survival in relation to summer wetness
   - -- Does summer wetness increase mortality?
   - -- How do individual species and sub-specific variants of those species differ in their response to summer wetness?
   - -- Are there any patterns related to genus, or the origins of the species in response to summer wetness?

II. Survival in relation to winter cold
   - -- Is mortality increased by exposure to sub-zero temperatures?
   - -- How do individual species and sub-specific variants of those species differ in their response to winter sub-zero temperatures?
   - -- Are there any patterns related to genus, or the origins of the species in response to winter cold?

III. Seed ecology and establishment;

- Is it possible to germinate perennial South African species outside in the UK?
- How does sowing time affect field emergence?
- What are typical values for species in terms of field emergence?
- How do different species differ in their ease of establishment and persistence?

IV. Establishment and longer-term competition

- How does life form, canopy architecture and foliage height influence establishment of multi-species communities?
- How does life form, canopy architecture and foliage height influence competition and long term survival of species within multi-species communities?

1.2.2 Research objectives

The objectives of the research were:

I. To utilise different pot based methodologies to investigate plant growth and mortality over summer and winter.

II. To study the influence of collection location, plant age, location with the experiment and screen protection on winter cold and summer wet tolerance of forbs, evergreen geophytes and summer dormant geophytes.

III. To understand the ecology of germination and emergence of species that are currently not understood in comparative terms

IV. To investigate the effects of plant life form, canopy architecture and foliage height on short to high plant community development, individual mortality and floral performance.

1.2.3 Research rational and strategy

Research was undertaken as two phases (Fig. 1.2). This started from autumn 2010 with the investigation of bottomless pot experimentation in different substrate types and depths outdoors. With the observation of foliage damage and mortality assessment, understanding was gradually developed to plan the winter cold and summer wet tolerance experiment involving over 250 species and more accurate measurement and data recording (Chapter 3-4). Laboratory germination and pre-sown treatment, in parallel with outdoor hardiness experimentation, also informed the second phase of the research. Cold/wet tolerance experiments were ran continuously from autumn 2011, followed by the field competition experiment with 30 forb and geophyte species, which were selected according to information gathered in phase one and seed availability (Chapter 5). Management mechanisms were studied as the competition experiment proceded.

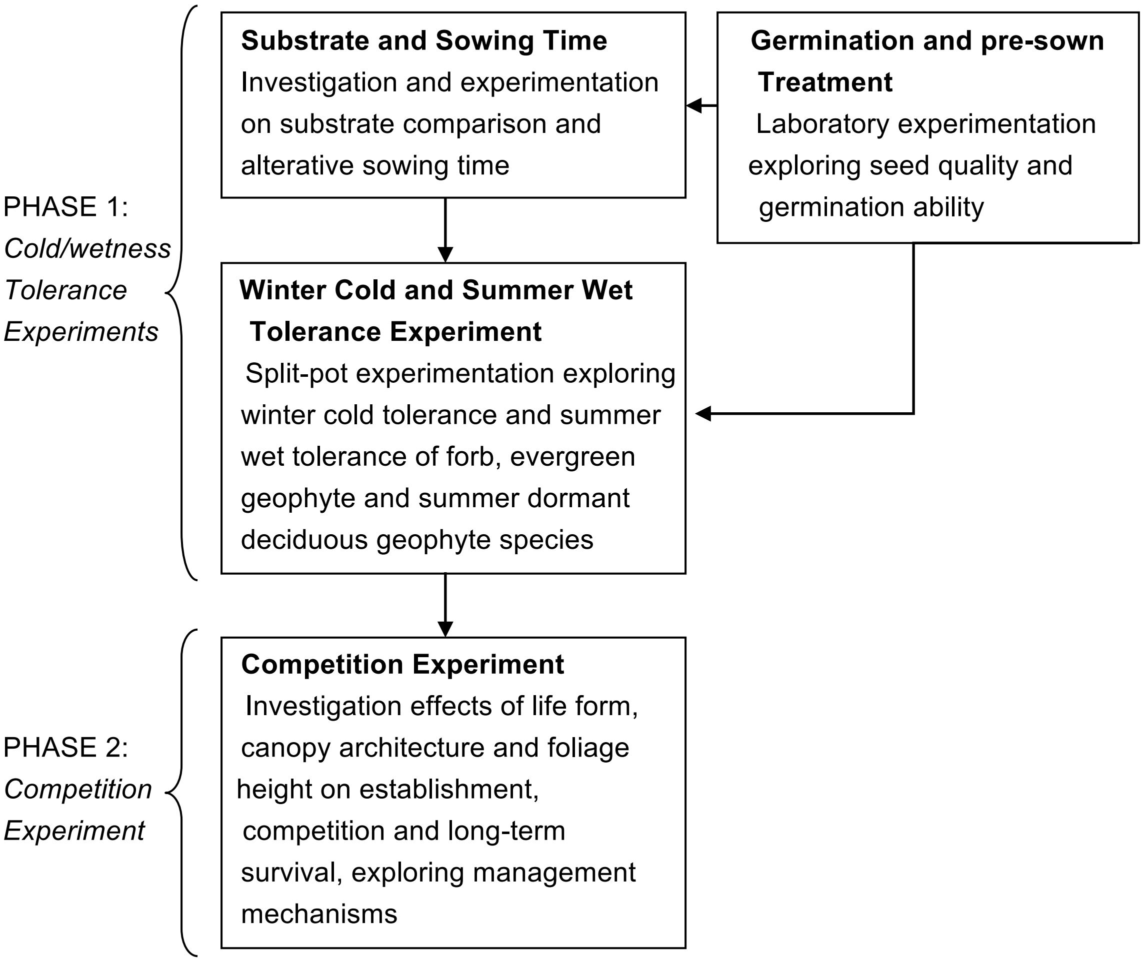

Fig.1.2 Research phases into the application of west SA plants to establish Mediterranean plant communities for use in the warming cities of Maritime Western Europe. Key experiments are indicated in each box.

CHAPTER 2: LITERATURE REVIEW

2.1 The development of naturalistic herbaceous planting in urban contexts

2.1.1 Background

Naturalistic herbaceous planting is, by definition, natural-looking designed communities of herbaceous plants often arranged in layers with random, repeating patterns. It gains its inspiration initially from nature (Wiley, 2004), especially its wild character (Oudolf and Kingsbury, 2005). It is designed based on principles largely drawn from the understanding of relatively natural plant communities, and especially plant establishment, competition, and distribution in the habitat under specific climatic conditions. However, the aim is to reproduce the characteristics of a planting community rather than copying directly and completely (Dunnett, 2004). It emphases visual dynamics, but also combines thinking about ecological principles (Dunnett and Hitchmough, 2004) to provide multi-function services. Species richness in planting works to support local fauna by providing habitat and food opportunities, which helps to improve biodiversity in urban settings.

Sustainable principles can be built into the community helping to realise maximum self-organising capacity in the long-term period with less irrigation and energy consumption. Although natural-looking, this type of planting can be designed in any spatial forms on the ground, geometric such as linear or bubble shaped patterns on plans, within which repetition of plants is a major contributor to planting character. Repetition of single eye-catching plants, often as emergent elements with vertical structure, or a group of plants with similar colour and form is often evident in the design language. Its layered structure allows maximisation of the seasonal interest per m^2 of ground surface.

High species richness within designed herbaceous community allows the flowering time to be extended over a long period. Alternatively, flowering time can be altered through plant selection and management to flower in a few specific months if required. For instance, the designed naturalistic meadow communities in London 2012 Olympic park were delayed to flower approximately 2 months after their normal display time by cutting to the ground in May. Sowing (though sometimes combined with planting) is sometimes used by designers as an effective approach to the establishment of such plant communities, particularly on a large scale (Hitchmough, 2013). In practice, a drier, and wetter, or more shade or sun tolerating sowing mixes can be created to meet different requirements according to distinctive soil types and sun exposures.

In Western Europe, 'naturalistic' in the sense of designed plant communities is a concept that can be dated back to the 19th century, when William Robinson (1838-1935) wrote *The Wild Garden* 1874 (Robinson and Darke, 2009). In her later years Gertrude Jekyll (1843-1932) famous for her colour scheme planting, promoted a naturalistic style mainly in woodland with many non-native species gathered from different continental areas (Bisgrove, 1992), guiding the development of naturalistic planting in light shade condition for much of the 20th century. In 1957, the *Hardy Plant Society* was founded, which provided a platform for information and experience exchange on perennials that then fed into planting palettes that could be used to support naturalistic planting (Oudolf and Kingsbury, 2015).

Interest in the use of native plants as design elements began in Chicago in the 1920s, to recreate prairie vegetation and increase native diversity in parks. This was led by Jens Jensen, and became widely known as the 'prairie school' (Grese, 2014). One of the most influential people in the ecological based landscape design during that period was not a landscape architect, but a forestry photographer Aldo Leopold. His ecological aesthetic philosophy emphasised integrating aesthetics and biodiversity values in forest landscape (Gobster, 1995). In the 1980s, designing in the prairie spirit became a trend in public landscapes, plantsman like Roy Diblik started to grow Midwestern North American native perennials (Diblik, 2015). Professor Darrel Morrison worked in the University of Georgia stressed 'each design should reflect and reveal the local landscape character' (Kingsbury, 2004) also delivered his principles into practice through native meadows in a series of Botanical Gardens. These movements are in part a response to the diversity and richness of the North American herbaceous flora.

Since the 1980s, there has been increasing interest in biodiversity in relation to planting across the world. In the USA the Surface Transportation and Uniform Relocation Assistance Act of 1987 (Federal-Aid Highway Act of 1987) required native wildflower seeds or seedlings be planted as part of any landscape projects on the federal highway system (STURAA, 1987). 'Wildlife Gardening' appeared in Britain and native species were encouraged for use in gardens as more wild-looking and multi-layered structure by using trees, shrubs and perennials to support wildlife (Baines, 2000). Together with the Department of Transportation in California, the Department of Transportation in Texas, successfully encourage native flowers to spread over roadsides central reservations, followed by Arkansan (AHTD, 2015), Indiana (Dana et al., 1996), Virginia (Harkess et al., 1997) and Iowa. The road commissions of Iowa manage the planted vegetation by burning rather than mowing or spraying (Line, 2000). At present, North American transportation agency policy is to create and maintain attractive landscape and helps to restore the natural environment through rebuilding diverse highway corridors and roadside ecosystems by using more herbaceous plants and grasses rather then merely using woody plants (FDM, 2006; MacDonagh and Hallyn 2010; Kingery et al., 2014; AHTD, 2015; OW, 2015).

On a large scale the use of native species is both desirable and sensible. But there are other traditions of ecologically based design with non-native species that have been particularly important at the smaller scale. In Germany, the first randomised nature-like plant combinations were developed by Karl Foerster (1874-1970) in early 20th century. He insisted that it was necessary to look to nature and brought plants not commonly known as garden plants back into gardens. He also softened the planting by introducing grasses such as *Calamagrostis x acutiflora* 'Karl Foerster'. German nurseryman Ernst Pagels (1913-2007) developed varieties of another widely used grass species, *Miscanthus sinensis*. These ornamental grasses were brought into North America in late 1950s, and were propagated and promoted for the commercial market (Darke, 2007). Hermannshof, a private botanic garden in Weinheim has been historically important to German landscape thought with a succession of re-creations over 200 years. In the late 1970s, it became a public experimental garden following the suggestions of Professor Richard Hansen. Plants were regrouped by their common habitat and growing conditions following Hansen's concept in his book (Hansen and Stahl, 1993) and the garden was reopened for display in 1983.

In Britain the nurserywoman Beth Chatto was important in developing the idea of using the right plant for the right place was one of the leading promoters of ecologically aware naturalistic planting (Chatto, 2008). She developed her ideas in the relative dry environment of Essex (Chatto and Wooster, 2000) working mainly with non-native plants that fitted her particularly severe conditions.

Since the early 1990s, Hermannshof, directed by Cassian Schmidt has set the benchmark for naturalistic planting in Germany and attracted more and more specialists to explore innovative plantings. In the Netherlands, one of the originators of naturalistic planting was Rob Leopold, His great contribution was his hardy annual mixes, which inspired Piet Oudolf in his early days. In 1980s, Leopold's seed company became the first able to provide wildflower seeds commercially, mainly annuals, which gradually raised the interest of meadow applications (Den Dulk, 2005). Leopold also helped to establish the *Perennial Perspectives Foundation*, and he was the real driving force in the perennial movement in Netherland. Between the 1970s and 1980s, there was a limited diversity of valuable perennials in Netherland, and plantsman searched for new more wild type plants mainly in the UK due to the climatic similarity (Oudolf and Kingsbury, 2015). In the 1990s, tussock grasses became widely used by Oudolf in to build in structure in planting. Through practice, Oudolf then shifted the balance from grasses to more decorative perennials. He started to look the architectural form of plants, the performance when plants were dying and the appearance when plants were dead. The deadheads and dry stems of late-season perennials were seen as a long season structure to Oudolf and he emphasised the materials in space and time through design (Oudolf and Kingsbury, 2005). Generally speaking, the Netherlands and Germany were more advanced than other European countries in the process. The parks, central reservation of roads and tramways, roadside woodland edges at Amstelveen, a suburb of Amsterdam, presented wildflower plantings as part of the city infrastructure even in as early as 1990s (Kingsbury, 2004).

In 1994 the first Perennial Perspectives conference was held in the Kew Gardens. A number of speakers from Germany, the Netherlands and UK gathered together to discuss the new development of naturalistic planting, including Chatto and Piet Oudolf. Kingsbury (2005) regarded this event as the turning point of the movement of naturalistic planting. German and Dutch's wildflower applications in urban infrastructure have strongly influenced European designers in the field. After 10 years joint efforts by both pioneer gardeners and design professionals, naturalistic planting with much lower maintenance than traditional planting eventually brought a new trend to public attention in the 21th century. More and more works occurred in western countries by designers, such as Dan Pearson in the UK, Roy Diblik in the USA, Professer Cassian Schmidt and landscape architect Heiner Luz, Professor Wolfram Kircher from Anhalt University in Germany. Most of Piet Oudolf's signature works are in the USA, Michael King in Netherland, Gilles Clément in France and the well known 'Sheffield School' in the UK with Professors James Hitchmough and Nigel Dunnett, who argued for 'enhanced nature' (Dunnett and Hitchmough, 2004). Hitchmough and Dunnett are pioneers of horticultural ecology and of integrating principles derived from ecological science into planting designs.

Despite all of the work of these designers mainly being with non-native species, or a mix or non-native and native species, at a policy level in urban landscapes, most of the focus has remained on the use of native species in naturalistic design. In relatively small countries with small native floras such as the UK (Hitchmough, 2013), some researchers (Hitchmough, 2008) started to believe that the composition of naturalistic plantings could be altered by introducing non-native species from similar habitats in different regions of the world (Kingsbury, 2004), and research was carried out in the UK (Hitchmough and Woudstra, 1999; Hitchmough et al., 2001; Hitchmough et al., 2004; Hitchmough et al., 2005) and some other European countries, such as the Netherlands, to prove this hypothesis (Woudstra and Hitchmough, 2000). In the past 20 years, Dunnett and Hitchmough have worked on communities of both annuals and perennials, however, both of them use non-native species to some degree to enrich their designed nature-looking plantings in order to extend the display period of a planting community. Dunnett was highly influenced by Rod Leopold (Kingsbury, 2005) and created even more dramatic colourful annual mixes for use in cities though the University company *Pictorial Meadows*. Hitchmough focused on non-native perennial mixes that draw inspirations from different parts of the world and with a theme of achieving transparency in his layered planting structure by using plants with basal leaves. Long continuity of flowering was another goal (Hitchmough, 2004).

Commercial mixes of randomised herbaceous perennials that do not need to involve a designer, appear in 2001 in Germany and are sold as *Silber-sommer* (Silver Summer) (Oudolf and Kingsbury, 2013). This new approach had originally arisen out of collaborations between the nursery industry and horticultural-landscape architectural educational and research institutes in Germany and Switzerland. The idea of naturalistic planting has now becoming far better known in the public. More and more younger generation designers and horticulturists are expressing interests in this naturalistic herbaceous planting, for instance, Sarah Price in the UK and Adam Woodruff in the USA.

In the past 5 years interest in Western Europe, to develop the use of designed naturalistic herbaceous vegetation has grown substantially. Sites such as the 2012 London Olympic Park have created opportunities to create large scale sustainable and novel designed urban naturalistic landscape, deeply exciting the public imagination (Hopkins and Neal, 2012). Visitors inspired by these positive and innovative design principles have attempted to expand these ideas to their own gardens and local public landscapes.

Some of these types of ecologically based urban vegetation have been established on waste materials, even in some cases on the previously contaminated land, where contamination may in some cases slow down growth and benefit the retention slow growing plant species. Professionals increasingly seem to see this planting design method as the new trend of future plantings. On a small scale, it is possible to produce even more finely detailed showcase meadows, such as Oxford Botanical Garden (MB, 2015) to exhibit the process of establishment and simple maintenance of ecological based planting communities.

In Weinheim, Germany, central reservations, roundabouts and sideways towards Hermannshof are now all planted with wildflowers in a more nature-like style (Hermannshof, 2014). Prairie communities in Hermannshof are established on dry and nutrient-poor conditions, where mirrors the tough conditions in urban contexts in Germany. As a leading exploration land of naturalistic planting in Germany, Hermannshof is now in collaboration with many of universities and researchers to develop even more sample planting communities for urban use.

In North America, Oudolf has successfully delivered his vision of new nature in the city, via such projects as the Lurie Garden in Chicago Millennium Park's and The High Line in New York. Although the Lurie Garden was supposed to represent the once extensive grass dominant prairies of mid America, more non-native flowering perennials were elaborately designed into the native grassland model to celebrate naturalism and satisfy visitors. The High Line promotes naturalistic schemes by using native and non-native species.

2.1.2 Potential of naturalistic herbaceous vegetation in future landscape design and green infrastructure network

With the boom of urbanization, planners in most developed and developing countries started to rethink what green-space has meant in the past and, more importantly, what it must contribute in the future. When facing climate change at the same time, this issue is ever more challenging. A creative and meaningful rethinking of this new ecological understanding in planting is potentially of enormous value to green infrastructure design and management (Hitchmough, 2013).

Large scale projects, such as ‘The High Line’ in New York and particularly ‘2012 London Olympic Park’, represent as the turning point in urban park design in both American and Europe towards a naturalistic and ecological approach to landscape even within high density urban areas. Maintenance of large areas of this type of vegetation has relatively low inputs of time and resources per unit area with simple operations. The resulting attitudes of both professionals and the public are often positive leading to a new landscape design model, which is now spreading to other parts of the world. Some highly maintained beddings and highly irrigated large-scale mown grass are to be replaced by more sustainable vegetation as designed naturalistic planting communities. At least some urban people desire to experience and enjoy city life in nature-like contexts. In practice, this naturalistic planting can operate at various scales, from a very big scale to a very small area. It can not only be used to form a landscape structure at the scale of parks, recreation of a brownfield, or equally applicable to woodland areas, but also can be designed to recreate natural hillsides that cut through the landscape towards city gateway by highlighting the green corridors through wonderful colours, or frame the commercial outlets in both urban and sub-urban ranges, or any other large but difficult to maintain areas in urban settings. It also can be used in greenroof designs (Dunnett and Kingsbury, 2010) to reduce the building runoff as well as providing visual interests.

Water-wise plants can form a wet planting community under the same design principle to infiltrate storm water, appearing as rain gardens or wetland swales (Dunnett and Clayden, 2007). This idea and design principles can even be used to integrate into existing ‘grey infrastructure’ (urban built structures) to re-organise the city layout. It is important to maximise the aesthetic appeal of these types of vegetation to ordinary people, in particular ensure there are colours other than green), which will add more attractiveness seasonality (Ozguner and Kendle, 2006) to infrastructure. As species are typically used to replicate randomly in designed naturalistic planting communities, the whole surface will in essence, turn to a certain colour when it blooming, which will generate extremely strong visual impressions amongst ordinary people. When applied in large scale, however, an overall planting strategy and the detailed specifications on preparation, establishment and management have to be developed prior to commencing planting.

As the studies by Smith et al. (2006a; 2006b) clearly revealed, large areas of spatially and taxonomically complex vegetation of either woody plants or herbaceous or a mix of both could much better support urban biodiversity, as well as increase carbon capture compared to equally size mown grass (Hitchmough, 2013). Thus the practices of this new type of designed vegetation have real value in many urban landscapes around the world.

2.1.3 The capacity of non-native plant species to support biodiversity?

British naturalist Hewett Cottrell Watson raises the idea of the 'native' in the mid-nineteenth century, to highlight the value of "nativeness" (Thompson, 2014). He was less interested in non-native (exotic or alien) species, however, he did not see them as inferior. Attitudes towards the cultivation of non-native species have been continuously debated over the last 30 years in Western Europe (Özgüner et al., 2007) but much longer in some parts of world such as the USA. Prior to this non-native species seemed to be acceptable (Reichard and White, 2001) in designed vegetation. Then from 1970's on, however, natives in both practice and urban biodiversity-conservation theories were viewed as increasingly good and the only sustainable design elements in urban landscapes (Laurie, 1979; DEFRA, 2008) in Britain, and this was mirrored in many other western societies. Nativists have tended to judge all exotics as unquestionably bad, largely because of the rather lazy idea that non-native species were fundamentally invasive. As a result, non-natives in general became seen as a threat to native species by potentially disturbing the balance of an ecosystem (Schmitz and Simberloff, 1997; Gilbert and Anderson, 1998; Parker et al., 1999), inducing floral and faunal extinction (Wilcove et al., 1998), and hence hostile to the sustainability paradigm (Peretti, 1998).

Many of these initial arguments were based on the idea of the Ecologist Charles Elton (Groves 2009), who envisaged a future in which only aggressive non-native species existed in his book *The Ecology of Invasions by Animals and Plants* (Elton, 1958). Most non-native species however do not possess the biological traits to be invasive; nor is invasiveness a unique property of non-native species (Thompson et al., 1995; Reichard and White, 2001; Sagoff, 2005). For instance, a small number of highly productive native species, like *Pteridium aquilinum*, *Molinia careulea*, which are extremely abundant, have highly harmful impacts on other native species in National Parks in the UK (Pakeman and Marrs, 1993; Brown, 1999). Based on analysis of extensive data from almost 500 survey sites across the UK in 1990 and 2007, Thomas and Palmer (2015) have recently argued that non-native plant species did not threaten native diversity at a scale of nation-wide, and the previous negative judgments on non-native species have been exaggerated. From a broader perspective, these findings may also reflect the situation in other nations in the world. In particular, most horticultural species don't have the typical ecological characteristics of being an invasive species (Thompson, 2014); this is particular true of the species used to create complex multi-species plantings, where the goal is for species not to dominate their neighbors. As a result most of these species are likely to be stress tolerators, rather than the ruderals and competitors that typify invasive species. In the USA, since the production of its Invasive Species Policy in 2002, Chicago Botanical Garden for example recognised that most exotic plants are not invasive but greatly enrich peoples lives, support local wildlife, and have revised their initial position in their new Invasive Species Policy 2011 (CBG, 2011). Many more botanical gardens and research institutes in different countries had the similar understanding through observations and investigations, and gradually challenged the dogmatic perceptions about aliens (Thompson, 2014).

Many non-native plants initially have minimal fitness in a new environment, whereas fitness may increase over time following evolutionary change in response to different temperature and rainfall patterns from the original habitat, leading to more robust phenotypes. Only when species are introduced to climates with very similar growing conditions to their wild habitat or which have high seed production and efficient seed dispersal, or are rhizomatous, can the species become invasive (Thompson, 2014). Moreover, endemic fauna or fungal pathogens may also naturally keep populations in check (Duncan, 2010). Thus attractive non-native species of low reproductive potential may be particularly suitable for use in urban conditions (Hitchmough and Hang, 2013).

With global warming, defining natives and non-natives in terms of fitness is becoming ever more difficult. This follows the much longer trends in evolution and expansion of plants across the world in the last two million years (Thompson, 2014). Thompson (2014) has argued that it is very difficult to give an accurate definition of native and non-native. Alpine species that are restricted to mountains today were much more widely distributed in cooler periods (Oke and Thompson, 2015). Species from the south of the USA are becoming better fitted to more northerly areas (Mckenney et al., 2007). Hitchmough (2013) believed that climate change would profoundly impact upon the use of the native flora for horticultural purposes in urban contexts because some species would be increasingly poorly-fitted, and more plants from other countries might become better fitted or even “native”.

The second reason that many nativists have argued against non-native species in the past twenty years was their supposedly poorer ability to support native fauna (Wilcove et al., 1998). However, this position is increasingly difficult to sustain. In Britain, evidence derived from the thirty years' work of Jennifer Owen (Owen, 2010) and the research "BUGs" project (Gaston et al., 2004; Thompson et al., 2003; Smith et al., 2006a) suggests that non-native species also performed well and were potentially extremely valuable to native invertebrates. Non-native plant species also can support biodiversity similarly as native species does in urban contexts (Hitchmough and Wagner, 2011). Many exotic plants are culturally important both to human beings and fauna by providing food, shelter and vegetation structure (Siemann, 1998; Kendle and Rose, 2000; Shapiro, 2002; Owen, 2010). Evidence is also building that many species in designed naturalistic planting communities based on ecosystems originating in biogeographically similar regions, North American Prairie grassland for instance (Hitchmough, 2004) or Sino-Himalayan *Primula* wet meadow (Hitchmough and Innes, 2007), can equally support native European wildlife. On the other hand, climate fit need to be considered as well in relation to anticipated climate shifts (Davis, 1989; Hitchmough, 2011). There are some signs that attitudes towards non-native species are beginning to change amongst ecologists if not always native conservation practitioners. In Melbourne, Australia, for example, a very aggressive natives are good and exotics are bad understanding has traditionally prevailed, there is now growing argument amongst urban ecologists that structure and complexity may be more important than nativeness (Kirkpatrick, et al., 2007).

2.1.4 Contemporary naturalistic planting design Mediterranean regions of the world

Most of the review of naturalistic planting thus far has focused on the temperate world with abundant rainfall. There is growing interesting in using native vegetation in Mediterranean parts of the world. For instance, the Green Point Park (10.5 ha in total) located adjacent to the Cape Town Stadium was a flagship project using native vegetation in South Africa, built for the 2010 World Cup and proposed to be an urban eco-center. This biodiversity showcase garden features over 300 species of trees, shrubs, forbs (broad leafed-herbaceous plants) and geophytes. Geophytes include all the bulbous plants with storage organs of rhizomes, corms, tubers and true bulbs (Manning et al., 2002). Many of the planted areas are organised by typical eco-systems of the region in order to illustrate how plants naturally occur together in mountain Fynbos, Renosterveld, Sandveld and coastal areas. Whereas this is mainly an educational showcase garden, from a landscape design point of view, with combinations and compositions mirroring the wild habitat. Many of the communities are fire dependent but the site has not be designed to allow this to happen as part of management.

Southern and central parts of California, widely known for its iconic spring display of orange poppies (*Eschscholzia californica*) and other winter growing ephemerals, still has limited application of native species in naturalistic herbaceous plantings in cities. One of the reasons for this is that it is difficult to produce successful year round vegetation in Mediterranean regions where forbs, grasses and geophytes are generally subject to some form of summer dormancy. From 1998 the California Department of Transportation developed a program to establish and evaluate native meadow-like grassland ecosystem along roadsides and highways and to rebuild the historical planting communities since 1998 (NWP, 1998; Line, 2000). The deeper-rooted (relative to mown grass) native wildflowers are more drought-tolerant, which can help to improve erosion control, as well as potentially having major benefits to biodiversity. Much of the early work was relatively unsuccessful. They have now selected species that are drought-resistant and require little or no water to survive on roadsides (Harper-Lore and Wilson, 2000). The “Osher living roof” (2.5 ha) created in 2007 at California Academy of Sciences in San Francisco is key representative of the use of Californian native plants in the naturalistic style in the city. Many native herbaceous plants were established on slopes or flats on the roof with just 150mm of substrates. The building roof created unique micro-climates which have driven different distributions of the initially planted plants.

Generally speaking, the development of designed naturalistic herbaceous vegetation in Mediterranean climate is less well developed than is the use of naturalistic vegetation in temperate regions. This is in part because of the problem of plant dormancy during the summer months, as is the norm in the Mediterranean region. The other reason is that there has been less ecologically informed interest in how to assemble communities of these species in large-scale designed landscape. In near Mediterranean Australia, for example, the use of native species is highly developed, but most large-scale native plantings in urban greenspace and in green infrastructure are essentially just horticultural simulacra. This is because no attention is given to regeneration strategy as part of the design process, so it is generally impossible to manage such planting successfully to regenerate the canopies *in situ* or to allow for seed regeneration, because no thought has been given to this.

When it comes to herbaceous plants and geophytes few people in Mediterranean regions have worked out how to create naturalistic planting design involving these species that looks acceptable in summer. Mostly such planting involves only shrubs that are year round green. This challenge is addressed directly in this PhD study by looking at how shrubs, sub-shrubs, forbs, and geophytes from the Mediterranean regions of South Africa can be used to create new vegetation types in the warming cities of Britain.

2.2 The ecology of South African winter rainfall forbs and geophytes in their wild-habitat

2.2.1 Environment, Vegetation type and characteristics

The basic climate division in the Cape Floristic region is into winter and summer rainfall areas, as well as a year round area in the middle (Fig. 2.1). The winter rainfall area occupies the Western portions of SA from the coast to the inland central plateau, experiencing cool to cold, wet winter months and dry warm summer months with strong southeasterly winds. The bioregions of Southwest South Africa and their temperature patterns are shown in Fig. 2.2-2.3. The research discussed later in this thesis drew heavily on Mucina and Rutherford (2006) *The Vegetation of South Africa, Lesotho and Swaziland.* Manning and Goldblatt (2002) *The Colour encyclopedia of Cape bulbs*. was also an extremely useful reference text.

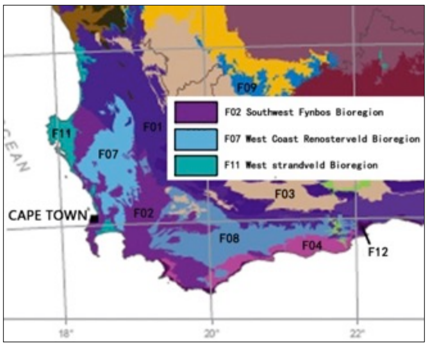

Fig. 2.1 Map of South Africa showing prime rainfall zones (adapted from Moll, 2006);

Fig.2.2 Bioregions of South Africa within winter rainfall zone (adapted from Mucina and Rutherford, 2006);

(image removed for copyright reason)

Fig.2.3 Examples of the Climate diagrams in relation to three bioregions mentioned in Fig.2.2 (adapted from Mucina and Rutherford, 2006).

2.2.1.1 Vegetation Structure and composition

In the Cape Floristic region, the ecology, composition, conservation status and distribution of the nine biomes as well as 435 vegetation types defined at a scale of 1:1 million map was defined. The main biomes are Fynbos (82%), with patches of Succulent Karoo (12%), Subtropical Albany Thicket (3%) and Afrotemperate Forest (0.1%) (Mucina and Rutherford, 2006; Huntley, 2012). The climate and soil determine the vegetation structure and composition in each biome.

As mentioned above, the climate (see Fig. 2.2-2.3) is typically Mediterranean, with summer drought the norm in the west but declining towards the east where summer-rainfall occurs. The degree of summer drought decreases with altitude in the inland mountain areas. Fynbos (or ‘fine bush’, from the Dutch word *fijnbos*, pronounced ‘fayne-boss’, latitude 31^0-35^0 S), refer to the finely leafed xeromorphic plants and open, treeless heathland with predominant sandy, nutrient-poor soil derived from sandstone and granite (Mucina and Rutherford, 2006), which occur from flat coast to inland mountains rising up to 2000 metres (Mucina and Rutherford, 2006; Manning, 2007). In the most part of the soils are far poorer than the soils of other Mediterranean-type ecosystems, with the exception of southwestern Australia (Huntley, 2012). Rainfall is however especially on the coast and the mountains relatively high (Manning *et al.* 2002). Floristically, Fynbos is characterised by Restionaceae, Proteaceae and Ericaceae, in addition with geophytes from other families. Grassy, shrub-land Renosterveld (literally means 'rhinoceros vegetation', as Black Rhinoceros were once frequently found feeding amongst the unpalatable shrubs *Elytropappus rhinocerotis,* latitude 32^0-34.5^0 S), occupies 25% of the Cape Floristic Region (Low and Rebelo, 1996). This occurs mainly in the Western Cape, commonly in combination with fynbos (Moll, 2006). These vegetation types occur on a range of soils from pure sand to heavy clay (Manning, 2007). The fertile clay soils (Cowling and Richardson, 1995) of the Cape lowland are subject to temporary anaerobosis.

Because the soils are more nutrient-rich than fynbos, more Renosterveld has been converted over the past 150 years to productive agriculture (Donaldson et al., 2002), with mere 2% left today (Chandral et al., 2009). Grasses are historically abundant in Renosterveld, especially *Themeda triandra*, as well as species from *Pentaschistis* and *Ehrharta* (Kemper et al., 1999). There are 9 basic fynbos communities, 4 kinds of renosterveld community types and western strandveld recognised in SA vegetation. Fynbos vegetation are subdivided in Mucina and Rutherford (2006) into Sandstone Fynbos, Sand Fynbos, Granite Fynbos, Quartzite Fynbos, Shale Fynbos, Fynbos Shale Band Vegetation, Silcrete, Ferricrete and Conglomerate Fynbos, Alluvium Fynbos and Limestone Fynbos. Renosterveld is grouped into Shale Renosterveld, Granite and Dolerite Renosterveld, Alluvium Renosterveld and Silcrete and Limestone Renosterveld (Mucina and Rutherford, 2006). In areas of low rainfall, the succulent karoo (meaning arid, dry, hard ground) occurs on clay soils (Manning et al., 2002). It is dominated by dwarf shrubs, most of which have succulent leaves.

Renosterveld and fynbos are both typically composed of a shrubby layer with an extremely diverse and dense forb/geophyte layer (Campbell, 1985; Dallman, 1998) with related but different dominant species composition. For instance, typical Fynbos plants such as Protea and Erica are absent or are present at very low abundances in Renosterveld. Renosterveld, in particular, is charactered by its richness of winter/spring-flowering geophytes (Donaldson et al., 2002). The geophytes in winter rainfall region can be divided into two groups according to growth cycle: winter-growing (summer deciduous) and evergreen-semi-evergreen species. The ecological character of winter-growing geophytes is to be dormant during the summer period (Duncan, 2006). They begin to produce new vegetative growth in autumn, as temperatures begin to fall after the warm, dry summer (Duncan, 2010), and complete the growth cycle by spring after a period of rapid growth. Typically they produce flowers between late winter and early summer (IBS, 2014), with most species entering dormancy by early summer until the following autumn. The evergreen species grow naturally in both the winter and all season rainfall areas, undergoing a short dormancy at some period in the year (Duncan, 2000). They produce new foliage in every spring and summer while maintaining the older leaves of last year.

Evergreen species occur in a wide range of habitats from full sun to deep shade (Duncan, 2010), and provide great opportunities for various designed plant communities. The following pictures (Fig.2.4–Fig.2.6) from field trips prior to and during this PhD. research show the community structures and the appearance of some shrubs, forbs and geophytes in their wild-habitat.

Fig. 2.4 *Dimorphotheca cuneata (*white) and *Gazania krebsiana* on Roggeveld mountains (>1500m) (photo taken by Ye Hang).

Fig. 2.5 *Hesperantha cucullata* and *Bulbinella eburnifolia* in *Muraltia* dominated Renosterveld near Nieuwoudtville (photo taken by Jame Hitchmough).

Fig.2.6 *Hesperantha pauciflora* and forbs near Nieuwoudtville. (photo taken by Jame Hitchmough).

2.2.1.2 Species richness and pollination diversity

The Cape Floristic region has remarkable species richness (i.e. number of species present) and the high level of endemism (Manning et al., 1997). It covers only 0.04% of the world's land surface (90760 km^2 in extent), while its 9381 species is roughly 16 times the species density of the Boreal Floral Region (Eurasia and North America), which occupies over 42% of the world's land surface (Huntley, 2012). The Amazon Basin forest has just one third as many species per 10,000 square kilometers (Huntley, 2012) as that of the Fynbos.

In terms of pollination and potential contribution to local biodiversity, winter-growing geophytes attract a wealth of pollinators including insects, birds, even rodents (Moll, 2006; Proches et al., 2006). Competition to attract pollinators is believed to have played an important role in the high levels of plant speciation. Though some of them merely have a short display season, the pollinators could vary from special oil-collecting bees to generalist beetles and bees (Donaldson et al., 2002). Oil-collecting bees are especially attracted to *Diascia* and *Hemierris* flowers by oil held in the corolla. Pollination by flies and butterflies greatly increase seed production in a large majority of species. The butterfly *Aeropetes tulbaghia* is recorded as the sole pollinator of a numerous red-flowered geophytes. Long-tongued flies are important pollinators for the long-tubed corollas of *Lapeirousia* and *Babiana* (Huntley, 2012). Species with sweet scent, like *Gladiolus carinatus*, are mostly pollinated by honey-bees and solitary, large bees. Species with tubular flowers and long perianth tubes are adapted for pollination by a number of sunbirds. For instance, *Babiana thunbergii, Gladiolus floribundus, Lachenalia bulbifera* and *Watsonia tabularis* are naturally attractive to sunbirds (Moll, 2006; Manning and Goldblatt, 1996).

Similar-looking *Romulea sabulosa* and *Romulea monadelpha* growing on different soils attract different monkey beetle species for pollination. This is because the beetle larvae were laid on a chosen type of soil, associated with the distribution of these two species rather than according to the particular feature of plants themselves (Huntley, 2012). Geophytes with attractive nectar and pollen are also of considered to be in a great value for supporting wildlife even when they were used in a suitable new environment outside of South Africa.

2.2.1.3 Cycles of competition for light, soil nutrients and water in Fynbos and Renosterveld

(1) Fire

The habitats a plant has evolved in has an over-riding impact on what species will tolerate as landscape elements (Migahid et al., 1996; Kleijn et al., 2008; Cristina et al., 2010; Hitchmough, 2013), therefore it is essential to pay attention on the study of wild plant communities in which species originate. As the dry summers became more common five million years ago, fire became a significant driver in the ecosystem dynamics (Huntley, 2012). In both Fynbos and Renosterveld, the vegetation is typically highly flammable (Cowling and Richardson, 1995; Mucina and Rutherford, 2006; Van Wilgen et al., 2010), and the fire-sensitive shrubby layer is usually the dominant component of the vegetation when fire occurs in summer and early autumn (Van Wilgen et al., 1992). Periodic fire in Fynbos and Renosterveld rejuvenate the vegetation by releasing the nutrients locked up in plant tissue back into the soil (Stock and Lewis, 1986; Manning et al., 2002), and clear away tall moribund vegetation that is shading the lower species (See Fig. 2.7). The temporary elimination of shading (Gill, 1981) allows many forbs and geophytes adequate access to sunlight (Le Maitre and Brown, 1992; Manning, 2007) and be able to utilise the space previously occupied by fire-sensitive shrubs. This freeing up of resources such as nutrients and light, also allow them to produce visually dramatic flower displays to attract pollinators (Duncan, 2006). (See Fig. 2.8) The initial community dominants post-fire are often re-sprouters (for example evergreen geophytes like *Aristea* and fire tolerant shrubs such as *Leucadendron salignum*) that regenerate from basal buds. Within woody species numerically most species are post fire re-seeders. Before the shrubby layer (be the species re-sprouters or re-seeders) regains dominance, until the next fire event, it typically allows plants re-establishing by sprouting from a woody rootstocks or germinating from seeds to persist within the community for 5-15 years (Le Maitre and Brown, 1992; Van Wilgen et al., 2010). In contemporary South Africa, the important role of fire in these ecosystems has been gradually understood and prescribed burning has been often used for management and conservation of these ecosystems as well as local Botanical Garden Kirstenbosh in Cape Town (Stock and Lewis, 1986; Manning and Goldblatt, 1997; Van Wilgen et al., 2010; Huntley, 2012).

Most of the geophytes in Renosterveld prefer to grow in the absence of canopy cover. The potential tolerance of shade of the small geophytes in such communities are rarely mentioned in the ecological literature, but is of great interest in establishing Mediterranean type of urban planting communities. As the shrubby layer develops most geophytes cease to flower and enter protracted periods of subterranean dormancy, a process which is poorly understood.

Fig. 2.7 Mountain fynbos post fire (photo taken by Jame Hitchmough).

Fig. 2.8 *Babiana melanops* blooming in mountain fynbos post fire near Tulbagh.(photo taken by Jame Hitchmough)

(2) Grazing

Both Fynbos and Renosterveld are adapted to cycles of recurrent disturbance as animal browsing of community dominants (Parker and Lomba, 2009). Historically, the first indigenous human inhabitants of the region utilised Renosterveld plants as food, medicine and grazing because of its nutrient-rich soils (Thring and Weitz, 2006; Nortje and van Wyk, 2015). Animals that lived in the Fynbos Biome, for example antelope, zebras, rhinos and elephants, used to spend most of their time in the Renosterveld, feeding on the grass, herbs and shrubs. The Khoi Khoi pastoralists therefore grazed their sheep and cattle almost entirely in Renosterveld for centuries, as did the Dutch settlers in the 18th and 19th centuries (Kemper et al., 1999). The Khoi Khoi burned the veld regularly to stimulate the growth of grass (for grazing) and geophytes, which they ate. Long periods of exposure to disturbance from grazing animals had profound effects on plant community structures, vegetation processes as well as ecosystem properties. A large majority of plants declined in farming areas at low altitudes during the land transformation that occurred post European settlement, which was accompanied by the drainage installation, road construction, fertilizer run-off, the utilisation of weed killers of natural habitats at Cape Flats (Goldblatt and Anderson, 1986).

Increased soil fertility also had an effect on the structure of plant communities. Less than14% of Acid Sand Plain Fynbos remains, none of which was formally protected until 2011 (Huntley, 2012). Renosterveld of the Tulbagh area and Caledon area was particularly bad affected. Encouragingly, the land management community have gradually recognised the issue, and tried to graze avoiding flowering periods of the important species. This alternation reduces the risk of extinction to the flora by keeping sheep and cattle away from the certain patches while geophytes blooming. The least damaged habitats are typically those that occur at higher altitudes in the Cape Flora Region, which are subject to less grazing and other disturbance (Huntley, 2012). These endemic species are now the priorities on conservation under the Convention on Biological Diversity.

2.3 The utilistion of South African species in cultivation and as design elements

Early plant collectors were fascinated by the richness of the flora of South Africa in mid 17th century, and took specimens back to Europe for study (Cowling and Richardson, 1995). Wild South African flowers were then displayed in flower shows across the world since mid 20th century (Huntley, 2012). Kirstenbosch Botanical Garden has exhibited annually at the Chelsea Flower Show, the world’s most prestigious flower show, from 1976 onward and won over 30 gold medals for its wonderful species. This allowed great input of availability into the cultivation market, with more and more species, cultivars and hybrids of *Pelargonium*, *Gladiolus, Watsonia, Freesia, Lachenalia, Ornithogalum, Ixia, Amaryllis* etc. With the exception of Mediterranean regions of the world mostly these genera are important as either cut flowers or pot plants rather than as large scale landscape applications. Relatively poor tolerance of winter cold in Europe and North America was initially recognised as the main cause of limited of landscape utilisation, where this is not a limitation many species possess elegant appearance, with a potentially long flowering season and are eminently suitable to garden and landscape applications. In their original habitat, the highest geophyte species richness is naturally associated with the lower altitude Mediterranean climates of South Africa, however there are also many other winter geophytes associated with Mediterranean or year round rainfall climates that are found on mountains at altitudes of >1500m (Mucina and Rutherford, 2006), like Matroosberg, Pakhuis Pass, Groot Swartberg mountains and the Roggeveld area, where they experience low winter temperatures and wet soils. These latter species are of particular interest to Britain nowadays with increasing wet autumn-winter climate, and are potentially well fitted, especially in the heat island climates of cities. Seeds of these species are under different stress conditions and can generally produce seeds which are resistant to similar conditions (Bewley and Black, 1994). These geophytes are greatly in productivity, with flowering height varying from ground level to >1.00m, which can be used to create visually novel and exciting naturalistic planting. For example, evergreen species *Aristea inaequalis* with long, narrowly sword-shaped, ever-bluish green looking foliage with reddish margins and upright stems of striking blue flowers can be attractive as a repeating element (Manning et al., 1997). Tall-growing evergreen geophytes like *Aristea macrocarpa, Aristea capitata (syn. A. major)* (Duncan, 2010)**,** and deciduous species like *Watsonia borbonica, Watsonia vanderspuyiae*, exceed 1.5-2.0m in height in flower (Manning et al., 1997). Their architectural basal foliage and flowers atop tall naked stems look dramatic as emergents from a geophytes meadow comprised of many species of small growing geophytes mixed with evergreen forbs and dwarf mound forming shrubs. Moreover, shrubby species *Erica* in SA, with 682 out of a global total of 816 species (Huntley, 2012), in fynbos at high elevations has great potential as a component of naturalistic heathland planting or combined with other plant types associated in the wild habitat. The long-term flower display from spring to the end autumn in different species with pinks, mauves and complex mixes of greens and yellows, potentially provides structure in nature-looking plantings as medium height layer. In addition, the majority of *Restionaceae*, known as Cape reeds, which were almost unknown to gardens in SA and beyond, have been shown by researchers in Kirstenbosch to be excellent structure plants in large-scale landscapes. These species also can be used in nature-looking plantings played as emergent elements.

2.3.1 Phenology of germination, emergence and growth

Mediterranean winter-growing geophytes naturally germinate or begin to produce new vegetative growth following autumn rainfall, complete the growth cycle by spring, and then enter a dormant period during summer (Manning et al., 2002). Therefore, early autumn is regarded as the optimum sowing time for winter-growing geophytes, when temperatures begin to fall and with conditions of relative low soil moisture stress (Duncan, 2010). Forbs commonly germinate in autumn or spring.

2.3.1.1 Germination, emergence and early stage growth

(1) Germination and emergence

Germination is invariably crucial when introducing a new species to cultivation. After sowing onto substrate, seeds uptake water (imbibition), in preparation for the emergence of the radicle and radicle elongation in the germination period (Bewley and Black, 1994). This is then followed by seed emergence. Seeds that fail to germinate or delay of germination under favorable condition (Bewley, 1997) or that can’t complete germinate in unfavorable conditions are defined as dormant (Baskin and Baskin, 2014). Even if non-dormant seeds won’t germinate until they experience the required environmental factors (Hilhorst and Karssen, 1992; Bewley and Black, 1994). Broadly, seeds can be broadly divided into two groups: recalcitrant (desiccation-sensitive) seeds with short viability with high moisture content which need a high level of moisture to maintain viability but which show rapid germination, and orthodox (desiccation-tolerant) seeds relatively long viability but with low moisture content (Walck et al., 2011). In seeds of most varieties imbibition of water takes place rapidly following sowing (Bewley and Black, 1994). Germination may be restrained if the amount of water is too low (Botha and Johannes, 1985; Kranner et al., 2010), particularly species derived from wetland conditions (Evans and Etherington, 1990). Although moisture was of vital importance for change from seed germination to seedling establishment (Evans and Etherington, 1991), too much water, however, may cause severe moisture stress to seedlings, especially those from dry and infertile habitats (Hitchmough et al., 2001).

As essential as water, temperature is another driver in stimulating seed to germinate (Covell et al., 1986; Baskin et al., 1995) and increasing the germination rate (Garcia-huidobro et al., 1982). Species from temperate alpine areas, prairie areas and plains at high latitude are used to germinate in cold-wet condition (Shimono and Kudo, 2005), thus autumn sowing in practice ensures winter chilling in situ (Walck et al., 2011), or pre-treatment of chilling seeds in fridge (Baskin and Baskin, 2014) is an alternative method to enhance the germination through creating low temperature environment.

Mediterranean species that germinate in autumn after hot summers may require warm stratification to break dormancy or are non-dormant after maturity (Kahmen and Poschlod, 2008). Fluctuating temperatures are more effective in breaking dormancy (Thompson and Grime, 1983; Fenner, 1995). Generally speaking, speed of seed germination can be categorised into rapid, medium and slow germination (Baskin and Baskin, 2014). For better germination, collection of seeds at maturity is also important. Seed age and their storage conditions (in terms of moisture content, temperature and oxygen) before sowing (Harrington 1972), insect predation equally determinate seed vigor in germination and seed longevity (Bewley and Black, 1994). Usually, seeds collected recently (Ghassemi-Golezani and Dalil, 2011) with bigger seed weight (Powell, 1988) and under specific storage condition can display more vigor in germination, because seeds would commonly loose their vigor and viability during storage.

Leishman et al. (2000) indicated that seed size was also related to seedling size and seedling survival, with larger seeds likely to show better seedling survival. In the establishment phase, vigor of seed will largely restricted by water and heat stress (Kranner et al., 2010), and the seedlings require a period of time to become fully established usually accompanied with high mortality rates (Fenner, 1985). The conditions prevailing during the window of emergence is crucial to natural ecosystem, cropping systems (Gardarin et al., 2012) as well as designed planting community, especially multi-species plant communities established through sowing (Hitchmough et al., 2003).

In terms of establishment and flowering period of Mediterranean geophytes, temperature is widely considered to be the major external factor in controlling germination, growth and flower development (Hartsema, 1961; Duncan, 2010). Winter-growing geophytes sown in autumn between 12-18°C (Duncan, 2010) when the air and soil temperature dropped markedly at night typically show much better germination and emergence. A wide range of research has explored the temperature patterns for germination and growth of winter-growing geophytes, mainly under laboratory conditions. Based on the data gained from the controlled conditions, plant field ecology can be predicted (Grime and Hodgson, 1969). Temperatures from 20-25°C are effective for some Gladiolus (Tan Nhut et al., 2004). *Watsonia vanderspuyiae* were found to germinate optimally within a temperature range of 10-20°C (Ascough et al., 2008). Lachenalia germination starts at about 15°C (Slabbert and Niederwieser, 1999). Irrespective of the temperature at which species germinate, the normal pattern in winter growing Mediterranean geophytes and also forbs and shrubs is to germinate as the temperatures decline in autumn.

The ability of winter-growing geophytes to germinate when sown in the spring as temperatures rise has not been covered in the literature. Duncan (2010) suggests that only Ixia, Sparaxis and Tritonia are able to do this. It would seem that there has been no research on this nor collation of data from horticultural experience. In the author's MA experiment in Sheffield Botanical Gardens (Hang, 2010), the species that germinated well at times other than autumn tended to come more from coastal or coastal mountain regions where some summer rainfall occasionally occurs and spring germination is less likely to prove lethal. Species from very dry summer climates such as *Bulbinella nutans* and *Bulbinella latifolia* commonly appear to have an obligate need for autumn sowing (Hang, 2010). There also however seem to be patterns associated with taxonomy, for example as a genus Mediterranean Watsonia species seem able to germinate both in the autumn and in spring, whilst the Asteraceous genus Corymbium seems to be an autumn germinating obligate. Sowing South African species in spring might be attractive in practice in cooler condition as a means of gaining an extra growing season before experiencing cold winters.

2.3.1.2 Seed treatments to maximize seedling germination and emergence

Seed pre-treatments are used to break seed dormancy and promote germination. Temperature (winter chilling *in situ*, chilling in fridge), light, hot water, gibberelins, smoke and scarification can all have some effect on various species (Slade and Causton, 1979; Baskin and Baskin, 2014). Unlike temperate alpine plants, many species from high-mountain Mediterranean climate were able to germinate directly without pre-sown treatment such as low temperature pre-treatment (Giménez-Benavides et al., 2005). Propagation of Fynbos plants such as Protea, Erica, Helichrysum and species within the Restionaceae from seeds is usually difficult (Brown et al., 2004). Germination of some species from fire-prone habitats is deeply affected by fire (Brown, 1993). Heat, and smoke containing chemical factors trigger germination of deeply dormant seeds, particularly seeds with oxygen-impermeable seed coats (De Lang and Boucher, 1990; Le Maitre and Brown, 1992; Brown and Van Staden, 1997; Keeley and Bond, 1997).

More artificial approaches in horticulture and natural protection have been developed to increase germination. For instance, heat followed by cooling and wetting cycles, which mimic fire followed by rain in the habitat, was found to be effective on seed germination of Leucospermum species (Brits et al., 1993). Alternating diurnally temperatures also successfully stimulated seed germination of Leucospermum species from Fynbos (Brits et al., 2014). Plant-derived smoke as an important cue promoting seed germination has been identified to be one of the major implications for understanding of conservation biology, rangeland management, landscape re-vegetation and the horticultural and agricultural exploitation of wild plants (Brown and Staden, 1997). Gibberellins, cytokinins and ethylene have all been previously used to break seed dormancy in fynbos species (Brown et al., 1994), and may possibly interact with chemicals in smoke (Thomas and Van Staden, 1995).

Seeds of many species in South Africa exhibit dormancy and require specific conditions for germination that extend beyond temperature patterns. In a designed planting community, there will be many species with various seed types (non-dormant seed and dormant seed), potentially performing differently in germination and dormancy. Therefore, appropriate seed pre-treatments can help to control the germination rate of different growth forms and avoid unnecessary elimination at the early stage of establishment.

(1) Smoke treatment

Plant-derived smoke has been investigated to increase seed germination of a large number of species from South Africa, North America and Australia (Dix et al., 1995; Keeley and Bond, 1997; Tieu et al., 2001; Flematti et al., 2004). De Lange and Boucher (1990) burnt variable mixture of plant material from the fynbos vegetation to expose seeds to smoke, which boosted the germination in the Restionaceae from near zero up to over 90 percent for many species within a few days. Similar results were achieved for many other fynbos plants that had previously been impossible to germinate (Brown et al., 1994). Soon afterwards De Lange recognised that seed of responsive species could be made to germinate by soaking filter papers in water blended with smoke and dried out for future use through storing the active chemicals in the paper (so called 'smoke paper') (See Fig. 2.12). When needed, smoke paper is placed in a Petri-dish, wetted and seeds placed on the surface for up to 72 hours. A compound butenolide in plant-derived smoke was identified by Flematti et al. (2004) and compared to be the similar function as plant-derived smoke water in stimulating seeds germination. Butenolide is water-soluble and stable in the smoke below 118^{o}C (Flematti et al., 2004).

This technique is now widely used to treat South African seeds before sowing, with a particularly strong effect on species in genera such as Protea, Leucospermum, Leucadendron, Erica (Brown et al., 1993), plus families such as the Asteraceae, Bruniaceae, Crassulaceae, Geraniaceae, Mesembryanthemaceae and Restioaceae (Brown et al., 1994; Brown et al., 2003). However, in research into investigating more than 220 species from Cape Flora Region carried by Brown et al. (2003), it also indicated that even if most Erica species were smoke-responsive, not all of Erica species responded to smoke. Post-fire re-sprouters did not show positive on smoke response in comparison of post-fire re-seeders, which were deduced to have no obligate requirement for regeneration from seeds. Most woody species under test were re-sprouters or produce serotinous seeds, therefore they didn't exhibit the significant response to smoke.

Most geophyte species exhibited no special response on smoke treatment as well, with species particularly in Amaryllidaceae (Cyrtanthus), Hyacinthaceae (Albuca) and a majority of Iridaceae (Bobartia, Geissorhiza, Moraea, Romulea). In conclusion of this research, the scientists deduced that germination of non-serotinous annual and herbacecous species with no ability to re-sprout after fire was likely to be more strongly reliable on smoke stimulation. In the author’s previous experiment (Hang, 2010), the tested geophyte species from Aristea, Babiana, Bulbinella, Geissorhiza, Gladiolus, Ixia, Lachenalia, Sparaxis, Wachendorfia, Watsonia did not show a response to smoke.

Fig. 2.9 A commercial smoke paper ‘Cape seed primer’.

(2) Scarification

Where the permeability of seed coats to water is low this may prevent seed germination (Baskin and Baskin, 2014). When attempting to germinate species with hard seed coats from Fynbos, such as *Lanaria lanata*, smoke is only likely to have an effect when the seed coat does not prevent the ingress of water and oxygen (Brown et al., 2004). Hard coated-ness can be broken by either boiling water treatment (Cervantes et al., 1996; Gama－Arachchige et al., 2013) or mechanical abrasion using 100 grit sandpaper for between 10 and 20 seconds (Brown et al., 2004).

2.3.1.3 Seedling growth and mortality

After seedling emergence, soil moisture stress may have different impacts on seedling growth in comparison to the period of germination. Qi and Redmann (1993) found water stress promoted seed germination of C4 grass *Bouteloua gracilis* whilst restricting seedling growth and threatening seedling survival. The effect of moisture stress post germination on South African geophytes and forbs is little studied. Seedling herbivory at early stage of growth is an important factor that can also lead to high mortality (Hulme, 1996; Mole and Westoby, 2004). Whilst it is known that specialist geophyte predators such as mole rats are extremely important in general in South Africa, it is not know what effect they have on seedlings, as opposed to adult plants.

2.3.2 Environmental stress and South African plant growth in the UK

Environmental stress (external stress factor) is widely accepted in plant ecology as factors that limit plant biomass (Grime, 1977). Factors that affect or restrict a plant's metabolism, growth and development are regarded as plant stress by Lichtenthaler (1996). Stress involves factors from outside rather than inside of an organism, and is most commonly used in relation to key resources for growth, such as water, light and nutrients; as well as disturbance factors such as the activities of pathogens, human and herbivores; and phenomena like frost, soil erosion, fire and wind (Grime, 1977). Grime (2001) further simplified stress as 'the external constraints which limit the rate of dry matter production of all or part of the vegetation'. Based on the duration time, stress factors can be classified into short-term stress and long-time stress, or based on strength, into low stress and strong stress (Lichtenthaler, 1996). Tolerance and sensitivity are used to describe stress factor (external stress) response of a certain plant (Kranner et al., 2010). There are two basic models to describe plants' response to environmental stress in the literature. One is the two-strategy model 'r-and K-selection' developed by MacArthur and Wilson in 1967, which was frequently described as a tradeoff between colonization and competition (Hastings, 1980; Crawley and May, 1987; Tilman, 1994; Ehrlen and Groenendael, 1998; Lipowsky et al., 2012; Bohn et al., 2014). The other is the CSR three-strategy model created by Grime's (1977) which deals explicitly with perennial herbaceous vegetation, but has been applied to other life forms (Chapin, 1980; Aerts et al., 1990; Reich et al. 1992; Lamber and Poorter 1992; Bolker and Pacala 1999; Frenette-Dussault, 2012;

Schmidtlein et al., 2012; Pierce et al., 2013). In CSR model, plant response strategy to environmental stress was cataloged into three distinct types. Plants in high productive site with low stress and low disturbance were defined as 'competitors', plants from high productive condition with low stress but high disturbance were named as 'ruderals', while plants from unproductive site with high stress and low disturbance were 'stress-tolerators'. Stress-tolerant plants are particularly important in designed Mediterranean planting communities. Plant populations evolve over long periods of time to be fitted and tolerate the conditions prevailing in their habitats, and in addition to stress factors such water and light, plants are also adapted to grow within the temperature ranges associated with the habitat. When placed in cultivation environments, which differ markedly from those in their wild habitats, plants will perform differently according to their genetically defined stress tolerances (Larcher et al., 1990; Larcher et al., 2010). Initial assessment of stress tolerance characteristic of a given plant is a key stage in considering a new plant for use in naturalistic plantings, as a precursor to exposing plants to competition with other species. Different stresses usually exert different impacts on vegetation (Grime, 1977) with the extreme factors of winter cold and summer wetness to most of species. As discussed in 2.3.1, seed germination, seedling emergence and early growth are the three key stages with regard to a plant development, and especially critical for the establishment of individual plant in a newly created plant community.

Fay and Schultz (2009) studied the effect of soil moisture variability on grasses and forbs in a North American prairie plant community. Plant tolerances to cold and wet stress have been widely investigated on commercial crops and woody plants (Redman et al., 2011; Tian et al., 2011; Quinn et al., 2015), rather than in urban designed landscape. Species from tropical or subtropical regions, when introduced to temperate geographical locations, may be injured or killed even by non-freezing low temperatures, by presenting symptoms of chilling (0-15^{o}C) damage on leaves, chlorosis or growth retardation (Sanghera et al., 2011). Necrosis is common when near freezing (<0^{o}C) temperatures are experienced. Early development stages of germination, emergence and seedling growth of a plant are regarded to be more sensitive to environmental stress in comparison of adult stages (Fay and Schultz, 2009).

2.3.2.1 Tolerance of Winter cold

South Africa mainly lies at latitudes between 34 and 24 degrees south, while the UK lies between 50 and 58 degrees north. This is a very big mismatch in latitude, and it is much colder in the UK than in SA. Western South African plants mainly grow in winter, and hence are particularly prone to injury in the UK, which normally require winter protection (Manning and Goldblatt, 2002). This experience reflected typical genotypes tested previously were chilling sensitive species, however, South Africa is a very mountainous country and this counteracts greater proximity to the equator. Species distributed at high altitude above 1000-1500m may experience -6ºC or colder with a long period of frost (Mucina and Rutherford, 2006). Therefore, it is theoretically possible to introduce species from these regions to outdoor conditions in the UK. Cold tolerance in geophytes is generally strongly related to cold experienced in their natural distributions (Hamasha and Hensen, 2009; Humara et al., 2000; Debussche et al., 2004; Khodorova and Boitel-Conti, 2013). Hitchmough and Cummins (2011) found that populations of South African species collected from the coldest provenances were typically the most cold tolerant. Many species from these colder habitats were able to tolerate -6°C even as very young seedlings, and to be held at these temperatures for extensive periods and still escape damage.

As a general statement, populations of the large majority of the winter-growing SA species from low altitude are not very cold tolerant in the UK, and colder climates. There are, however, conspicuous exceptions to this, *Gladiolus tristis* for example, is typically long lived outdoors in southwest England (Duncan, 2000), and has survived outside unprotected in Sheffield in the authors preliminary experiments through some the coldest winters in the C21st in 2010. This cold tolerance may come from this species being distributed in low-lying edges of stream and seasonal wetlands which act as frost pockets in winter. An increasing range of species have been grown outside of greenhouse and cold frames by members of the Alpine Garden Society (Hitchmough and Cummins, 2011) over the past decade. In the past six years, populations of species, such as *Aristea major, Kniphofia uvaria* and *Watsonia schlecteri* have survived outdoors in Sheffield (northern England) during colder than average winters (Hitchmough and Cummins, 2011). In Cummins's (2010) study, there were 11 winter-growing geophytes and 2 forbs from the Cape

Flora Region that survived the cold winter 2009-2010 in Sheffield Botanical Garden, with young seedlings in pots experiencing -7.5°C. *Ixia curvata* and *Romulea komsbergensis* were observed as the most cold tolerant species (Cummins, 2010). This suggests the possibility of outdoor survival of South African Mediterranean plants in Northern England. The winter cold tolerances of many more species have been evaluated comparatively in this study.

Species with populations in the Roggeveld area (a raised inland plateau with an altitude of 1000-1600m) experience severe winters (down to -16°C in the vicinity of Sutherland) (MO, 2015) in the winter-rainfall zone (Smale, 2006). The minimum temperatures experienced on the upper portions of mountain peaks are not known, temperatures are rarely recorded in these remote locations but are probably well become -10°C. The mountains further from the sea are generally the coldest (Mucina and Rutherford, 2006), for example, the Cold Bokkeveld (1200-1600m) and Groot Winterhoek Mountains (1000-2077m), the Swartberg (1500-1800m), and the Hex River Mountains, including the Matroosberg, at 2250m, the tallest mountain in the Western Cape. Even mountains in Northern Western South Africa, such as Kamiesberg (1100-1450m) in Namaqualand experience 10-30 frost days annually at these altitudes (Mucina and Rutherford, 2006). A full review of winter temperature regimes in South African can be found in Mucina and Rutherford (2006) however these data are largely derived from climatic modeling rather than on observed data. Species from these mountains typically possess relative high tolerance of cold winter and frost.

Factors favoring winter growing South African species in the UK are climate change and localised urban heat islands. The UKCIP02 emission scenarios report predict winters in southeast England will become warmer by between 1.5 ºC and 3.5 ºC by the 2080s, and very cold winters will become increasingly rare (Hulme et al., 2002). In addition, winters are also likely to become wetter by between 10% and 30% by then. Hence cold stress to these species will gradually become less, particularly in highly urbanised landscape settings. Urban heat islands in the UK are already responsible for large differences in the severity of winter minima between city centers and surrounding rural landscapes.

Table 2.1 Summary of Climate and Precipitation in Sheffield over the research period in comparison with weather statistics in Cape Floral Region, South Africa. (Data from: SWP 2015)

Year	**Sheffield**			**Cape Floral Region, South Africa**		
	Highest Temp.(ºC)	Lowest Temp.(ºC)	Total Rainfall(mm)	Summer Temp.(ºC)	Winter Temp.(ºC)	Annual Rainfall (mm)
2010	31.8 (July)	-8.9 (Dec.)	852.9	Most within 20-27.5. Maximum temperatures reach 38C, hotter inland	Most within 2-15, minima of -1/-2, at the coast, down to -10 or colder above 1200m altitude	Most within 500-1250 Some < 500
2011	26.9 (Aug.)	-3.8 (Dec.)	957.7			
2012	27.2 (July)	-6.7 (Feb.)	973.9			
2013	30.1 (Aug.)	-4.9 (Jan.)	739.8			
2014	28.0 (July)	-1.4 (Dec.)	950.8			
2015	32.4 (July)	-2.0 (Feb.)				
1955-onwards			828.5			

2.3.2.2 Summer wet tolerance

Winter-growing geophytes and forbs only experience period of wet in winter and period of dryness in summer. This is very different pattern to the year round wetness in the UK. Summer wetness, therefore, becomes another challenge to using these species in UK urban landscapes. Most of anecdotal literature suggests that South African summer dormant (winter-growing) geophytes are sensitive to summer rainfall in the UK (Duncan, 2006), however, the responses of most species are simply not known. Climatically the Western Cape has steep rainfall gradients, annual rainfall is highest in the southwest, which reaches 3000mm in the mountains above Stellenbosch, and 380-760mm a year in the lowlands. (Duncan, 2000; Manning et al., 2002) Species from the coastal mountains often experience soils that are occasionally wet in summer (Manning, 2007). Some species, like *Gladiolus carneus* and *Gladiolus tristis*, grow in seasonally damp areas in wild habitats (Manning et al., 2002), and both species are normally cultivated in summer moist soils in the UK. Species that grow along streams, such as *Gladiolus angustus,* or in seasonal wetlands, such as *Wachendorfia thyrsiflora,* can endure heavy watering in cultivation in South Africa during the summer (Manning et al., 2002). On the interior plateau of the Cedarberg and Cold Bokkeveld, rainfall reaches more than 1250mm a year in some mountain ravines (Manning et al., 2002), but the soils are often highly permeable, derived from sandstone. There is much anecdotal evidence that when SA winter growing geophytes are grown in very sandy soils (Manning et al., 2002), they are relatively tolerant of summer irrigation or natural rainfall. Species like *Sparaxis elegans* naturally grow in the very dry summer rainfall climate of the Roggeveld Plateau (Nieuwoudtville to Calvinia) is listed as highly sensitive to summer moisture in South African literature (Duncan, 2010). This species is however found on clay soils and tolerated summer rainfall in the author's experiments (Hang, 2010). Species such as *Moraea speciosa* from the interior mountain valleys on parts of the Bokkeveld-Roggeveld Escarpment and in the Tanqua Basin with less than 250mm rainfall a year are supposed to be most intolerant to wet summer (Manning et al., 2002). Some of these species will benefit from higher summer temperatures derived from Climate Change (Hulme et al., 2002), resulting in soils drying out more quickly, although this may be counterbalanced by more intense summer rainfall.

Evergreen or semi-evergreen (species having a short dormant period immediately after fruiting) geophyte species from the Cape Flora Region require some moisture throughout the year, which are correspondingly likely to be more tolerant of wetter summers. The effect of summer rainfall during the establishment and summer mortality of these geophytes as well as forbs, shrubs was investigated in this research.

2.4 Competition in designed plant communities

2.4.1 Competition

Early in mid-19th century, Darwin (1859) broadly described competition in a habitat as "struggle for existence". In order to more clearly define the terminology 'competition', Grime (1979) added in a word 'neighboring' to restrict range and degree of impact, and emphasised competition in vegetation is "the tendency of neighboring plants to utilise the same quantum of light, ion of a mineral nutrient, molecule of water, or volume of space". Because of seed dispersal and plant mortality, neighborhood of a plant is changing throughout the time (Tilman, 1994). Competition happens both above and below ground (Grime, 2001). Competitive abilities of plants are usually various. Even a certain species may perform greatly different in competition in various growing conditions (Grime, 1977). This strongly relates to plant growth rate (Grime and Hunt, 1975), which was explained by Fitter and Hay (2001) to be the increase of plant dry weight within a period of time, which reflects plant size and its potential competitive ability. In the Competitor-Stress Tolerator- Ruderal model (CSR model), Competitive plants (namely superior competitor, also see section 2.2.3 environmental stress) may grow rapidly, producing more leaves or bigger leaves to form dense canopies, develop bigger root coverage to absorb water and nutrient (Grubb, 1994), or develop storage organs to promote above-ground expanding (Chapin et al., 1990) to become dominant. While Tilman (1982; 1988) in his Resource Ratio model believed that plants that were most tolerant of low resources level were the most competitive and could eventually replace other species in the community, this is not what seems to happen in real plant communities. The CSR model has been much more widely applied as management tool to predict reactions to changes occurred in ecosystems (Dickinson, 1998), and in designed landscape (Grime, 1986; Dunnett, 2004) in terms of plant selection (Grime et al., 2007) and management. The height of an established perennial plant is beneficial to it capturing more light in a community (Grubb et al., 1982). A comparative study of 44 herbaceous plants carried out by Gaudet and Keddy (1988) showed that the ability of a plant to compete for light relied upon the height and morphology of its shoots. Species with growing points on the top of the upright stem are most advantaged, whereas species with growing points close to ground sometimes developed few massive basal leaves to increase light capture. Shoot thrust was recognised by Campbell et al., (1992) to be another factor which affects competitive interactions. It refers to the capacity of pushing the foliage of a neighbor plant aside or resisting displacement by neighbor plants. The rate of uptake of water and nutrient (below-ground interactions) largely determinates the rate of building up shoots (Mahmoud and Grime, 1976), which is an essential prerequisite of a successful aboveground competition.

When vegetation develops, leaf canopies expand, which gradually changes the light quality within a community, then competition occurs. Due to perennial species, and in particular stress tolerators mainly building up their storage organs rather than leaves, growth rate in the first growing season is relatively low (Fitter and Hay, 2001). Grubb (1998); Coomes and Grubb (2003) have pointed out seed size of species in the same functional group is a crucial factor to affect seedling establishment and survival in the competition. It is generally considered that bigger seeds are prone to form bigger seedlings to compete for resources with close-by seedlings, however, species with smaller seeds tend to be superior colonizers in occupying more space (Turnbull et al., 1999; Leishman et al., 2000; Yu and Wilson, 2001). Coomes and Grubb (2003) indicated the ability of species regeneration within a community also depends on the dispersal range of seeds. As large seeds were less prone to be fully buried than smaller seeds (Thompson and Grime, 1983), they were better at achieving high plant abundance in the community (Murray et al., 2005).

Although the competitive ability of species is largely subject to their genetic make up, it is also subjected to the restricted extent of environment to allow the species express their competitive characteristics (Grime, 2001). In the nutrient-poor meadow, the growth rate and competitive ability of certain species, especially grasses, may be largely restricted by mineral nutrient stress (Brenchley and Warington, 1958). When fertilised, these species would rapidly extend and dramatically change the nature of the community (Grime, 2001). Competitive abilities of plants may also reduce due to leaf or root loss caused by disturbance such as predation (Burt-Smith et al., 2003) or damage such as frost (Grime, 2011).

In high resource environments, for example where there is abundant water, nutrients, and light, the most productive species in that community, typically dominate the biomass, and this is referred to as Dominance. In unproductive low resource environments, a situation known as co-existance tends to occur, as there are insufficient resources for any one species to become dominant. These processes are however highly relative, and even in resource poor environments it is common to find some evidence of dominance.

As in nature, within designed planting community created by sowing or planting also allows multiple species to coexist by partitioning space (Turnbull et al., 2004). Once the plant community has been established, competition for light and other resources starts between individuals, with growth rate and ultimate size reduced distinctively, and typically leads to ‘self-thinning’ and a relative balance with sustainable density by the beginning of the second growing season (Hitchmough et al., 2008). Quick growing big species with overshadowing leaf canopies tend to eliminate small neighboring plants by dominating the light (Schwinning and Weiner, 1998), the most critically important resource in a planting community (Hitchmough, 2013) but historically seen as of less importance in traditional planting design that soil factors.

Newly established seedlings are prone to be eliminated through competition with previously established plants (Hutchings and Booth, 1996). Only shade-tolerant small species are typically able to survive and co-exist (Hitchmough, 2004; Ahmad and Hitchmough, 2007; Sayuti, 2013). Therefore, germination phenology of regeneration, leaf phenology, canopy size, spatial arrangement of species, growth rate as well as shade-tolerance ability normally influence population dynamics in the longer term, determining the species composition and diversity of plant communities (Walck et al., 2011). In species diverse plant communities, dominant, subordinate and transient species are normally co-existance (Grime, 1998) to ensure stability in ecosystems (Hooper et al., 2005).

In designed planting community, reducing the nutrient content of the soil is often used to restrict some fast-growing species in order to balance the growth rate of other species in the designed planting community to better ensure co-existance.

2.4.2 Competition in wild occurring Mediterranean plant communities

In habitats with low to relatively low productivity, such as many areas in Mediterranean climates, the leaf canopy of plants are commonly reduced and relatively widely separated, so that competition is more restricted mainly to root systems below ground rather than shoot systems as in temperate ecosystems. Plant growth rate as ever is influenced by the favorability of environmental condition and the abundance of resources (Fitter and Hay, 2001) and so Mediterranean species also respond in this same way. Faster-growing perennial species occur in productive habitats, (Grime and Hunt, 1975; Lamber and Poorter, 1992), while unproductive habitats often support slow-growing species (Beadle, 1962; Bradshaw et al., 1964). Examples of this can be seen in Mediterranean climates along drainage corridors, which are dominated by

Phragmites and similar species, and competition for light is the dominant factor. When a plant from productive habitat is introduced to an unproductive site, its growth will usually be seriously disadvantaged. In reverse, when a plant from unproductive habitat is introduced to a site with fertile conditions, it may grow more quickly and larger in size, however it is still likely to be outcompeted by the more rapid growing species that naturally occur in these habitats.

2.4.3 Competition as a factor in designing South African Mediterranean planting communities re-sprouting shrubs, forbs and geophytes.

This research chose Fynbos and Renosterveld as inspirations for planting design, and explored how species could be combined in Mediterranean-like plant communities to maximise the duration of attractiveness, the intensity of flowering display and interest and at the same time facilitate easy and sustainable management techniques. One of the means by which to manage competition in designed vegetation is to organise species into distinctive layers:

2.4.3.1 The Forb dominated ground layer

In semi-natural habitats in South Africa, this layer is only normally permanent in environments where severe summer moisture stress or grazing prevents the development of a taller canopy that would cast shade. This is the situation for example on much of the Roggeveld escarpment, where there is an evergreen ground layer composed primarily of low growing (generally less than 300mm tall) rosette forming forbs, mainly drawn from the Asteraceae, including genera such as *Arctotis, Dimorphotheca, Gazania* and *Ursinia*. Succulent species such as *Aloinopsis* species are also present with non-succulent forbs. On sites where there is sufficient rainfall to permit taller biomass, these forb layers are ephemeral, only lasting for the first two years after a fire. As a result most of the species that form these ground layers are shade intolerant, and are only likely to be able to persist in productive conditions if the systems is cut off at ground level on an annual cycle to continue to permit light ingress.

2.4.3.2 Emergent geophytes layer

An emergent geophytes layer would be able to push through the spaces between the forb layer, and typically flower later than early flowering species in the ground layer. Most of the geophytes in Renosterveld are only able to grow and flower in the absence of taller canopy cover. This occurs in semi-natural landscapes by fire temporarily removing the taller canopy, and in low intensity agricultural landscapes as in the case of the Roggeveld, this is partly achieved through animal grazing-summer drought. The potential tolerance of shade of the small geophytes in such communities are rarely mentioned in the ecological literature, but is of great interest in establishing Mediterranean type of urban planting communities. As the shrubby layer develops most geophytes cease to flower and enter protracted periods of subterranean dormancy, a process which is poorly understood.

These species could include geophytes such as *Babiana* (Goldblatt and Manning, 2007), *Bulbinella, Gladiolus* (Goldblatt and Manning, 1998), *Moraea* (Goldblatt and Anderson, 1986), *Ornithogalum, Watsonia* (Goldblatt, 1995) et. Height of plants in this layer will vary enormously from 200mm, to 2000mm (when in flower). Most species in this geophytes layer are summer deciduous, but there are also many evergreen species, typically with fan-like or grassy foliage, as in *Aristea, Dilatris, Kniphofia, Pillansia* and *Watsonia*, that have year round structure. Most of these species have a common morphology, basal grassy foliage and tall (relative to the foliage) naked stems with flowers at the top of. Plants with erect form, or with leafless flowering stems are usually less competitive with lower growing plants in mixtures. The leafless stem allows permeability visually, while floating flowers in space above. The spatial arrangement allows for many species to be accommodated per m^2 , and for very dramatic flower effects to be created. Tall leafy geophytes such as *Bulbinella latifolia*, are going to be much better at competing for light than small species such as Romuleas. The wide diversity of SA geophytes available will allow flowering to commence in autumn and continue through to mid-summer. All these emergents have to be post-fire re-sprouters.

2.4.3.3 The emergent coppice shrub layer

The shrub layer in the Mediterranean ecosystems are normally tall and eventually shade out the underlying species, leading to their death, therefore this layer is the ultimate dominant. In nature most Mediterranean plant communities are ultimately dominated by shrub layers, the flowery layers are short lived except when coppicing or fire is used at regular intervals. In the designed planting community, this layer has to be the most fractured and discontinuous, to ensure that the species in the lower two layers not been eliminated by the shade of the shrubs. Ideal species for this layer are those that respond to fire in their habitat by re-sprouting from the base to form coppice shrubs. This allows the entire system to be cut off every year if required in late August or early September, flash burnt if required, and then to re-sprout in-situ. Management is greatly simplified and sustainability is enhanced when all species in a planting community can be subjected to the same management approach applied uniformly in space and time. Species for this layer that are investigated in this research include; *Anisodontea*, *Brunia, Dimorphotheca, Hermas, Hirpicium, Mimetes, Lessertia, Protea, Scabiosa* and *Syncarpha.*

Fig.2.10 (left) *Lessertia frutescens* at Gannaka Pass, the edge of the Roggeveld 1400m (right) *Hirpicium alienatum* in wild habitat. (both photo took by Ye Hang)

2.5 Establishing high density multi-layered communities of South African Mediterranean planting communities

2.5.1 Options

To date the work that has been done on establishing multi-layered plant communities has mostly occurred in practice, in Australia, California and South Africa and has relied mainly on planting. There has also been some research via restoration ecology approaches to Fynbos/ Renosterveld (Van Wilgen et al., 1992; Cowling and Richardson, 1995). In general, very little research has been undertaken to date on creating these communities through sowing or planting.

2.5.1.1 Increased density

One of the prominent disadvantages of establishing planting community through planting is the difficulty to achieve the plant densities that are apparent in semi-natural plant communities. Traditionally, planting more than 9 plants/m^2 is just too expensive. These densities are commonly too low to prevent the asymmetrical competition (Hitchmough and Fieldhouse, 2004) that results in rapid weed invasion. Establishing vegetation through seeding in-situ (Hitchmough and Dunnett, 2004) costs less but makes it relatively easy to get very high densities (Gemmell, 1977; Ash et al., 1994; Dunnett and Stokes, 1998; Turnbull et al., 2004; Hitchmough et al., 2008; Baasch et al., 2012; Kirmer et al., 2012; Fischer et al., 2013), and easier to build in multiple layers as well as reduce resource inputs for both establishment and management compared to traditional ways (Oudolf and Kingsbury, 2005). Due to the high densities of plants per m^2 arranged in multi-layered arrangement, key resources (water, nutrients and light) that drive weed invasion can be restricted (Kristensen et al., 2008). The extra sand mulch layer as top of the sowing substrate also can increase longer-term resistance to weed invasion (Hitchmough et al., 2003; Hitchmough and De la Fleur, 2006; Sayuti and Hitchmough, 2013) and create different visual effects (Hitchmough and Dunnett, 2004; Oudolf and Kingsbury, 2013). Therefore, it is a useful method of creating species-rich naturalistic planting communities with diverse structures in urban landscapes based on semi-natural stereotypes (Luscombe and Scott, 2004; Hitchmough, 2011). Standard seedling target per square metre is usually 50-150 plants (Hitchmough, 2004). Sowing *in-situ* requires appropriate conditions, such as timing in relation to temperature and soil moisture and post-sow operations, such as raking seed into the sowing mulch, irrigation and in some case jute mat to stabilize the surface and retain some soil moisture (Hitchmough, 2014).

The sowing approach has been applied in research studies to establish the summer-rainfall communities of South African species since 2009 (Sayuti and Hitchmough, 2013). Mediterranean plant communities, Fynbos and Renosterveld in particular, are interesting models for new ecologically based naturalistic planting designs, as most of the geophytes, forbs and other species are, in common with most Mediterranean species, intolerant of shading (Manning, 2007). This poses interesting design challenges when creating new vegetation types involving multiple canopy layers of species. In Renosterveld, geophyte density per m^2 may over 10,000 individuals (Dallman, 1998). Many individual geophytes from this region, however, are too small to be established individually at the densities required as traditional plantings. In traditional plantings, to get a long season of flowering at least 18 geophyte species would need to be planted per square metre. Assuming that at least 3-5 plants of each species were required to provide sufficient impact, then this would require 60-100 plants/m^2. This suggests that the most economically realistic mean of creating designed versions of these plant communities is by sowing.

2.5.1.2 Weed control

In an urban environment in particular, competition with weeds from the soil seed bank (Hitchmough, 2004) is one of the major barriers to create naturalistic vegetation types successfully (Hitchmough and De la Fleur, 2006). In Western Europe ruderal weed species often commencing growing very early in spring and outcompete many slower growing wild plant species, especially on productive soils. Hence effective weed control is essential to reduce competition in the early stages of naturalistic plant communities. Sowings normally fail if the site was not initially weed free, for the seedlings would be outcompeted by weeds (Hitchmough and Hang, 2013). Therefore, development of sowing substrate (Wells et al., 1989) is as important as vegetation density control. Weed seed free materials applied to form a layer on the surface is an effective approach in practice (Graham, 2008). Hitchmough and De la Fleur (2006) found a sand layer 75-100mm deep was extremely effective as a sowing mulch.

Species from Fynbos and Renosterveld grow in winter, which may increase their capacity to resist invasion by having a relatively closed canopy during the winter months when invasion often occurs in Britain.

2.5.2 Challenges

The introduction and application of Cape Flora species in UK presented an exciting challenge on the aspect of winter cold tolerance, summer wet tolerance outdoors without protection, as well as the suitable substrate.

2.5.2.1 Plant selection

A constantly changing and dynamic landscape is potentially attractive to the public. In designed flower-rich planting communities, one of the main challenges is to select as many suitable and attractive species as possible to extend flowering period into late summer. In winter growing Mediterranean communities, most species flower in spring to early summer so it is important to try to have some species that will flower later in the summer, prior to cutting in August-September. At the same time, selection of species with similar maintenance treatment is essential to achieve management without intensive maintenance interventions. Therefore, the plant selection focus should be placed on the characteristics of plants in each layer. The principles were summarised by Hitchmough (2013) as follows: most species should have similar potential productivity; slow growing species must ideally be those with shade tolerance and low palatability to slugs and snails; fast growing species must be less in quantity and occur discontinuously to avoid shading neighbors leading to their decline.

2.5.2.2 Substrate

Appropriate sowing substrate is important in establishing naturalistic planting communities. Fynbos is nearly always found on free draining sandy soils, while Renosterveld is on less free draining shale or clay soils. Generally, the closer the planting substrate is to the wild substrate, in terms of key properties such as drainage and oxygenation the better species are likely to fit the planting site. In terms of geophytes, although individual species are found in all habitats and on all types of soil, many favor more fertile soils derived from granite, shale, or dolerite in nature (Manning et al., 2002). Manning et al. (2002) also found that in cultivation these species did well in a substrate consisting of coarse-grained sand, loam and compost, or a substrate mixing coarse river sand with fine potting medium. Some geophytes are lithophytes, in their habitat, evergreen *Aristea inaequalis* mainly grows in rock crevices in sandstone outcrops, while *Ixia curvata* and *Watsonia borbonica* usually occur on rocky slopes in sand. Species such as these and *Wachendorfia* and *Tritoniopsis* (Manning et al., 2002), may be suited to cultivation on brick rubble soils. *Aristea inaequalis* germinated and established best in a 150mm depth of sand in Hang's (2010) spring-sowing test, which is presumed to be because there was more oxygen available to sown seeds. Research at the Royal Botanical Gardens, Kew, found that South African geophyes grew well even in pure sand. Many plant species of unproductive habitats grow extremely successfully in pure sand (weed seed bank free material), overlaid as a 100-200mm layer over underlying soil, and this is probably a useful general substrate for many South African species. In many cases these needs could be met simply by using a deeper layer of sand as a sowing mulch.

In Sheffield, species such as *Babiana villosa, Gladiolus tristis, Lachenalia orchioides var. glaucina* and *Sparaxis elegans* that naturally occur on clay flats and other heavy soils were observed to perform best in 75mm of John Innes potting compost overlaying a clay based soil rather than 75mm sand and 150mm sand overlaying the same clay based soil (Hang, 2010). The John Innes soil based compost used in this experiment had a much higher water holding capacity than the sand. *Aristea inaequalis* and *Wachendorfia paniculata* two species that occur almost exclusively in nutrient-poor, well-drained, rocky sandstone-derived soils grew well in highly fertile (Hang, 2010) JI based soil. High soil fertility however often promotes the growth of vigorous weedy species in ecological designed communities (Hitchmough, 2004). Therefore, balancing the capacity of plant seedlings to grow and weeds to establish is highly related to substrate, which has to be carefully considered especially in the establishment of plant communities.

Seed sowing used to establish plant communities often allows “waste” soils, namely unproductive substrates (Graham, 2008), including sub-soils, mineral aggregates, brick rubble and crushed concrete (Bradshaw and Chadwick, 1980), which helps to further reduce (on some sites) establishment costs and provide almost weed free conditions initially (Hitchmough et al., 2001). Stress tolerating species were observed to successfully establish even on highly alkaline blast furnace slag in North-west England (Gemmell, 1977; Ash et al., 1994), and postmining sites in Germany (Baasch et al., 2012; Kirmer et al., 2012) through natural colonization. Hitchmough et al. (2001) previously tested seedling emergence, survival and initial growth of some native UK and European forb and grass species from dry, unproductive habitat in low productivity urban “waste” substrates. Fischer et al. (2013) recently reintroduced native meadow-like grassland as a model onto urban wasteland for developing low-maintained planting community, and showed that urban wasteland was a very suitable habitat for species rich grassland vegetation. More and more researches and practices are carrying on to deliver the idea into urban hostile sites under the changing economic climates to restore or recreate novel vegetation with low input. As different substrates have various capacities of holding moisture and air, which are important factors for seedling emergence and establishment (Bullock, 1991; Handreck and Black, 2010), species from Fynbos are potentially suitable in waste soils, where they are not sensitive to the frequently high pH. Nutrient limitation always restricts vegetation development and a planting community structure (Grime, 2001), as previously discussed in section 2.3 in this Chapter, However, it might support more species co-existance within the community. Species richness in communities tends to decline with the increasing of nutrient in soil, due to competitive species capturing resources and rapidly accumulating biomass (Al-Mufti et al., 1997). Phosphorus (P) and Potassium (K) were found to be essential key nutrients in determining community composition (Critchley et al., 2002), with high P levels associated with low diversity (i.e. distribution of species in relation to dominance), and high K associated with high diversity conversely (McCrea et al., 2001). Therefore, the target number of species and proportion of dominant species in a community is necessary to co-consider in relation to soil components and fertility. Most current research is largely based on grassland vegetation (McCrea et al., 2001; Hitchmough et al., 2001; Walker et al., 2004; Hitchmough and De La Fleur, 2006; Graham, 2008; Baasch et al., 2012; Fischer et al., 2013), while little research has been undertaken to date on the establishment of geophyte species of visual interest on waste soils. It seems likely that Fynbos geophytes will have low nutrient requirements than Renosterveld geophytes.

2.6 The application of sustainable establishment and management techniques

Sowing seeds in-situ to avoid the cost of plants (seed< £2.00/㎡ as opposed to >25.00 ㎡ for plant materials) (Török et al., 2012; Hitchmough and Hang, 2013) and also transport. Once the communities have been established, effective but simple maintenance is critical to ensure the appropriate development of the communities (Hitchmough, 2004). Ecologically based planting communities often have higher plant density and species diversity and to retain this practices that increase competitive elimination through fertilising or watering must be avoided. Some maintenance approaches can be borrowed from nature conservation practice (Luken, 1990), in which the same practice is applied to the whole of the vegetation (Hitchmough, 2013) on the same day. No fertilising or watering, typically reduces the rate of weed invasion (Harkess et al., 1997; Blumenthal et al., 2005).

2.6.1 Annual Defoliation cycles for maintaining nature-like herbaceous vegetation

2.6.1.1 Cutting

The most simple and sometimes effective way of managing meadow-like planting communities is annual cutting and removal of the canopy at certain time of the year (Kirkham et al., 1996; Coulson et al., 2001; Marriott et al., 2003). When this activity is normally undertaken depends on the growing season cycle of the vegetation. In practice (Hitchmough, 2013), a European native wildflower meadow is usually being cut off and the biomass being removed away in July or August; while summer growing North American prairie-like grassland communities and high altitude eastern South African mountain grassland communities are cut in late February or March prior to growth. In terms of winter-growing plant species, the planting communities would finish display in mid to late summer by which time many of the deciduous geophyte species would be dormant. This suggests that annual cutting could be applied to South African species in late summer or early autumn.

2.6.1.2 Burning

Fynbos and Renosterveld are both flammable plant communities, which are adapted to cycles of fire. Although fire is a temporally and spatially variable factor in all Mediterranean ecosystems, it is essential to the very existence of Fynbos and Renosterveld (Hoffman et al., 1987; Le Maitre and Brown, 1992). The fires are key determinants of species composition, vegetation structure and successional patterns (Bond and Keeley, 2005; Kraaij, 2010), as well as important factors of temporary reduction of competition (Hoffman, 1987). The space that has been created by fire allows sunlight to reach the soil surface, which provides opportunities to promote the development of geophytes and forbs (Manning, 2007). In the wild, a significant number of species only flower or germinate after burning (Le Maitre and Brown, 1992; Brown, 1993). Even in species that do not require fire to flower, flowering, particularly in geophytes is often more abundant post fire. In contemporary South Africa the important role of fire in these ecosystems has been gradually understood and prescribed burning has been often used for management and conservation of these ecosystems (Stock and Lewis, 1986; Manning and Goldblatt, 1997; Van Wilgen et al., 2010). (See Fig.2.11-2.12 images from online resource) In urban Cape Town, Kirstenbosh Botanic Gardens manages its Fynbos plantings through burning (Huntley, 2012).

(images removed for copyright reason)

Fig. 2.11 (left) Controlled fire in a Fynbos community. Fig. 2.12 (right) Mountain fynbos post fire showing mass flowering of *Watsonia borbonica* (photo taken by James Hitchmough).

Some geophyte species are so adapted to fire that are never seen in flower except after a fire, such as *Gladiolus phoenix* in the Bain's Kloof Mountains (Goldblatt and Manning, 1998). Once burned, the plants flower extremely well the season after fire and set a large amount of seeds. (Goldblatt and Manning, 1998) The use of low intensity flash burning (Hitchmough, 2004) could therefore be used in late summer or early September (after the vegetation has been strimmed off) in public sites for these types Mediterranean planting communities as a low input means of maintaining viable communities after annual removal of biomass by cutting to promote the rate of seed germination or plant re-shooting. Flash burning has been successfully applied in practice of North American prairie-like grassland communities and high altitude eastern South African mountain grassland communities with summer growing grasses, geophytes and forbs (Hitchmough, 2013). Regular cutting with flash burning can effectively limit the weedy species from the outside and ensure a good appearance of the planting community in the coming year.

2.7 Key Genera of interest to the research and ultimately practice

Full understanding of the ecological and horticultural characteristics of key genera associated with SA Mediterranean plant communities is a precondition of selecting the right plants for designed communities. In the wild, shrubs, forbs and geophytes naturally form various community structures depending on water, light, soil conditions and altitude. Currently, most of the literature is based on a horticultural perspective, which can be drawn from as reference but by itself is insufficient for plant community design.

SA Mediterranean species can be split down into sub-groups on the basis of life form, including summer deciduous geophytes, evergreen geophytes, forbs and shrubs. Each sub-group contains species with different heights, canopy structures and ecological traits and growing cycles.

2.7.1 Summer deciduous geophytes

The Cape Flora Region has more than 2200 geophyte species (Huntley, 2012), most of which are summer deciduous. For the past few decades, Kirstenbosch geophyte expert Graham Duncan has tested over 900 geophyte species from wild collections, and found that many could survive in gardens in Southern Africa except the very coldest areas (such as the central Great Karoo), or areas with extremely wet winters (such as the southern suburbs of Cape Town), or areas with very wet, humid summers (Kwa-Zulu Natal). In Duncan's rather cautious horticultural approach, most of the remaining species are protected in glasshouse nearly all the year around except some potted bulbs put outside during their flowering period. (Duncan, 2010) The following paragraph highlight geophyte genera that appear to have great potential of application in the UK landscaping under climate change, being long-lived, having excellent tolerance toward winter cold and summer wetness, and largely unpalatable to slugs and snails. Information provided, except the mentioned books or journals, based on a number of sources: the Pacific Bulb Society official website (http://www.pacificbulbsociety.org), South African photographer Colin-Paterson Jones' official website (http://www.colinpatersonjones.co.za), Flickr website (https://www.flickr.com).

(1) **Babiana** (Irisdaceae)

Babiana are long-lived species with very attractive flowers and forming multiple clumps. All these characters are important for designed communities. Many species are naturally found in seasonal wet locations so they can potentially tolerate summer moist soils in the UK. They are relatively small (typically<300mm tall) deciduous geophytes, which can be used as emergent amongst evergreen forbs. *Babiana* is a member of the Irisdaceae, with 88 recognised species of southern and central Africa, in which 86 species flower in winter or early spring (Goldblatt and Manning, 2007). Geographically, *Babiana* naturally occurs in the extreme southwest with highest winter rainfall and in Namaqualand and southwestern Namibia where the climate is a semi-arid to arid (Goldblatt and Manning, 2007). The majority of *Babianas* have bright blue to violet flowers, sometimes heavily scented. Red-flowered species *Babiana ringens* and *B. thunbergii* are pollinated by sunbirds (Goldblatt et al., 1999). Because of their long-lasting and brightly coloured flowers, some species have been popularly cultivated in particular the species have large flowers, such as *Babiana villosa* (Manning et al., 2002). *Babiana cuneata, B. vanzyliae, B. sambucina* and *Babiana dregei,* are found at up to 1400-1600m. *Babiana thunbergii*, a coastal sand dune species is the largest *Babiana* with erect stem and bright red flowers grows up to 1000mm in height and can flower over 3 months, but seems unlikely to be cold tolerant given its coastal distribution.

(2) **Bulbinella** (Asphodeliaceae)

Bulbinella are very attractive and elegant plants, with a rosette of basal leave and a single flowering stem. They are desirable emergent plants in layered planting community, which grow from 600mm up to 1000mm when flowering. Although they have long-lasting columnar racemes with hundreds of yellow orange or white flowers, they are not yet well known in cultivation. In the wild, thousands of *Bulbinellas latifolia* and *B. nutans* favor seasonally wet sites, often on heavy clays soils on mountain plateaux (Manning et al., 2002). Many species occur in the region of Nieuwoudtville, on the Roggeveld Plateau at 800-1500m. Most species flower in late winter to spring, with *B. caudafelis* (up to 80cm) produces white flowers with pink keels in late spring-early summer. *Bulbinella divaginata* flowers in autumn.

Fig.2.13 (top left) *Bulbinella nutans* in Renosterveld on the Roggeveld Escarpment, in an area with extremely low winter temperatures (Sutherland) (photo by Ye Hang); (top right) *Bulbinella latifolia* var. *doleritica* near Nieuwoudtville (photo by James Hitchmough); (bottom left) *Bulbine alooides* in fynbos on the Bokkeveld Escarpment; (bottom middle) *Bulbinella nutans ssp. nutans*; (bottom right) *Bulbinella cauda-felis* in fynbos (all bottom three photos were taken by Colin-Paterson Jones).

(3) **Gladiolus** (Irisdaceae)

Gladiolus is a large genus and many species have large, brightly coloured flowers, and in design terms are an ideal element in layered naturalistic planting. There are 165 species in SA, 110 in the Cape (Manning et al., 2002). *Gladiolus tristis* and *G. liliaceus* both with tall stems and large flowers are well known in cultivation. Most of *Gladiolus* species are extraordinarily attractive in appearance (see Fig. 2.14) The markings on the tepals in many *Gladiolus* are recognised as "nectar-guides" to draw a pollinator's attention to the nectar hidden within the flower, mainly long-tongued bees in the habitat (Manning et al., 2002) but much wider than this in cultivation. *Gladiolus* species have a wide altitudinal range and occupy many different types of habitat. *Gladiolus splendens, G. marlothii, G. pritzlii* and *G. saccatus* are found on the high escarpment (1800m) near Sutherland and Middelpos, with average annual rainfall 250-300mm and entirely winter rainfall. Another high altitude species is *G. equitans* in the Kamiesberg mountains (1000-1500m), and *G. cardinalis* from wet shaded faces up to 2000m on the Matroosberg Mountain (2300m).

Gladiolus distinguish itself from some other genus in terms of flowering time, extending almost throughout the year from autumn (for example *G. hirsutus*) through to mid summer (*G. cardinalis*) (Goldblatt and Manning, 1998). The summer flowering species are useful for their late display period as a winter-growing geophyte in a mixed planting community. Species are adapted to grow on various substrates in the wild, from acidic sandstone to nutrient-rich clay soil. Many *Gladiolus* species are fragrant, especially those pollinated by moths. Flowers of most *Gladiolus* close partially in the late afternoon except species with pale-coloured flowers, often with brownish markings and pollinated by moths (Goldblatt and Manning, 1998).

Fig.2.14 (top left) *Gladiolus cardinalis* forms a substantial biomass three years after planting (photo taken by James Hitchmough); (top right) *Gladiolus angustus* in Cape Peninsula; (bottom left) *Gladiolus maculatus* on the Cape Peninsula mountains (bottom right) *Gladiolus carneus* in the Table Mountain National Park (last three photos were taken by Colin-Paterson Jones).

(4) **Hesperantha** (Iridaceae)

Hesperantha species are mainly small elegant geophytes that have narrow mainly linear leaves. They are described as easy to grow species in South Africa (Manning et al., 2002). The eastern species *Hesperantha coccinea* is widely cultivated and successfully grown outdoors in herbaceous borders in the USA and UK (Manning et al., 2002). Nevertheless, *Hesperantha* from the Cape Floral Region are much less well known. The species with colourful flowers open during the day, and species with white flowers are usually moth pollinated and flower late in the day as in *Hesperantha cucullata*, with white flowers with red to brown on the outsides, and highly fragrant when open (Manning et al., 2002). In the author's field trip in South Africa in early September (spring in south-hemisphere), *Hesperantha cucullata* (15-30cm) was seen flowering together with white *Bulbinella cauda-felis* on mountains near Middelpos (1000m). This species is from one of the coldest areas in western cape where experiences over 50 days frost days (Mucina and Rutherford, 2006) is an ideal low-growing geophyte species which can be used in the emergent geophyte layer in designed planting community. Relatively large pink-purple flowered *Hesperantha pauciflora* (8-24cm) is also from cold areas, such as Bokkeveld Plateau (1200-1600m) (Manning et al., 2002). The day-blooming species *Hesperantha vaginata* (120-180mm has tulip-like flowers, deep yellow in colour with chocolate markings. It was found in Bokkeveld escarpment as well on heavy clay soil. Generally, *Hesperantha* species are pollinated by bees, moths and flies.

Fig.2.15 (left) *Hesperantha coccinea* in the Malolotja Nature Reserve; (middle) *Hesperantha cucullata* in renosterveld on the farm Biekoes on the Bokkeveld; (right) *Hesperantha pauciflora* in renosterveld on the Bokkeveld Escarpment (all three photos were taken by Colin-Paterson Jones).

(5) Ixia (Iridaceae)

Ixia species are relatively small flowered but are very graceful in appearance and sometimes striking. Flowers are commonly crowded at the tops of their slender stems and fully displayed on sunny days. They mostly have small corms that have a relatively shorted time to reach flowering size (potentially in the second year after seed germination) (Manning et al., 2002). This fast developing traits is useful in designed geophyte planting community where most geophytes only flower in the third year at the earliest. The orange flowered *Ixia maculata* has been cultivated since the 18th century in Europe (Manning et al., 2002). *Ixia rapunculoides* (15-70cm) with large, half-nodding to drooping, mauve or blue flowers was mentioned by Manning *et al.* (2002) as having a greater degree of cold tolerant than most species of the genus due to its 800-1000m altitudinal distributions. Another tall spring flowering species *Ixia thomasiae* (50-80cm) with pink flowers occur on stony clay areas in Roggeveld (900-1300m). Another winter to spring flowering species is *Ixia curvata* (25-50cm) with deep pink flowers from rocky slopes in the Calvinia district (900m), an extremely cold tolerant species. Generally, in *Ixia* species, the short-tubed flowers are pollinated by bees and the long-tubed flowers are pollinated by flies. Some species with dark markings in the center are pollinated by monkey beetles, such as *Ixia dubia.* (Manning et al., 2002).

(6) **Moraea** (Iridaceae)

Moraea is another large genus, with channeled bifacial leaves and *Iris*-like flowers. There are 65 of 119 recognised *Moraea* species are restricted to the winter rainfall area in South Africa (Goldblatt and Anderson, 1986). *Moraea* produce single corms which are mainly small. However, species usually have very short flowering sessions. Many species are distributed at high altitude and seem relatively cold tolerant. Many of the glamorous lowland Renosterveld species, like *Moraea aristata* and *Moraea loubseri* are critically endangered (Goldblatt and Anderson, 1986), *Moraea tulbaghensis*, *Moraea gigandra* and *Moraea calcicola* are marked as endangered. Owing to the spread of agriculture on clay lowlands east and north of Cape Town (Swartland district), the species mentioned above which are endemic to this area have been much reduced in the past decades. Though the individual flowers of a plant open only for a single day, the plant produces many flowers to extend flowering period to weeks. The tallest *Moraea* in the western cape is the pyrophyte *M. ramosissima* and *M. pendula*. *Moraea pendula*, is endemic to the Kamiesberg mountains (1000-1200m) where it experiences very cold winters. Spring flowering species *Moraea villosa ssp. villosa* found on Versveld Pass on Piketberg is from altitude of 800-1000m. Widespread species *M. ramosissima,* occurs primarily in mountain areas, and always in wet conditions, is likely suitable for wet summers. Some species, *M. angusta* and *M. anomala* for example, only flower well after a fire when the surrounding fynbos vegetation cover has been destroyed. These species normally grow on exposed habitat, which are likely less shade tolerant in a designed community.

Fig. 2.16 (left) Post-fire summer flowering *Moraea ramosissima*, Kleinmound, Western Cape; (right) *Moraea bifida* near Nieuwoudtville (photo took by Colin-Paterson Jones)

(7) **Romulea** (Iridaceae)

The short stemmed, but extremely attractive, very large flowered (in relation to their size) *Romulea* have small corms. In South Africa seedlngs should reach flowering size in the second year, but this does not occur in the UK. They are represented best in the drier climates but their habitats are often wet in spring where they form extensive carpets (Manning et al., 2002). The large, scarlet flowered species from Bokkeveld (with average elevations of 1600m) and Roggeveld (900-1300m) Escarpments, especially *R. amoena*, *R. monadelpha, R. sabulosa* and *R. unifolia,* are among the most spectacular and are potentially hardy in the UK. On high plateau on the Roggeveld, *Romulea komsbergensis* near Middelpos (1000m) tolerate cold winters and soils that remain wet into at least early summers. (see Fig. 2.17 below). Most species are all spring flowering, but the blooming time is relatively short at less than three weeks. *Romulea atrandra* can flower up to 3 months from early spring to early summer. (Manning et al., 2002). A large majority of *Romulea* species are pollinated by honeybees, and species with large red flowers are pollinated by monkey beetles (Manning et al., 2002).

Fig.2.17 (left) *Romulea atrandra* flowering in spring on the Roggeveld Escarpment; (photo took by Colin-Paterson Jones) (right) A large area of *Romulea komsbergensis* in very wet conditions in company with *Gazania rigida* on the Roggeveld Escarpment near Middelpos, (photo took by Ye Hang)

(8) **Sparaxis** (Iridaceae)

Sparaxis are medium sized species that have bright flower colours from orange, scarlet to pink and strongly marked with contrasting yellow and dark purple to black centers (Manning et al., 2002). *Sparaxis tricolor* was first introduced to Holland in 1792, and various hybrids have been propagated from *S. tricolor and S. elegans,* which are endemic to the 800-1000m escarpment around Nieuwoudtville. *Sparaxis pillansii* is much less known but is a tall species found along drainage lines in the same region. Most of the other species, for example *S. grandiflora* are distributed at lower altitudes and are likely to be much less cold tolerant. Manning et al. (2002) suggested that many species of the genus would grow in outdoor condition in mild winters and even in summer rainfall areas. The orange and pink flowered species with short tubes are pollinated by monkey beetles and flies (Manning et al. 2002).

(9) ***Watsonia*** (Iridaceae)

Watsonia is naturally restricted to the winter-rainfall region and the summer-rainfall region of South Africa (Goldblatt, 1989). This is potentially one of the most useful geophyte genera, the plants range from small to large but most have large very attractive flowers, and species can be found that flower from early spring to mid summer. Two of the most attractive small species are

Watsonias humilis and *W. spectabilis. Watsonia* usually flower best (in some cases only) in the next year after fire in the Western Cape. Pink *Watsonia borbonica* flower in spring after a summer burn with orange *Pillansia templemannii* in the Kogelberg Biosphere Reserve, and with the orange form of *Watsonia tabularis* in early summer on Steenberg in the Table Mountain National Park. Many *Watsonia* are plants of seasonally moist or wet areas that dry out in later summer in the Western Cape. Many of the Western Cape species are summer deciduous. In the Wesern Cape the species found at the highest altitudes are *W. schlecteri* (evergreen), *W. stokoei*, and *W. marlothii* which occurs up to 1800m in the Swartberg range.

Some large species of *Watsonia* have been used as a component of roadside plantings in and around Cape Town (Manning et al., 2002), however, many more cold-tolerant *Watsonia* can be explored to be used in landscapes even in other continental area under suitable climate conditions. *Watsonia* are pollinated by a diversity of animal species.

Fig.2.18 (left) *Watsonia tabularis* flowering in summer with *Micranthus junceus* below after a fire in the Table Mountain National Park; (middle) Pink *Watsonia rogersii* flowers with orange *Pillansia templemanii* and white *Lanaria lanata* amongst the burnt skeletons of *Leucadendron xanthoconus* and other reseeding shrubs after the previous summer's fire in the Palmiet River valley in the Kogelberg Biosphere Reserve; (right) *Watsonia tabularis* flowering with *Aristea bakeri (=A.confusa, A. macrocarpa)* in spring after a summer fire on the Cape Peninsula, SA. (all three above photos by Colin-Paterson Jones)

2.7.2 Evergreen geophytes

(1) Aristea (Iridaceae)

*Aristea*s are very elegant large evergreen geophytes, with fan-like basal leaves and dense clusters of often large deep blue flowers, which grow up to 1.8m high when flowering. The genus is an ideal emergent geophyte in designed plant communities. Their flowers are short-lived as in *Moraea*, but flowering continues for 4-6 weeks. Seedlings usually need at least 3 years to reach flowering size. On the Western Cape mountains, *Aristea* mostly grow in rocky sandstone habitats, and often flower in mass after a summer fire (Manning et al., 2002). *Aristea bakeri (=A. confusa, A. macrocarpa)* in fynbos can quickly produce flowers in next summer after burning. *Aristea inaequalis* is perhaps the most attractive species, and is becoming widely cultivated in California. *Aristeas* have not been a widely researched and used in practice as might be expected. *Aristea capitata* has already been cultivated by local nurseries and planted out for display in gardens and street plantings in Western Cape cities and towns. In the UK this species has survived temperatures as low as -6ºC, the foliage is often killed but regrowth occurs from below soil level in spring. *Aristea* are sensitive to transplanting as seedlings, but readily established by sowing *in situ*. Most *Aristea* species are pollinated by bees, while few of them from southwestern Cape are pollinated by monkey beetles (Manning et al., 2002).

Fig.2.19 (left) Post-fire spring flowering of blue *Aristea bakeri (=A.confusa, A. macrocarpa)*, orange *Watsonia tabularis* with the burnt skeletons of *Palmiet, Prionium serratum*, in the Cape Peninsula mountains. (right) *Aristea bakeri* flowering with *Ixia odorata var. hesperanthoides* in recently burnt veld in the vlei south-east of the Franschhoek Pass in the Boland mountains, Western Cape, SA. (both photos took by Colin-Paterson Jones)

(2) **Dilatris** (Haemodoraceae)

Dilatris is a highly distinctive genus of 4 very attractive evergreen perennials, with interesting colours of stem, basal sword-like leaves and shapes of flowers. They forms large clumps over time, and have a long flowering season, sometimes up to 5 months. Like the related genus *Wachendorfia, Dilatris* is also endemic to the winter rainfall region with most species naturally occur from near Tulbagh and Kogelberg north to the Cedarberg and east to the Swartberg, commonly in sand on rocky sandstone slopes. They flower best after a fire (Manning et al., 2002). Most species have mauve flowers except *D. viscosa* which has yellow flowers and reddish stems. They are pollinated by bees and monkey beetles. *Dilatris ixioides* is found up to 1500m in the inland Cedarberg Ranges, suggesting that it is potentially a cold tolerant species.

Fig.2.20 (left and right) *Dilatris ixioides* flowering in summer near the top of Galgeberg in the Riviersonderend mountains two years after burning, Western Cape. (photos took by Colin-Paterson Jones)

(3) **Kniphofia** (Asphodelaceae)

In the Western Cape, *Kniphofia* species are represented by 4 tall species, approximately 1-1.2m tall in flower (*W. praecox, W. sarmentosa, W. tabularis, W. uvaria*), all with orange-red flowers and and long basal leaves that are V shaped in cross section. They all occur at moderate to higher elevations in moist to wet soils along drainage lines (Manning et al., 2002), which act as frost hollows. They typically tolerate more winter cold and summer wet than many other Western Cape geophytes. *Kniphofia sarmentosa* can flower for up to 5 months, from mid-winter to July, and is a very useful species. This species is also moderately rhizomatous forming open colonies in wet sites, in general *Kniphofia* are very permanent plants. Flowering is generally greatly stimulated in the wild by burning in the preceding season (Manning et al., 2002). Most *Kniphofia* species are adapted for sunbird pollination, while some are pollinated by bees (Manning et al., 2002).

Fig.2.21 *Kniphofia sarmentosa* flowering on Roggeveld Escarpment near Middelpos. (photo took by Ye Hang)

(4) **Lanaria** (Lanariaceae)

Lanaria lanata is the only species and is most conspicuous in the year following a fire. The basal foliage is strap like, and quite attractive, the inflorescences are covered in think white wool. It is a medium sized robust species that would be widely used, but the seeds are extremely hard seeded and very difficult to get to germinate. Widely distributed, mainly in the mountains in the Western Cape.

Fig.2.22 (left) *Lanaria lanata* flowering after a fire in the Bains Kloof mountains, Western Cape; (right) *Lanaria lanata* flowering at the Kogelberg Biosphere Nature Reserve. (photos took by Colin-Paterson Jones)

(5) **Watsonia** (Iridaceae)

Watsonias naturally distributed along the southwest coastal areas, some appeared in Cedarberg and few extended into Namaqualand and Roggeveld region. Some of higher altitude species of *Watsonia* found in the Western Cape are summer evergreen for example, *W. fourcadei, W. marlothii, W. schlechteri*, and *W. tabularis*. Among which, *W. marlothii* and *W. schlechteri* exist in inland Groot Swartberg mountains in Roggeveld region. These are all highly attractive and potentially useful species.

Fig.2.23 (left) Post-fire spring flowering of *Watsonia tabularis* in the Cape Peninsula mountains;(right) *Watsonia schlechteri* flowering in early summer in the Kogelberg Biosphere Reserve, Western Cape. (photos took by Colin-Paterson Jones)

2.7.3 Evergreen forbs and dwarf shrubs

(1) **Arctotis** (Asteraceae)

This is a relatively large genus, some species are annuals or short lived perennials (for example *A. fastuosum*), others are long lived perennials as in the case of near alpine *A. adpressa*. Most species are very attractive spring flowering species, that are intolerant of shade.

Fig.2.24 (left) *Arctotis adpressa;* (right) *Arctotis gumbletonii* (photos took by Ye Hang)

(2) **Erica** (Ericaceae)

Erica is a large genus in the Fynbos biome, with more than 682 species. However, many *Erica* species only occur on a single mountain or coastal plain, with a relatively small natural distribution. These patches are threatened and limited by increasing agriculture, urbanization or the invasion of alien vegetation, with over 100 species in this genus endangered. Kirstenbosch has a collection of 252 species of this rather difficult garden genus on well drained acid quartzitic soils on the (Huntley, 2012). In natural, *Erica* always occur accompanied by some shrubs in Fynbos or in combination with *Ericas* species with the same flowering period but in different colours. *Erica sitiens* flowers with *Leucadedron laureolum* amongst restios in fynbos in the Kogelberg Biosphere Reserve, Western Cape. White *Erica denticulata* with pink *Erica bergiana* and red *Erica inflata* bloom at the same time in summer in the Groot Winterhoek Wilderness Area of western Cape. *Erica mammosa* flowers in summer on the rocks in the same area, which ranges from 1000 to 2077m. *Erica* are typically long lived, often with very attractive flowers and the species that re-sprout, post fire, allowing them to respond to mechanical coppicing would be valuable plants were it not for the seed being so fine as to make germination problematic in sown plant communities.

Fig.2.25 (left) *Erica pillansii* flowering in spring with *Brunia albiflora* in the Kogelberg mountains, Western Cape, (right) *Erica mammosa* flowering on the rocks beyond in the Groot Winterhoek Wilderness Area, Western Cape (photo by Colin-Paterson Jones).

(2) **Dimorphotheca** (Asteraceae)

In contrast to *Erica* species in these genera are relatively short lived, but are fast growing, highly attractive in flower, and bloom for a long time. Two of the key species are the shrubby *D. cuneata,* which is widely distributed both in Western and eastern South Africa. Most populations are white and associated with Rennosterveld, but in the Kamiesberg the species is orange. This species is a post fire re-seeder, but has some capacity to be coppiced through mechanical pruning. *Dimorphotheca nudicaulis* has white flowers and is a more herbaceous species, and capable for re-sprouting following severe pruning, and possibly also post fire.

Fig.2.26 (left) *Dimorphotheca cuneata* white form showing its round clump along road near Middelpos; (photo took by Ye Hang) (right) *Dimorphotheca cuneata* orange form on Kamiesberg (photo by James Hitchmough).

(3) Gazania

There are approximately twelve species, nine perennials and three annuals in the Western Cape. The most widespread species is *G. krebsiana*. All species are found in sunny habitats and are intolerant of shade. They are fast growing and relatively long lived in unproductive habitats, but quite short lived under productive conditions. *Gazania heterchaeta* is unusual in that it spreads by suckering, potentially making it the most useful species for designed vegetation. Almost all species are extremely attractive in flower.

Fig.2.27 (top left) *Gazania krebsiana* near Middlepos (photo by James Hitchmough) (top right) *Arctotis campanulata* flowering with *Babiana attenuate* and *Felicia merxmuelleri* on the Kamiesberg mountains, Namaqualand; (bottom left) *Gazania krebsiana*, *Mesembs, Ruschia spinosa* and the shrubby *Tripteris sinuata*, flowering with the Roggeveld Escarpment beyond, Tanqua Karoo; (bottom right) *Gazania krebsiana,* white-flowered *Cotula nudicaulis* and *Dimorphotheca cuneata*, blue *Felicia australis* and emergent yellow-flowered *Bulbinella latifolia var. latifolia* and Ixia rapunculoides in renosterveld of Roggeveld. (last three photos took by Colin-Paterson Jones)

CHAPTER 3: GERMINATION AND EMERGENCE RESPONSES OF WINTER-GROWING SOUTH AFRICAN GEOPHYTES, FORBS AND SHRUBS

3.1 Introduction

Comparitive studies of the germination and emergence of winter-growing South African species was undertaken prior to field emergence tests (discussed in Chapter 2, section 2.3.1), to provide data to guide subsequent sowings and to allow the researcher to become more familiar with the species, their seed and its germination and emergence. In contrast to the more scientific research reported later in this thesis, this stage of the research was relatively heuristic and opportunistic in nature. Seed was often available only in small amounts, for limited periods of time from a given source and hence investigations were undertaken to discover as much as possible about germination and emergence given these limitations to provide a basis for decision making on species selection later in the research.

Sowing of multi-species seed mixes has to be undertaken on the same day, therefore, making appropriate decisions on sowing time is often crucial in achieving successful establishment of most of the component species in the first phase. In the horticultural literature (Duncan, 2010) winter-growing geophyte species are reported to be best sown in autumn, whilst summer-growing geophyte species are reported to be best sown in spring. This experiment tested whether these statements hold true, and for what species. Actual published data on these responses is difficult to find and it seems that much of these pronouncements are anecdotal, although autumn germination is in general a common strategy in many Mediterranean species (Duncan, 2010; Manning et al., 2002). By germinating at this time of year, seedlings experience almost six months of cooler moister conditions for establishment.

Cummins (2010) undertook research on the emergence of over 30 South African Mediterranean species in field sowing autumn 2009 and her observations provided a platform for the author's preliminary research in March 2010. Most of the tested winter-growing geophytes and shrubby

Dimorphotheca germinated well, but many forbs in *Gazania* and *Arctotis* showed very low field emergence in her experiment. In the outdoor spring sowing in 2010 (Hang, 2010), different depths and types of substrates (75mm sand, 75mm soil and 150mm sand) were studied to compare the responses of a number of species. Germination took place at early April approximately one month after sowing with no significant differences in terms of mean emergence and rate of emergence of all species in response to substrate type and depth. In this study (Hang, 2010), approximately 71.4% of the tested species (17 species in total) showed field emergence >30%. Following these initial findings (as discussed in Chapter 2 section 2.4.2.2 substrate), a standard substrate of 40% grit, 40% sand and 20% peat compost was confirmed for the expansion of this very preliminary experiment. Because most of the first tested winter-growing geophyte species showed the capacity to emerge when sown in spring, seeds of a wide range of species were then tested to see which species could only germinate at a specific time of year. Following extensive review of all relevant literature (Brown et al., 1994; Manning et al., 1997; Manning et al., 2002; Duncan, 2006; Mucina and Rutherford, 2006; Grime, 2011; Baskin and Baskin, 2014) on the communities and individual species, followed by field trips in their habitats, more than 300 species were selected to test emergence within wild collected seeds, from Fynbos and Renosterveld biomes.

3.1.1 Objectives

The specific research questions associated with this study were:

I. To study the effect of sowing time on percentage emergence of a wide range of species.
II. To study the promotion of germination by pre-sowing treatments.

3. 2 Methodology

Most seeds tested were purchased from Silverhill Seeds in western South Africa. Seeds were mostly wild collected, however a few species were collected from cultivated plants grown from wild collected seeds. The origins of the purchased seeds were recorded in the database as an essential reference for estimating the cold experienced in the habitat. Seeds were selected manually for germination tests to ensure malformed, or unusually small seed etc., was not used. Seed weights of species were measured via a scientific balance to calculate number of seeds per gram for future application to sowing practice, as well as to compare the potential of different seed batches of that species. 10 samples of 100 seeds were weighed to calculate seed weights (see Table 3.3) Some species were chosen to undertake laboratory experiment in petri-dishes with controlled light and temperature, as a comparison to those sown outdoors in spring or autumn.

3.2.1 Germination in Laboratory Experiments

As discussed in section 2.3.1.2, plant-derived smoke has been investigated to increase germination of a wide range of species from South Africa, particularly forb/ shrub species from genera such as *Protea, Leucospermum, Leucadendron, Erica,* and families such as the Asteraceae, Bruniaceae, Crassulaceae, Geraniaceae, Restioaceae and Mesembryanthemaceae (Brown et al., 1994; Brown et al., 1993). *Albuca clanwilliamgloria, Anisdontea anomala, Arctotis acaulos, Arctotis adpressa, Arctotis diffusa, Arctotis gumbletonii, Dimorphotheca cuneata* (orange), *Dimorphotheca cuneata* (white), *Gazania heterochaeta, Gazania krebsiana, Gazania leipoldtii, Gazania othonites, Hermannia stricta, Lessertia frutescens, Lessertia rigida, Scabiosa africana,* were chosen to assess germination response to smoke treatment in petri-dishes in early September 2010 under temperatures equivalent to those experienced outdoors in Sheffield. Each species consisted was sown in three replicate Petri-dishes, containing 15 seeds each. Two discs of Waterman filter paper were placed in the 90mm diameter Petri-dishes, Seeds were treated with a smoke water solution as many of these species had previously shown poor germination without this Approximately 10ml of smoke solution was added to each dish. Petri-dishes were then closed and wraped with clear plastic film to retard evaporation, and placed in the growth cabinet.

Germination was tested under alternating temperature of 20 and 10 ^{o}C, for 14 and 10 hrs day/night, respectively. Time of radicle emergence and shoot emergency were recorded at approximately weekly intervals.

3.2.2 Emergence in the Outdoor Experiment

3.2.2.1 Autumn Sowing

The first autumn sowing was undertaken in November 2010 with species sown in late November to early December 2010 in a glasshouse. The second autumn sowing started on 24th August 2011. The third autumn sowing was in September 2012. Duncan (2010) found that most winter-growing species were able to germinate between 12-18°C following autumn sowing. However, the experiment was also interested in testing whether species could germinate when sown late in the year at lower temperatures. Glasshouse sowing observations (Hitchmough personal communication) on *Babiana cuneata* from Moedveiloon, Nieuwoudtville sown on 5th December 2009 recorded no germination until 2010 autumn. In contrast *Babiana* vanzyliae from Nieuwoudtville sown on the same day germinated in winter. *Watsonia laccata* germinated in winter outside even sown on 12th December 2010.

(1) November 2010 sowing

Fifty geophyte, 1 forb and 1 shrub species (see Table 3.3 below) which anecdote suggest germinate best in declining tempertures were sown in pots as eight replicates. All seeds were purchased late in 2009 or early 2010 from South Africa and had been fridge stored at 4^{o}C. Pots were 7x7 cm filled with the standardized substrate (40% grit, 40% sand and 20% peat compost) and seed was scattered evenly on the surface. Each pot contained 15-20 seeds, depanding on the total amount of seeds availability, the actual number sown in each pot was recorded. *Romulea* species, *Daubenya aurea*, *Arctotis adpressa* and *Heterolepis aliena* were treated individually with smoke water and soaked before sowing, because the germination rate could be promoted greatly by smoke treatment based on previous experiences (Hitchmough personal communication). The sown pots were then covered with a 5mm layer of coarse grit. Large seeds were covered with a deeper layer of grit, The sowing time was recorded on a white label together with species name and seed numbers sown in that pot. Pots were watered and placed in the glasshouse. Pots were watered every 3-5 days. Germination data were recorded as seedling counts. Any weeds that appeared were removed with eyebrow tweezers without disturbing the surface. Pots with no germination in the first growing season were held over till March 2011.

(2) August-November 2011 sowings

Sowing started in late August as seeds became available and ended in November 2011. Thirty-nine geophyte, 8 forb, 1 succulent and 4 shrubby species (see Table 3.3 below) were sown, with 8 replicates of each species. Each pot contained between 15-25 seeds each pot, with the actual number recorded on the label. *Aloinopsis spathulata, Podalyria leipoldtii, Syncarpha vestita,* and *Arctotis, Dimorphotheca, Gazania* species which require smoke-water treatment were treated individually before sowing. After labeling and initial watering, pots were placed on weedmat outdoors. Emergence data was obtained as previously described. Weeds were removed manually when necessary.

(3) August-September 2012 sowings

These species were mainly from high altitude and were sown in autumn 2012 in order to test their winter cold and summer wetness tolerance as Phase 2 of Winter Cold and Summer Wetness experiment in Chapter 4. All the sowing process was same as August-November sowing in autumn 2011 above.

3.2.2.2 Spring Sowing

As discussed in Chapter 2.3.1, both the author’s preliminary outdoor and glasshouse sowing experiment in 2010 had shown that some winter-growing geophyte species were able to germinate when temperatures were rising, rather than declining. These included; *Babiana dregei, Babiana fragrans* many *Watsonia* species, *Gladiolus tristis, Gladiolus floribundus, Aristea confusa*

(Hang 2010).

(1) Spring 2011 Sowing

In order to gain further information on the capacity of winter growing species to germinate in spring, 68 geophyte, 7 forb, 4 succulent and 7 shrubby species (see Table 3.3 below), were chosen for the outdoor germination test in March 2011. Seeds of individual species were sown following the same procedures as for autumn sowing with seedling counts undertaken for comparison with the autumn sowings of the same species. During their dormant period in summer, deciduous geophyte species were all covered with ventilated transparent “screens” during summer 2011 to keep the pots dry. In mid-August, species that hadn’t germinated or germinated poorly (<30%) were removed from the covers and exposed to rainfall to promote a second wave of germination. Evergreen geophyte species, succulents, forbs and shrubs were exposed to summer rainfall without cover. Species that were not covered and that died during the summer (mainly forbs and evergreen geophytes), were recorded. Watering was undertaken once a week if no significant rain had occurred in that week. Any weeds appeared in pots were removed carefully without disturbing the surface.

3.2.3 Specific Treatments

In order to maximise germination rates, various pre-sown treatment were used. Smoke treatment was used mainly for forb and shrub species, and scarifying was mainly used for species with hard coat. Seeds of wind-dispersed species have shown a significant germination response to smoke treatment (Brown et al., 1994), with more effective germination when sown on the soil surface. Smoke-responsive shrub, forb species (as discussed in chapter 2) mainly have to be soaked in smoke water for 48-72 hours to get good germination. Species chosen for smoke treatment are listed in Table 3.1 below. In species with sufficient seeds the differences between smoke and non-smoke treatment were compared. Commercially available smoke impregnated filter papers were soaked in 50ml of deionized water prior to usage to wet filter papers within petri dishes.

Podalyria leipoldtii with solid hard seed coat had to be scarified for 15 seconds with sand paper in order to remove some parts of the seed testa. Tiny seeds, *Aloinopsis spathulata, Crassula dejecta* for example, were covered with very thin layer of grit after sowing. *Erica tumida*, *Erica cerinthoides* and *Erica densifolia* were sown on a peat compost. All the pots with transplanted corms or new sown seeds were put in trays, watered and placed outside.

Fig. 3.1 (left) Smoke treatment through soaking smoke paper in petri-dishes; (right) sown seeds distributing evenly on the soil surface of unit pots.

Table 3.1 Species that used smoke treatment before sowing. “Smk” indicates smoke-treated before sowing and “Non-Smk” indicates without smoke treatment before sowing.

Albuca clanwilliamgloria (Smk and Non-Smk)	*Arctotis acaulis* (Smk)	*Arctotis adpressa* (Smk and Non-Smk)
Anisdontea anomala (Smk and Non-Smk)	*Arctotis campanuflora (diffusa)* (Smk and Non-Smk)	*Arctotis gumbletonii* (Smk)
Daubenya aurea (Smk)	*Dimorphotheca nudicaulis* (Smk and Non-Smk)	*Dimorphotheca cuneata* (white) (Smk and Non-Smk)
Dimorphotheca cuneata (orange) (Smk and Non-Smk)	*Erica cerinthoides* (Smk and Non-Smk)	*Erica tumida* (Smk and Non-Smk)
Euryopus othonoides (Smk)	*Felicia filifolia* (Smk)	*Freesia furcate* (Smk)
Gazania rigida (Smk and Non-Smk)	*Gazania heterochaeta* (Smk)	*Gazania krebsiana* (Smk and Non-Smk)
Gazania leipoldtii (Smk and Non-Smk)	*Gazania othonites* (Smk and Non-Smk)	*Gazania pectinata* (Smk)
Hermannia sericta (Smk and Non-Smk)	*Heterolepis aliena* (Smk)	*Ursinia sericea* (Smk)
Lessertia frutescens (Smk)	*Lessertia rigida* (Smk)	*Romulea subtistulosa* (Smk)
Romulea amoena (Smk)	*Romulea atrandra* (Smk)	*Romulea sabulosa* (Smk)
Romulea komsbergensis (Smk)	*Romulea monadelpha* (Smk)	*Ruschia spp.* (Smk)
Scabiosa Africana (Smk and Non-Smk)	*Stachys rugosa* (Smk)	*Ursinia spp.* (Smk)

Table 3.2: **Characteristics of the species that were tested for emergence characteristics** Information derives from Manning and Goldblatt (2002) *The Color Encyclopedia of Cape Bulbs* and the Pacific Bulb Society official website (http://www.pacificbulbsociety.org).

Species	**leaf phenology**	**Habitat**	**Flower-ing Height (mm)**	**Flower colour**	**Flowering season**
Albuca clanwilliamgloria	Deciduous	Deep sandy soils in fynbos dominated by Restionaceae	2000	yellow	October to November
Amaryllis belladonna	Deciduous	Loamy soils in seasonally moist sites	900	White to pink	February to April
Aristea capitata (=A. major)	Evergreen	Steep mountain slopes in sun or part shade 100-900m	1500	blue	October to December
Aristea bakeri (=A.confusa, A. macrocarpa)	Evergreen	Stony sandstone slopes from 200-1500m	1000	blue	September to December
Aristea inequalis	Evergreen	Sandstone rocks 500-900m	1500	blue	October to November
Babiana ambigua	Deciduous	Sandy flats and lower mountain slopes	50-80	Blue to mauve with white to cream markings	August to September
Babiana angustifolia	Deciduous	Damp clay flats and lower slopes, renosterveld	100-200	Dark blue to violet, lower tepals with black or red markings	August to September
Babiana cuneata	Deciduous	Rocky sandstone, or dolerite slopes and flats	100	deep blue, white spear shaped markings outlined in dark violet	August to September
Babiana dregei	Deciduous	Rocky mountain slopes, sandy stony soil	150	deep purple-blue, white splashes	August to September
Babiana melanops	Deciduous	Sandy, granitic gravel flats and slopes in renosterveld	100-300	Dark blue or purple, darker in center	August to September
Babiana ringens	Deciduous	Sandy flat in fynbos	150-400	Red with yellow throat	August to October
Babiana thunbergii	Deciduous	Sandy flat and dunes, coastal	400-700	red	July to October
Babiana vanzyliae	Deciduous	Rocky sandstone soils in fynbos	40-120	Zygomorphic, yellow to mauve	August to September
Babiana villosa	Deciduous	Clay flats and slopes in renosterveld	100-200	Mauve or pink to dark red	August to September
Brunsvigia bosmaniae	Deciduous	Open flats, coastal sand, loam, or granite soils	400	Pale to deep pink	March to May
Bulbinella cauda-felis	Deciduous	Sandstone, granite, or clay	800	White with pink keels	August to December
Bulbinella eburniflora	Deciduous	Clay and sand	750	ivory	August to September
Bulbinella elata	Deciduous	Clay and granite soils	1000	cream	July to August
Bulbinella elegans	Deciduous	Various soils	600	Yellow to white with pink tinge	August to September
Bulbinella latifolia var. doleritica	Deciduous	Doleritic clay	1000	orange	August to September
Bulbinella latifolia var. latifolia	Deciduous	Seasonally damp sandstone or granite	1000	Bright yellow	August to October
Bulbinella nutans	Deciduous	Damp peaty soils	1000	Yellow or cream	July to October
Bulbinella nutans var. turfosicola	Deciduous	Mountain seeps	1000	cream	October to December
Daubenya aurea	Deciduous	Dolerite clay flats	50	yellow or red	September
Freesia caryophyllacea	Deciduous	Clay soils and limestone, renosterveld and coastal bush	50-100	Yellow or cream with yellow markings	April to June
Freesia corymbosa	Deciduous	Mainly stony sandstone slopes	250-500	Yellow, sometimes pink	August to November
Freesia fergusoniae	Deciduous	Clay soils, renosterveld	100-200	Yellow with orange markings	August to September
Freesia fucata	Deciduous	Clay slopes in renosterveld	80-200	White flushed purple with board yellow markings	July
Geissorhiza aspera	Deciduous	Mostly sandy soils, flats and slopes	100-350	blue-violet, sometimes with a darker center, rarely white	August to September
Geissorhiza inflexa red	Deciduous	Clay flats and slopes in renosterveld	120-350	Red	August to September
Geissorhiza splendidissima	Deciduous	Clay soils in renosterveld	80-200	blue-violet, blackish in the center	August to September

Species	**leaf phenology**	**Habitat**	**Flowering Height (mm)**	**Flower colour**	**Flowering season**
Gladiolus angustus	Deciduous	Streams and marshes on sandstone soils	600-1200	Cream to pale pink, with reddish, diamond-shaped markings on the lower tepals	October to November
Gladiolus brevifolius	Deciduous	Sandstone and shale slopes	200-800	Pink, rarely brownish or gray, with yellow markings on the lower tepals	March to May
Gladiolus cardinalis	Evergreen	Waterfall and wet cliffs	600-900	Large, red with white splashes	December to January the following year
Gladiolus carinatus	Deciduous	Sandstone slopes or deep coastal sands	300-600	Blue to violet or yellow, rarely pink, often with transverse yellow markings on the lower tepals	August to September
Gladiolus carneus	Deciduous	Sandstone slopes, often wet sites	250-600	Pink or white, often with dark pink markings on the lower tepals	October to November
Gladiolus caryophyllaceus	Deciduous	Sandstone flats and slopes	250-1100	Pink to mauve	August to October
Gladiolus floribundus var. floribundus	Deciduous	Dry clay, sandy, or limestone flats and slopes	200-450	White to cream or pinkish with dark median streak on all the tepals	September to November
Gladiolus hirsutus (= G.punctulatus)	Deciduous	Flats and rocky sandstone slopes	300-500	Pink to purple or whitish, lower tepals irregularly streaked with dark colour	Mainly June to October
Gladiolus maculatus	Deciduous	Mainly clay slopes	300-600	Brownish to buff with dark speckling	March to July
Gladiolus marlothii	Deciduous	Sandy slope in clay	450-600	Pale blue, Yellow markings	Mainly October
Gladiolus miniatus	Deciduous	Coastal limestone outcrops	150-400	salmon	October to November
Gladiolus saccatus	Deciduous	Dry shale slopes	250-800	Bright red, perianth tube cylindrical	June to August
Gladiolus splendens	Deciduous	Rocky clay, mostly near streams	500-1100	Bright red, the lower tepals green	September to October
Gladiolus teretifolius	Deciduous	Clay slopes in renosterveld	300-600	Red	May to August
Gladiolus tristis	Deciduous	Usually marshy sites on sandstone, clay, or limestone soils	400-1500	Cream with brown shading	August to December
Gladiolus undulatus	Deciduous	Marshy sandstone slopes	400-800	Whitish to cream, rarely pale mauve, often with faint pink markings on the lower tepals	November to December
Gladiolus venustus	Deciduous	Clay and sandstone slopes	120-350	Purple to pink with yellow markings on the lower tepals	August to October
Haemanthus coccineus	Deciduous	Forest，shaded coastal scrub and rocky slopes，open veld	400	Bright red	February to April
Hesperantha cucullata	Deciduous	Sandy and shale slopes, mostly renosterveld	150-300	White, red to brown on the outside	Mainly August to September
Hesperantha humilis	Deciduous	Sandstone and shale slopes, mainly in renosterveld	30-80	Deep pink to reddish	July to September
Hesperantha luticola	Deciduous	Stony flats in seasonal pools or watercourses	100	White with dark purple blotches	July to early Aaugust
Hesperantha pauciflora	Deciduous	Mainly in sandy soils	80-240	Pink to purple, rarely pale yellow	August to September
Hesperantha vaginata	Deciduous	Heavy clay soil	120-180	Yellow, often marked with dark brown in the center and toward the tips of the outer tepals	August to September
Ixia curvata	Deciduous	Rocky slopes	250-500	Deep pink	July to September
Ixia latifolia	Deciduous	Mostly clay soils in renosterveld	200-500	Deep pink to purple or mauve	September to November
Ixia maculata	Deciduous	Granite and sandstone flats and slopes, mostly fynbos	200-500	Orange to yellow with a dark, star-like center	September to October
Ixia rapunculoides	Deciduous	Mostly clay soils in renosterveld or Karroid scrub	150-700	Blue, mauve, cream or pink	August to September

Species	**leaf phenology**	**Habitat**	**Flower-ing Height (mm)**	**Flower colour**	**Flowering season**
Ixia scillaris	Deciduous	Stony granite, sandstone, and clay flats and slopes	250-500	Pale or deep pink	September to November
Ixia thomasiae	Deciduous	Stony clay flats and slopes	500-800	pink	September to October
Kniphofia sarmentosa	Evergreen	Mountain streams and moist hollows	1000	Reddish in bud, opening buff	June to October
Kniphofia uvaria	Evergreen	Seeps, marshes, and streams on sandstone slopes	500-1200	Orange to greenish yellow	Mostly October to December
Lachenalia aloides	Deciduous	Granite and sandstone outcrops	50-310	In combination of orange, red, yellow, or greenish blue, with greenish markings	May to October
Lachenalia bulbifera	Deciduous	Sandy slopes and flats, mainly coastal	80-300	Orange to red with darker red or brown markings and green tips	April to September
Lachenalia contaminata	Deciduous	Wet places	60-250	White with brown or reddish markings	August to October
Lachenalia mutabilis	Deciduous	Sandy and stony slopes	100-450	Pale blue and white with yellow tips, or yellowish green, with brown markings	July to September
Lachenalia orchioides var. glaucina	Deciduous	In heavy soils, often in partial shade, in large colonies	100-400	Greenish yellow or pale to dark blue	August to October
Lachenalia pallida	Deciduous	Clay flats in large colonies	120-300	Cream to dark yellow with brown or green markings	August to October
Lachenalia purpureo-caerulea	Deciduous	Grave flats	100-280	White and purplish blue with greenish brown markings	October to November
Lachenalia rubida	Deciduous	Sandy flats and slopes	60-250	Plain or densely spotted with pink or red	March to July
Lachenalia violacea	Deciduous	Habitat variable, usually in rocky places	100-350	Bluish green at base with magenta or purple tips	July to September
Lachenalia viridiflora	Deciduous	Granite outcrops	80-200	Bluish green	May to July
Lapeirousia azurea	Deciduous	Granitic soils in renosterveld	60-120	Deep blue with blackish markings	September to October
Lapeirousia neglecta	Deciduous	Rocky sandstone slopes above 800m	300-800	White or blue, the lower tepals with darker markings	November to December
Lapeirousia oreogena	Deciduous	Clay soils	50-100	Violet with cream and blackish markings	August to September
Moraea angusta	Deciduous	Rocky sandstone flats and slopes	200-400	Yellow to brownish, sometimes flushed with mauve	August to November
Moraea bifida	Deciduous	Clay soils in renosterveld	500	Yellow or pink	August to September
Moraea bipartita	Deciduous	Clay flats	150-450	Blue with yellow nectar	June to November
Moraea elegans	Deciduous	Clay slops in renosterveld	180-400	Yellow with outer tepals usually orange and green blotches	August to September
Moraea fugax	Deciduous	Deep sands and rocky sandstone and granitic soils	120-800	Blue, white, or yellow	August to November
Moraea gigandra	Deciduous	Clay soils	200-400	Blue, rarely white or orange, dark blue to brown nectar	September to October
Moraea macronyx	Deciduous	Rocky sandstone slopes	90-150	Deep yellow, the outer tepals with white nectar	September to October
Moraea pritzeliana	Deciduous	Sandstone and clay soils, mainly in renosterveld	100-350	Dark blue with cream nectar guides	September to October
Moraea ramoisissima	Deciduous	Damp sandy or stony flats and slopes	500-1200	Yellow with darker yellow nectar	October to December
Moraea speciosa	Deciduous	Flats and lower slopes, mainly clay	400-700	Blue with a pale cup, inner and outer tepals with yellow nectar	July to August
Moraea tripetala	Deciduous	Rocky sandstone and clay soils	200-450	Blue to violet, rarely white or yellowish	August to September
Moraea tulbaghensis	Deciduous	Clay flats in renosterveld	250-500	Orange to reddish, the outer tepals with iridescent blue or green or darkly speckled markings	September
Moraea villosa	Deciduous	Stony granite and clay slopes and flats	300-400	Purple, blue, pinkish, or orange, with dark markings and a yellow claw	August to September

Species	leaf phenology	Habitat	Flower-ing Height (mm)	Flower colour	Flowering season
Onoxiotis stricta	Deciduous	Marshes and pools	200-500	Pink with cherry red nectar guides	August to October
Ornithogalum dubium	Deciduous	Mountains and flats	100-500	Yellow to orange or rarely white	August to December
Ornithogalum maculatum	Deciduous	Usually sandy soils, often on rocks	80-500	Orange to orange-red or yellow	September to October
Ornithogalum multiflorum	Deciduous	Shallow soil on rocks	30-250	Yellow to orange	September to October
Ornithogalum thyrsoides	Deciduous	Sandy flats and lower slopes, often in marshes	200-800	White, usually with a dark center	October to December
Romulea amoena	Deciduous	Damp sandstone soils	80-150	Deep rose pink to red with black blotches and stripes in a cream or yellow cup	August to September
Romulea atrandra	Deciduous	Clay soils	60-120	Magenta to pale pink or white, with dark veins and blotches around yellow cup	July to October
Romulea eximia	Deciduous	Sandy flats	80-150 (rarely 250)	Old rose or red, with dark blotches around the greenish or pale yellow cup	August to September
Romulea komsbergensis	Deciduous	Damp loamy flats	80-120 (rarely 300)	Magenta with a narrow blue band around the yellow cup	August to September
Romulea monadelpha	Deciduous	Damp dolerite flats and outcrops	100-180 (rarely 300)	Dark red with black and silvery blotches	August to September
Romulea sabulosa	Deciduous	Sandy and clay slopes and flats	120-180 (rarely 400)	Pink to magenta or white, purplish zone around yellow cup	July to October
Romulea syrengodoeflora	Deciduous	Shale flats and slopes	120-200	Pink to purple	September to October
Romulea unifolia	Deciduous	Dolerite flats	150-300	Orange-red with black and yellow blotches	August to September
sparaxis elegans	Deciduous	Dry sandstone slopes	90-120	Yellow and white, flushed mauve on the outside	August to early September
Sparaxis grandiflora ssp acuticoba	Deciduous	Clay flats and slopes in renosterveld	100-250	Bright yellow	August to September
Sparaxis grandiflora ssp violaceae	Deciduous	Clay flats and slopes in renosterveld	100-250	Cream to violet, tepals markedly spathulate	August to September
Sparaxis maculosa	Deciduous	Clay slopes in renosterveld	100-200	Yellow with a dark maroon-black center	September
Sparaxis meterlekampiae	Deciduous	Rocky sandstone slopes	150-300	Violet marked with white	August to September
Sparaxis tricolor	Deciduous	Rocky sandstone slopes	120-300	Orange-scarlet, the center yellow, broadly edged with reddish black	August to September
Spiloxene capensis	Deciduous	Seasonally wet flats	100-350	White ,cream or yellow, rarely pink	July to October
Tritonia deusta	Deciduous	Clay or granite slopes in renosterveld	150-250	Orange with a yellow, star-shaped center, often with dark marks on the outer tepals	September to October
Tritonia karooica	Deciduous	Dry stony clay flats	100-180	Yellow flushed with orange	August to September
Tritonia pallida	Deciduous	Sandstone and clay slopes	200-500	Cream or pink to pale lilac	September to October
Tritoniopsis triticea	Deciduous	Rocky granite and sandstone slopes	500-900	scarlet	January to April
Veltheimia capensis	Deciduous	Rocky slopes	200-400	Pink or pale yellow, finely speckled with red	April to July
Wachendorfia paniculata	Deciduous	Mainly sandstone soils	200-700	Pale yellow to bright apricot	Mainly August to November
Watsonia aletroides	Deciduous	Clay slopes, mainly renosterveld	450	Red, rarely pinkish or mauve	September to October
Watsonia borbonica	Deciduous	Mainly rocky sandstone slopes, also granite and clay, 100-1500m	500-2000	Purple-pink, rarely-white	October to January
Watsonia fourcadei	Evergreen	Rocky sandstones slopes	2000	Mostly orange to red, rarely pink or purple	November to January
Watsonia laccata light purple	Deciduous	Sandstone slopes in Fynbos	300-400	Light purple	September to November

Species	leaf phenology	Habitat	Flower-ing Height (mm)	Flower colour	Flowering season
Watsonia marginata	Deciduous	Sandy and granitic soils	500-2000	Pink, rarely white or purple	September to December
Watsonia marlothii	Evergreen	Rocky sandstones slopes	600-1200	Mainly red to pink	November to January
Watsonia meriana	Evergreen	Sandy or granitic soils, often marshes and streambanks	600-2000	Red to orange, pink or marve	September to November
Watsonia schlechteri	Evergreen	Rocky sandstone slopes in Fynbos	400-1000	Scarlet	November to Febuary
Watsonia spectabilis	Deciduous	Sandy flats and plateaus, Often near water	250-500	Scarlet	August to November
Watsonia stokoei	Deciduous	Sandstone soils in seeps and marshes	1000	Red to orange, rarely purplish	November to January
Watsonia tabularis	Deciduous	Rocky sandstones soils	1500	Orange or pink	November to December
Watsonia vanderspuyiae	Deciduous	Sandstone outcrops	1000-2000	Dark red	September to November
Watsonia zeyheri	Deciduous	Marshes on sandstone, coastal to 100m	500-1200	Bright orange	November to January
Arctotis acaulis	Evergreen	Clay, granitic, and limestone flats in the southwestern and southern Cape	200	Orange, yellow or cream rays and a black disc	August to October
Berkheya herbacea	Evergreen	Sandstone slopes in the southwestern Cape	400	yellow	October to March the following year
Crassula coccinea	Evergreen	Sandstone outcrops in the extreme southwestern Cape	600	Bright scarlet	December to March the following year
Crassula dejecta	Evergreen	Rock outcrops in Namaqualand and southwestern Cape	400	White flowers tinged reddish	November to February the following year
Dimorphotheca cuneata white	Evergreen		1000	White rays with purple interspersed with copper on the reverse, and a yellow disc	May to September
Dimorphotheca nudicaulis	Evergreen	Sandstone slopes in the southwestern and southern Cape, sunny open areas	400	White rays, purple to copper on the reverse, and a purple disc	August to October
Dimorphotheca tragus	Evergreen	Sandstone slopes in Namaqualand and the northern West Coast		Orange or yellow rays	
Erica cerinthoides	Evergreen	Sandy flats and slopes, from the southwestern Cape to Mpumalanga	300-1800	Orange-red, flowering especially after fire	The whole year
Erica densifolia	Evergreen	Flats to middle slopes on the mountains of the southern Cape	1500	Red flowers with greenish-yellow lobes	September to May the following year
Euryops othonnoides	Evergreen	On the mountains among boulders and in rock crevices, vertical cliffs, mainly on Table Mountain sandstone	400	Bright yellow ray and disc florets	August to December
Felicia filifolia	Evergreen	Flats or rocky slopes, widespread through SA	1000	Blue to mauve rays and a yellow disc	August to December
Gazania krebsiana (orange)	Evergreen	Roadsides, flats and lower slopes	200	Yellow to orange or reddish rays with dark marks at the base	August to January the following year
Gazania pectinata	annual	Coastal flats and lower slopes in the southwestern Cape	200	Yellow or orange rays with dark marks at the base	August to November
Gazania rigida	Evergreen	Flats and lower slopes in the southwestern and southern Cape	250	Yellow or orange rays, usually with dark marks at the base	July to November
Geranium incanum	Evergreen,	Sandy and stony soils along the coast from the Cape Peninsula to the Eastern Cape	300	Pink to mauve (rarely white with pink veins)	July to December
Heterolepis aliena	Evergreen	Rocky, sandstone slopes and outcrops in the mountains of the southwestern Cape	300	yellow	September to January the following year
Lessertia frutescens	Evergreen	Sandstone to shale flats and slopes throughout southern SA	1000	red	July to December

Species	**leaf phenology**	**Habitat**	**Flower-ing Height (mm)**	**Flower colour**	**Flowering season**
Lessertia rigida	Evergreen	Stony and sandy flats and slopes in the southwestern Cape	500	Pink to purple	August to September
Leucadendron album	Evergreen	Sandstone slopes in the southern Cape	2000	Involucral leaves pale green to yellow	November to December
Leucadendron spissifolium spp. Fragrans	Evergreen	Sandstone slopes in the southwestern and southern Cape	1300	Involucral leaves large and ivory or pale green	August to October
Podalyria leipoldtii	Evergreen	Sandstone slopes in the northern mountains	2000	pink	August to September
Roella ciliata	Evergreen	Stony slopes and on dry heathy sands	500	White or blue with a dark ring or spots on the lobes	Aug-Mar but almost throughout the year
Scabiosa africana	Evergreen	Sheltered sandstone slopes on the Cape Peninsula	1000	lilac	July to November
Stachys rugosa	Evergreen	Rocky slopes and plateaus	1200	Pink, mauve or purple	
Ursinla sericea	Evergreen	Upper sandstone slopes	700	Yellow rays and disc florets	September to February

Figure 3.2 Geophyte and Shrub/forb/Succulent species tested in the experiment (photos were taken by James Hitchmough, Ye Hang, John Manning, Peter Goldblatt and South African photographer Colin-Paterson Jones (http://www.colinpatersonjones.co.za) with written permission.

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Albuca clanwilliamgloria
(Hyacinthaceae)

Amaryllis belladonna
(Amaryllidaceae)

Aristea confusa
(Iridaceae)

Aristea capitata
(Iridaceae)

Aristea inaequalis
(Iridaceae)

Babiana ambigua
(Iridaceae)

Babiana angustifolia
(Iridaceae)

Babiana cuneata
(Iridaceae)

Babiana dregei
(Iridaceae)

Babiana fragrans
(Iridaceae)

Babiana melanops
(Iridaceae)

Babiana ringens
(Iridaceae)

Babiana sambucifolia
(Iridaceae)

Babiana thunbergii
(Iridaceae)

Babiana vanzyliae
(Iridaceae)

Babiana villosa
(Iridaceae)

Brunsvigia bosmaniae
(Amaryllidaceae)

Bulbinella caudis-felis
(Asphodelaceae)

Bulbinella eburnifolia
(Asphodelaceae)

Bulbinella elata
(Asphodelaceae)

Bulbinella elegans
(Asphodelaceae)

Bulbinella latifolia var. doleritica
(Asphodelaceae)

Bulbinella latifolia var. latifolia
(Asphodelaceae)

Bulbinella nutans
(Asphodelaceae)


Bulbinella nutans var. turfosicola
(Asphodelaceae)


Daubenya aurea
(Hyacinthaceae)

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Freesia caryophyllacea
(Iridaceae)


Freesia corymbosa
(Iridaceae)


Freesia fergusoniae
(Iridaceae)


Freesia fucata
(Iridaceae)


Geissorhiza aspera
(Iridaceae)


Geissorhiza inflexa
(Iridaceae)


Geissorhiza splendidissima
(Iridaceae)


Gladiolus angustus
(Iridaceae)


Gladiolus breviflorus
(Iridaceae)


Gladiolus cardinalis
(Iridaceae)

Gladiolus carinatus
(Iridaceae)

Gladiolus carneus
(Iridaceae)

Gladiolus caryophyllaceus
(Iridaceae)

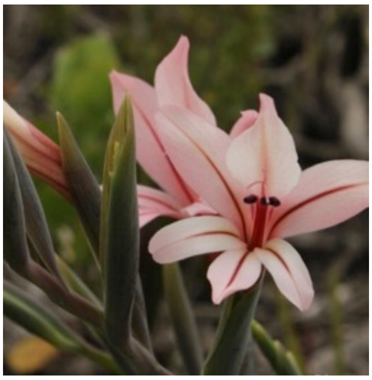
Gladiolus equitans
(Iridaceae)

Gladiolus floribundus var. floribundus
(Iridaceae)

Gladiolus hirsutus
(Iridaceae)

Gladiolus maculates
(Iridaceae)

Gladiolus marlothii
(Iridaceae)



Gladiolus miniatus
(Iridaceae)

Gladiolus saccatus
(Iridaceae)

Gladiolus splendens
(Iridaceae)

Gladiolus teretifolius
(Iridaceae)

Gladiolus tristis
(Iridaceae)

Gladiolus undulates
(Iridaceae)

Gladiolus venustus
(Iridaceae)

Haemanthus coccineus
(Amaryllidaceae)

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Haemanthus sanguineus
(Amaryllidaceae)

Hesperantha cucullata
(Iridaceae)

Hesperantha humilis
(Iridaceae)

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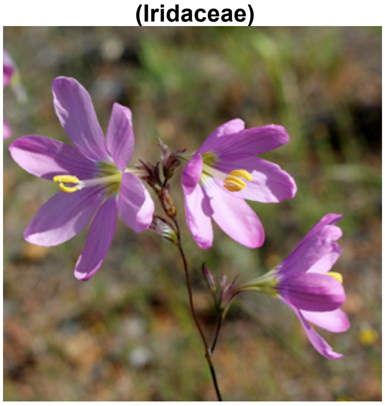
Hesperantha luticola
(Iridaceae)

Hesperantha pauciflora
(Iridaceae)

Hesperantha vaginata
(Iridaceae)

Ixia curvata
(Iridaceae)



Ixia latifolia
(Iridaceae)

Ixia maculate
(Iridaceae)

Ixia rapunculoides
(Iridaceae)

Ixia scillaris
(Iridaceae)

Ixia thomasiae
(Iridaceae)

Kniphofia sarmentosa
(Asphodelaceae)

Kniphofia uvaria
(Asphodelaceae)

Lachenalia aloides
(Hyacinthaceae)

Lachenalia bulbifera
(Hyacinthaceae)

Lachenalia carnosa
(Hyacinthaceae)

Lachenalia contaminate
(Hyacinthaceae)

Lachenalia mutabilis
(Hyacinthaceae)

Lachenalia orchioides var. glaucina
(Hyacinthaceae)

Lachenalia pallida
(Hyacinthaceae)

Lachenalia purpureocaerulea
(Hyacinthaceae)

Lachenalia rubida
(Hyacinthaceae)

Lachenalia violacea
(Hyacinthaceae)

Lachenalia viridiflora
(Hyacinthaceae)

Lapeirousia azurea
(Iridaceae)

Lapeirousia oreogena
(Iridaceae)

Moraea angusta
(Iridaceae)

Moraea bifida
(Iridaceae)

Moraea bipartite
(Iridaceae)

Moraea elegans
(Iridaceae)

Moraea fugax
(Iridaceae)

Moraea gigandra
(Iridaceae)

Moraea macronyx
(Iridaceae)

Moraea pendula
(Iridaceae)

Moraea pritzeliana
(Iridaceae)

Moraea ramoississima
(Iridaceae)

Moraea speciosa
(Iridaceae)

Moraea tripetala
(Iridaceae)

Moraea tulbaghensis
(Iridaceae)

Moraea villosa
(Iridaceae)

Onixotis stricta
(Colchicaceae)

IMAGE NOT AVAILABLE

Ornithogalum corticatum
(Hyacinthaceae)

Ornithogalum dubium
(Hyacinthaceae)

Ornithogalum maculatum
(Hyacinthaceae)

Ornithogalum multifolium
(Hyacinthaceae)

Ornithogalum thyrsoides
(Hyacinthaceae)

Romulea amoena
(Iridaceae)

Romulea atrandra
(Iridaceae)

Romulea eximia
(Iridaceae)

Romulea komsbergensis
(Iridaceae)

Romulea monadelpha
(Iridaceae)

Romulea sabulosa
(Iridaceae)

Romulea subfistulosa
(Iridaceae)

Romulea syringodeoflora
(Iridaceae)

Romulea unifolia
(Iridaceae)

Sparaxis elegans
(Iridaceae)

Sparaxis grandiflora ssp. acutiloba
(Iridaceae)

Sparaxis grandiflora ssp. violaceae
(Iridaceae)

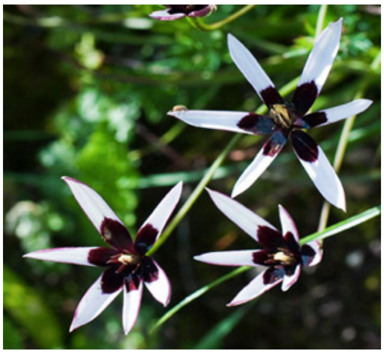
Sparaxis maculosa
(Iridaceae)

Sparaxis meterlekampiae
(Iridaceae)

Sparaxis tricolor
(Iridaceae)

Spiloxene spp. (orange)
(Hypoxidaceae)

Spiloxene spp. (yellow)
(Hypoxidaceae)



Spiloxene capensis
(Hypoxidaceae)

Tritonia deusta
(Iridaceae)

Tritonia karooica
(Iridaceae)

Tritonia pallida
(Iridaceae)

Tritoniopsis triticea
(Iridaceae)

Veltheimia capensis
(Asparagaceae)

Wachendorfia paniculata
(Haemodoraceae)

Watsonia alethroides
(Iridaceae)

Watsonia borbonica
(Iridaceae)

Watsonia fourcadei
(Iridaceae)

Watsonia laccata
(Iridaceae)

Watsonia marginata
(Iridaceae)

Watsonia marlothii
(Iridaceae)

Watsonia meriana
(Iridaceae)

Watsonia schlecteri
(Iridaceae)

Watsonia spectabilis
(Iridaceae)

***Watsonia* ‘stanford scarlet'**
(Iridaceae)

Watsonia stokoei
(Iridaceae)

Watsonia tabularis
(Iridaceae)

***Watsonia* ‘Tresco dwarf pink’**
(Iridaceae)

Watsonia vanderspuyiae
(Iridaceae)

Watsonia zeyheri
(Iridaceae)

Aloinopsis spathulata
(Aizoaceae)

Anisodontea anomala
(Malvaceae)

Arctotis acaulis
(Asteraceae)

Arctotis adpressa
(Asteraceae)

Arctotis campanuflora (diffusa)
(Asteraceae)

Arctotis gumbletonii
(Asteraceae)

Berkheya herbacea
(Asteraceae)

Cheiridopsis namaquensis
(Aizoaceae)

Crassula coccinea
(Crassulaceae)

Crassula dejecta
(Crassulaceae)

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Crassula perfoliata var. minor
(Crassulaceae)

Crotalaria humilis
(Fabaceae)

Dimorphotheca cuneata **(white)**
(Asteraceae)

Dimorphotheca cuneata **(orange)**
(Asteraceae)

Dimorphotheca nudicaulis
(Asteraceae)

Dimorphotheca tragus
(Compositae)

Elegia vaginaga
(Restionaceae)

Erica cerinthoides
(Ericaceae)

Erica densifolia
(Ericaceae)

Erica strigilifolia
(Ericaceae)

Erica tumida
(Ericaceae)

Esterhuysenia alpina
(Aizoaceae)

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Euryops othonnoides
(Asteraceae)

Felicia filifolia
(Asteraceae)

Gazania heterochaeta
(Asteraceae)

Gazania krebsiana(orange)
(Asteraceae)

Gazania othonites
(Asteraceae)

Gazania pectinata
(Asteraceae)

Gazania rigida
(Asteraceae)

Geranium incanum
(Geraniaceae)

Goniolimon speciosum
(Plumbaginaceae)

Hermannia stricta
(Malvaceae)

Heterolepis aliena
(Asteraceae)

Hirpicium alienatum
(Asteraceae)

Lessertia frutescens
(Fabaceae)

Leucadendron spissifolium spp. Fragrans
(Proteaceae)

Leucadendron album
(Proteaceae)

Podalyria leipoldtii
(Fabaceae)

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Roella ciliata
(Campanulaceae)

Ruschia spp.
(Mesembryanthemaceae)

Scabiosa africana
(Caprifoliaceae)

Stachys rugosa
(Lamiaceae)

3.3 Results

3.3.1 Germination in the Laboratory Experiment

Amongst the smoke-treated species, many showed a significant increase in germination following smoke treatment. Smoke treatment promoted the germination of forbs/shrubs very effectively after 72 hours, with the quick reponders commencing germination within 24 hours, for example *Arctotis acaulis, Arctotis adpressa and Scabiosa africana*. *Arctotis gumbletonii, Dimorphotheca cuneata* white, *Dimorphotheca cuneata* orange achieved 30-45% germination within 24 hours. *Gazania heterochaeta* (home produced seeds) achieved 20-40% germination within 24 hours but reached 100% germination within 48 hours of smoke treatment. In comparison, home produced seeds of *Arctotis campanuflora* were less influenced by smoke treatment with only 4% germination within 24 hours of smoke treatment. *Lessertia frutescens, Gazania othonites, Gazania rigida, Gazania leipoldtii, Euryops othonites* and *Gazania krebsiana* showed 100%, 100%, 100%, 90%, 70% and 50% germination respectively within 5 days after smoke treatment. *Lessertia rigida* showed 63.3% germination approximately 10 days after smoke treatment. *Erica cerinthoides* and *Felicia filifolia* showed 93.3% and 80% germination approximately 15 days after smoke treatment. *Hermannia sericta*, *Anisdontea anomala* and *Erica tumida* showed little or no response to smoke treatment, with maximum germination of 26.7%, 0% and 0%. Data on the response of these species to smoke treatment is summarised in Table 3.3 (marked with ‘L-Smk’).

3.3.1.2 Emergence in the Field Experiment

(1) November 2010 sowing

Most species were observed germinating under fluctuating temperatures between 15 °C and 5 °C. Emergence started from the beginning of November 2010 across the extremely cold winter to early Febuary 2011. Emergence of tested species is summarised in Table 3.3. *Albuca clanwilliamgloria, Babiana cuneata, Babiana dregei, Babiana vanzyliae, Bulbinella caudis-felis, Geissorhiza splendidssima, Gladiolus caryophyllaceus, Gladiolus marlothii, Gladiolus splendens, Gladiolus teretifolius, Moraea bifida, Moraea bipartite, Moraea ramoississima, Moraea tripetala,* *Romulea amoena, Romulea komsbegensis, Romulea eximia* showed high emergence (>70%) even sown as late as November, *Bulbinella eburnifolia, Bulbinella elegans, Bulbinella latifolia var. latifolia, Gladiolus cardinalis, Moraea gigandra, Ornithogalum dubium, Ornithogalum dubia ex Pisa* showed 50% emergence, while *Babiana thunbergii, Bulbinella latifolia var. doleritca, Bulbinella nutans, Daubenva aurea* gave approximately 10-20% emergence when late sown. *Babiana ringens, Laperirousia oregeona, Lapeirousia silenoides, Moraea elegans, Moraea macronyx, Ornithogalum maculatum, Romulea atrandra, Tritonia karooicum* had less than 10% emergence. *Hesperantha luticola, Moraea villosa, Moraea speciosa, Ornithogalum multiflorum, Romulea unifolia* did not emerge.

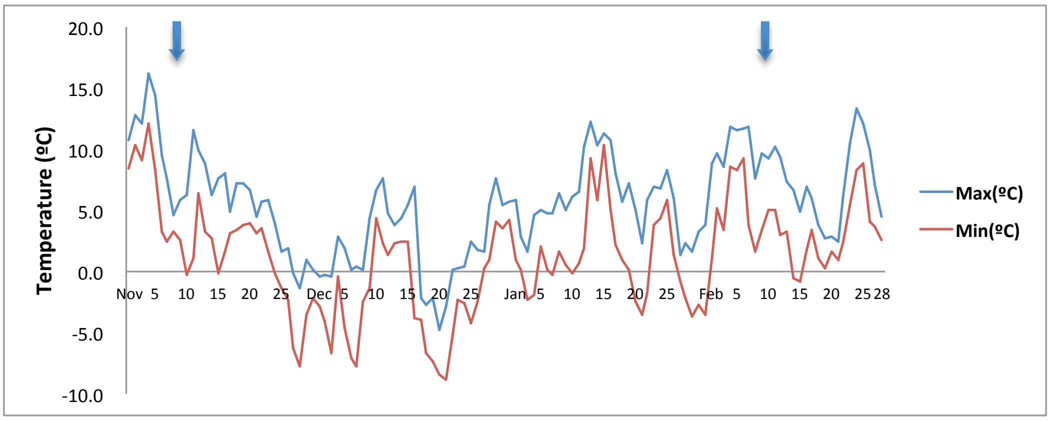


Fig. 3.3 Autumn sowing temperature between November 2010 and Febuary 2011(arrows frame the germination window).

(2) August-November 2011 sowings

Germination took place in some species within a week after sowing in late August and early September. Most species were observed emerging under fluctuating temperatures between 25 °C and 5 °C. Germination continued from September 2011 to late Febuary 2012. Approximately 85% of the 2011 autumn sowing species showed emergence >30%. *Albuca clanwilliamgloria* without any pre-treatment achieved 15% emergence only one week after sowing was the fastest emerging geophytes. *Kniphofia sarmentosa* started germination in the following week. In 3 weeks, pre-smoked *Dimorphotheca nudicaulis*, *Gazania krebsiana* and non-smoked evergreen geophyte species *Kniphofia sarmentosa* and *Kniphofia uvaria* showed high levels of emergence. For most forb/shrub species with smoke treatment and most of geophyte species emerged approximately one month after sowing. Forbs/shrubs grew faster than geophyte species in autumn.Emergence data is summarised in Table 3.3.

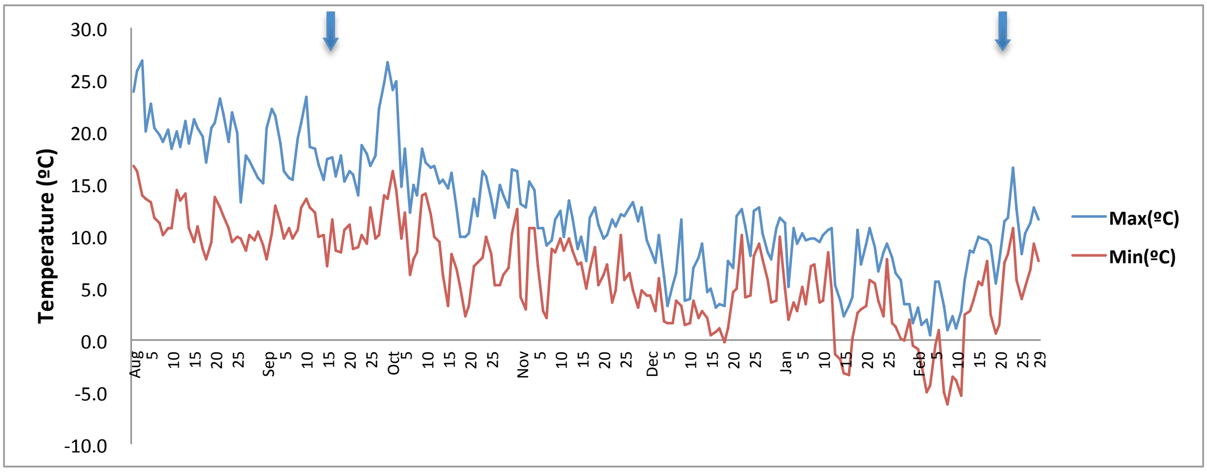


Fig. 3.4 Autumn sowing temperature between August 2011 and Febuary 2012 (arrows frame the germination window).

A large majority of deciduous geophyte species completed emergence within three months by early December. Seedling emergence continued throughtout winter even under 0°C till mid-March 2012 in the following species (some emerging at temperatures as low as -5 to -3°C): *Albuca clanwilliamgloria, Babiana ambigua, Babiana angustifolia, Babiana cuneata, Babiana fragrans, Babiana thunbergii, Babiana vanzyliae, Babiana villosa, Bulbinella elata, Bulbinella latifolia var. latifolia* (-5°C), *Freesia furcata, Geissorhiza splendidissima, Geissorhiza tulbaghensis, Gladiolus cardinalis, Gladiolus caryophyllaceus, Gladiolus floribundus, Gladiolus floribundus var. rudis* (-5°C), *Gladiolus miniatus, Hesperantha cucullatus, Hesperantha vaginata, Ixia curvata, Ixia latifolia* (-5°C), *Ixia maculate, Ixia rapunculoides* (-5°C), *Ixia scilliaris, Lachenalia pallida, Lachenalia rubida, Lapeirousia azurea, Moraea bipartita* (-5°C), *Moraea bifida* (-5°C), *Moraea* *pritzeliana, Moraea ramossisima, Moraea tripetala* (-5°C)*, Moraea tulbagensis* (-5°C)*, Moraea villosa* (-5°C)*, Sparaxis elegans, Sparaxis grandiflora spp. acuticoba, Sparaxis grandiflora spp. violaceae* (-5°C)*, Sparaxis meterlekampiae, Sparaxis tricolor, Spiloxene spp. (orange), Spiloxene capensis, Watsonia aletroides, Watsonia marginata, Watsonia meriana, Watsonia spectabilis, Watsonia vanderspuyiae, Watsonia zeyheri.*

Some everygreen geophytes and forbs also germinated over winter until mid-March 2012 as in the following species: *Aloinopsis spathulata, Aristea capitata (major), Aristea confusa, Arctotis adpressa, Crassula coccinea, Crassula dejecta, Dimorphotheca cuneata (white), Dimorphotheca cuneata (orange), Dimorphotheca nudicaulis, Gazania kresiana (orange), Geranium incanum, Kniphofia uvaria* (-5°C)*, Scabiosa africana, Watsonia marlothii, Watsonia tabularis, Tripteris opos.* A large majority of species reached peak emergence in early December, decling as winter cold intensified . Species that did not emerge in autumn 2010 or following spring sowing in 2011 germinated in autumn 2011, and the following species emerged at temperatures as low as -5°C between December 2011 to March 2012: *Babiana fragrance, Babiana ringens, Bulbinella nutans, Daubenva aurea, Freesia fergusoniae, Gladiolus carneus var. macowanii, Gladiolus floribundus var. floribundus, Gladiolus marlothii, Gladiolus venustus, Ixia latifolia, Ixia thomasiae, Lachenalia bulbifera, Lachenalia contaminata, Lachenalia orchioides var. glaucina, Lachenalia pallida, Lachenalia purpureo-caerulea, Lachenalia rubida, Lachenalia viridiflora, Lapeirousia silenoides, Moraea bifida, Moraea gigandra, Ornithogalum thyrsoides, Romulea amoena, Romulea atrandra, Romulea komsbergensis, Romulea sabulosa, Sparaxia maculosa, Sparaxis meterlekampiae, Tritonia deusta, Tritonia, pallida, Watsonia borbonica. Hesperantha luticola* didn’t emerge after autumn sowing 2011 but emerged in the following autumn 2012. Some geophyte species were shown to be able to emerge in the middle of winter at very low temperatures, for example, *Babiana vanzyliae, Hesperantha cocccineus, Hesperantha pauciflora, Hesperantha vaginata, Ixia maculate, Ixia rapunculoides, Sparaxis grandiflora subsp. acuticoba* and *Sparaxis tricolor*.

The emergence of species collected as seed from more than two locations were compared, but there was no clear pattern for most of species in these sowing.

(3) Sowing in spring

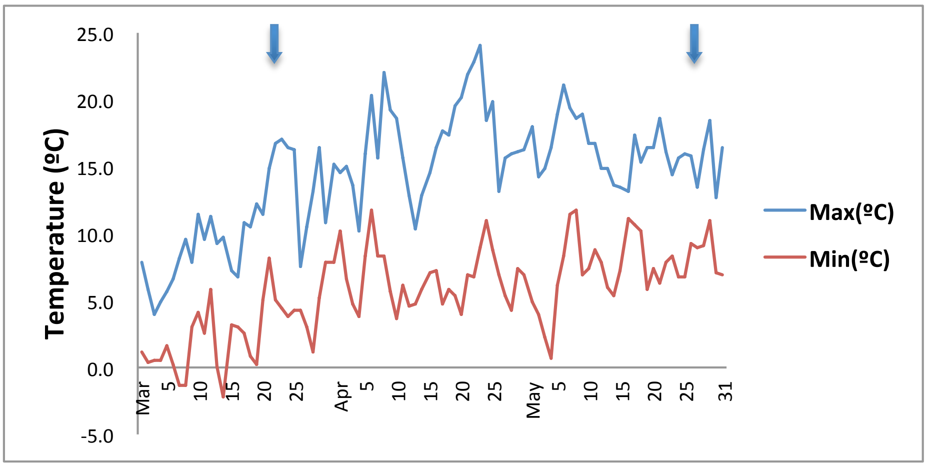


Fig. 3.5 Spring sowing temperature between Mar 2011 and May 2011 (arrows frame the germination window).

Approximately 37.5% of the 2011 spring sowing species showed high field germination (>30%), among which, 23.75% species showed very high capacity of spring field germination (>50%). These species (germination >30%) were proved sowing in rising temperature (spring sowing) was possible to get high field germination in some winter growing species. The list includes some smoke pre-treated shrub/forb species, such as *Dimorphotheca cueata (orange), Dimorphotheca nudicaulis, Dimorphotheca tragus, Syncarpha vestita, Gazania krebsiana (orange)*, and non-smoke treatment forb species *Scabiosa africana, Crassula dejecta, Geranium incanum*. Geophyte species *Aristea confusa, Aristea inequalis, Gladiolus floribundus, Gladiolus tristis, Lachenalia contaminate, Lachenalia orchioides var. glaucina, Ornithogalium thyrsoides, Wachendorfia paniculata, Watsonia aletroides, Watsonia borbonica, Watsonia laccata, Watsonia fergusoniae, Watsonia marginata and Watsonia vanderspuyiae* all showed over 50% field emergence. Other geophyte species *Aristea major, Babiana villosa, Geissorhiza inflexa (red), Gladiolus carneus, Gladiouls miniatus, Lachenalia aloides, Lachenalia pallida and Lachenalia viridiflora* showed 30-50% field germination rate. Emergence of species is summarised in Table 3.3.

Table 3.3 Mean of 3 sample weights (g) of all the tested species, plus emergence data for all field sown species sown in autumn 2010, spring 2011, autumn 2011 and autumn 2012. Location names refer to different collection provenances, species with or without smoke treatment were marked with "Smk" and "Non-Smk", species tested in the lab were marked with "L-Smk". Data was collected as numerical counts, then converted into % emergence. All data was based on at least 3 replicates, and in most cases, there were 5-10 replicates with 15-25 seeds/pot of individual species tested).

Species Name	**Mean weight (g)**	**Mean g/seed**	**No.of seeds /g**	**sowing in autumn 2010**	**sowing in spring 2011**	**sowing in autumn 2011**	**sowing in autumn 2012**
Albuca clanwilliamgloria	0.054	0.0027	373	Clanwilliam 98.5% (Smk)		Clanwilliam 15% (Smk)	
Anisdontea anomala							Nieuwoudtville 0% (Non-Smk) and 0% (L-Smk)
Arctotis acaulis	0.181	0.0091	110		Gouda 17% (L-Smk)		
Arctotis adpressa	0.031	0.0016	645		Komsberg 18.75% (L-Smk)	Komsberg 6% (Smk)	
Arctotis campanulata (diffusa)	0.114	0.0057	175		Kamiesberg 0% (Smk)	Kamiesberg 4% (L-Smk) and 6% (Smk)	Narie 800m: 0% (Non-Smk) but 5% (Smk)
Arctotis gumbletonii	0.104	0.0052	192		Patimis Pass-Home seed 29% (Smk)	Patimis Pass-Home seed 30% (L-Smk)	
Daubenya aurea				Roggeveld 47.5% (Smk)			
Dimorphotheca cuneata (orange)	0.156	0.0078	128		Kamiesberg 47.5% (L-Smk) but 31.5% (Smk)	Kamiesberg 30.5% (Smk)	
Dimorphotheca cuneata (white)	0.153	0.0077	130		Rooiwal 10% (Non-Smk) but 56.25% (L-Smk)	Rooiwal near Middelpos 55.63% (Smk)	Calvenia: 8.75% (Non-Smk) but 52% (Smk)
Dimorphotheca nudicaulis	0.139	0.007	144		Scarborough 70% (L-Smk) but 58% (Smk)	Scarborough 57% (Smk); Niewoudteville 78% (Non-Smk)	Daubenya area: 6.88% (Non-Smk) but 65% (Smk)
Erica cerinthoides							Swartberg 1500+m: 8% (Non-Smk) but 93.3% (L-Smk); Swartberg 1846m: 0% (Non-Smk) but 6% (Smk)
Erica tumida							Matroosberg south slope 1800m: 0% (L-Smk)
Euryops othonoides						Hex river Moutains 70% (L-Smk)	Hex river Moutains 38% (Smk)
Felicia filifolia	0.01	0.0005	2069				Rooiwal 19.38% (Smk) and 80% (L-Smk)
Freesia furcata	0.087	0.0058	172			Villiersdorp 90.5% (Smk)	
Gazania heterochaeta					Home seed 100% (L-Smk) and 62% (Smk)	Home seed 38.29% (Smk)	
Gazania krebsiana (orange)	0.117	0.0059	170		Namaqualand 63.75% (L-Smk) and 20.5% (Smk);	Namaqualand 17.5% (Smk); Rooiwal near Middelpos 50% (L-Smk)	Rooiwal 7.5% (Non-Smk)
Gazania leipoldtii						Kamiesberg 100% (Smk)	Kamiesberg 16.25% (Non-Smk)
Gazania othonites	0.052	0.0026	387			Rooiwal 100% (L-Smk)	Rooiwal 6.25% (Non-Smk)
Gazania pectinata						Kamiesberg 53% (Smk)	
Gazania rigida	0.094	0.0047	212			Komsberg 100% (L-Smk)	Komsberg 0% (Non-Smk) and 6.25% (Smk); 12.86% (Smk)
Hermannia stricta	0.021	0.001	968			Northern Cape 0% (Non-Smk) and 26.7% (Smk)	Northern Cape 0% (Non-Smk) and 0.63% (L-Smk)
Heterolepis aliena	0.024	0.0012	930		Cederberg 25% (Smk)		Perdaskop 1200m: 2% (Non-Smk) but 90% (Smk)
Lessertia frutescens	0.21	0.0105	95			Kamiesberg 100% (L-Smk)	Kamiesberg 13.13% (Non-Smk)
Lessertia rigida	0.227	0.0114	88			Roggeveld 63.3% (L-Smk)	Roggeveld 10% (Non-Smk)
Podalyria leipoldtii	0.669	0.0334	30			unkown 31.11% (scarified)	
Romulea amoena	0.027	0.0014	741	unknown 74.38%(Smk)			
Romulea atrandra	0.07	0.0035	286	Roggeveld 30%(Smk)			
Romulea komsbergensis	0.106	0.0053	189	Roggeveld 68.5% (Smk)			Roggeveld 35% (Non-Smk) but 74% (Smk)
Romulea monadelpha	0.185	0.0092	108				Rooiwal 10% (Non-Smk)
Romulea sabulosa	0.073	0.0037	274	Niewoudteville 40.18% (Smk)			
Romulea subtistulosa	0.195	0.0097	103				Bavisriver 28.75% (Non-Smk)
Ruschia spp.	0.013	0.0007	1538				top Franochoek moutains 18.13% (Smk); top Swartberg 19.38% (Smk)
Scabiosa africana					unkown 50.63% (L-Smk) and 6% (Non-Smk)		
Stachys rugosa	0.047	0.0024	426				Komsberg 22.86% (Smk)
Syncarpha vestita	0.027	0.0005	1852			Silvermere 10.5% (Smk)	Silvermere 12% (Smk)
Ursina sericea	0.024	0.0012	845		Lihte Karoo 11.25% (Smk)		
Ursinia spp.	0.023	0.0012	857				Daubenya near Middelpos 13.33% (Smk)

Species Name	Mean weight (g)	Mean g/seed	No.of seeds /g	sowing in autumn 2010	sowing in spring 2011	sowing in autumn 2011	sowing in autumn 2012
Aloinopsis spathulata					Komsberg 13.13%	Komsberg 8%	
Aristea confusa	0.076	0.0038	263		Stellenbosch 83.13%	unknown 56.5%	
Aristea inequalis	0.099	0.005	202		Niewoudteville 70.63%		
Aristea spp.	0.059 0.061 0.051	0.003 0.0031 0.0026	337 328 392				Perdaskop (west slope 800-900m) 85.63% ; Perdaskop west slope 940m) 75%; Perdaskop (north slope 1200-1250m) 28.75%
Babiana ambigua	0.071	0.0048	210	Scarborough 87.5%	Cape Peninsula 74.38%		
Babiana angustifolia	0.06	0.003	333		Swartland 85%	Swartland 73%	
Babiana cuneata	0.194	0.0097	103	Niewoudteville 92.2%		Middelpos 79%	
Babiana dregei	0.187	0.0094	107				Kamieskroon 1200+m 48.75%
Babiana fragrans					Bainskloof 60% stellenbosch 81.25%		
Babiana melanops	0.17	0.0113	88				Tulbagh 63.13%
Babiana ringens				Stellenbosch 26.25%			
Babiana sambucifolia					Stellenbosch 96.88%		
Babiana thunbergii	0.337	0.0169	59	West coast 33.75%		West coast 33.5%	
Babiana vanzyliae	0.1	0.005	200	Niewoudteville 95.83%		unknown 95%	
Babiana villosa	0.117	0.0059	171		Tulbagh 58.33%	Tulbagh 33.13%	
Bulbinella caudis-felis	0.02	0.001	1000	Cedarberg 71.25%			
Bulbinella eburnifolia	0.022	0.0011	923	Niewoudteville 58.75%			Nieuwoudtville 79.38%
Bulbinella elata				Pakhius Pass 100%		Bainskloof 28.5%	
Bulbinella elegans	0.052	0.0026	385	Sutherland 78.13%		Sutherland 14.86%	Rooiwal 21.25%
Bulbinella latifolia var latifolia	0.05	0.0025	397	Namaqualand 25%		Kamiesberg 80%	
Bulbinella latifolia var doleritica	0.101	0.0051	198	Niewoudteville 17.5%			
Bulbinella nutans	0.058	0.0029	345	Moedveiloon 56.25% Niewoudteville 16.25%			Nieuwoudtville 41.88%
Bulbinella nutans var. turfosicola	0.107	0.0053	188				Table Mountain 24.38%
Crassula coccinea					Table Mountain 23.13%		
Crassula dejecta					Bainskloof 22.5%		
Crotalarca humclis	0.253	0.0253	40				Rooiwal 11.88%
Dimorphotheca tragus	0.092	0.0061	164			West marl (sw) 10%	
Dimorphotheca tugax	0.072	0.0036	276		Namaqualand673m 36.67%		
Esterhuysenia alpina	0.022	0.0002	5538				top Matroosberg 20.63%
Freesia caryophyllacea				Stellenbosch 87.5%			
Freesia corymbosa				Eastern Cape 70.83%			
Freesia fergusoniae				Stellenbosch 87.5%			
Geissorhiza aspera	0.023	0.0005	2206	Malmsbury 95.31%	Cape Peninsula 73.75%		
Geissorhiza inflexa (red)					Tulbagh 80%		
Geissorhiza splendidissima	0.026	0.0013	779	Nieuwoudtville 96.88%		unknown 75%	
Geissorhiza tulbaghensis	0.013	0.0004	2368	unknown 76.56%	unknown 59.38% Tulbagh 88.13%		
Geranium incanum	0.111	0.0055	181		Mossel Bay 61.25%		
Gladiolus cardinalis	0.081	0.0041	247			Dunlop 69.5%	Matroosberg 1925m 37.5%
Gladiolus carinatus				Alan Hill 21.88%			
Gladiolus carneus	0.062	0.0031	323	B&T 76.56%	Bot river 79.38% B&T 11.88% Paarl moutain 70%		
Gladiolus carneus var. macowan					stellenbosch 96.88%		
Gladiolus caryophyllaceus	0.096	0.0048	208	Niewoudteville 92.19%		Niewoudteville 78.13%	
Gladiolus equitans	0.115	0.0058	174				Pendoorhoek 36.88% Leliefontein 29.38%
Gladiolus floribundus						Eastern Cape 81%	
Gladiolus floribundus var floribundus	0.092	0.0046	217		Eastern Cape 77.5% Bot river 65%		
Gladiolus floribundus var rudis				Mcgregor 68.75%			
Gladiolus hirsutis					Bainskloof 100%		
Gladiolus maculatus				Stellenbosch 96.88%			
Gladiolus marlothii	0.064	0.0032	314	Roggeveld 87.5%			
Gladiolus miniatus	0.073	0.0037	274		Arniston 95.83% Hermanus 56.88%	Hermanus 94%	
Gladiolus saccatus	0.067	0.0034	299			Loeriesfonten 12.8%	Loeriesfonten 36.25%
Gladiolus splendens	0.044	0.0022	455	Roggeveld 98.44%			Noaens River 46.43% Rooiwal 93.13%
Gladiolus tristis				Eastern Cape 76.56%			
Gladiolus undulatus				Bainskloof 95.31%			
Gladiolus venustus	0.065	0.0033	306		Clanwilliam 54.38%		
Haemantitus cocccineus					Hamtamsburg 96.88%		
Hesperantha cucullatus	0.049	0.001	1020			Nieuwoudtville 98.13%	
Hesperantha humilis				Sutherland 100%			
Hesperantha luticola	0.1	0.005	201			Roggeveld 19.38%	
Hesperantha pauciflora	0.031	0.0016	645	unknown 91.67%	Niewoudteville 83.13%		
Hesperantha vaginata	0.062	0.0031	323	Niewoudteville 54.17%	Niewoudteville 75.63%	Niewoudteville 28.13%	

Species Name	Mean weight (g)	Mean g/seed	No.of seeds /g	sowing in autumn 2010	sowing in spring 2011	sowing in autumn 2011	sowing in autumn 2012
Ixia curvata	0.068	0.0034	294		Sutherland 100%	Sutherland 75%	Komsberg 56.25%
Ixia latifolia	0.057	0.0029	351		Ceres 83.75%		
Ixia maculata	0.12	0.006	167	Malmsbury 70.31%		Swartland 96.88%	
Ixia rapunculoides	0.052	0.0026	385	Niewoudteville 82.5%		Niewoudteville 85%	
Ixia scilliaris	0.017	0.0003	2941		Paarl mountain 83.13%	Paarl mountain 93%	
Ixia thomasiae	0.215	0.0108	93		Roggeveld 78.13%		Middlepos 87.5%
Kniphofia sarmentosa	0.093	0.0046	216			Sutherland 79%	
Kniphofia uvaria						Kovebekkeveld 50.5%	
Lachenalia aloides	0.027	0.0006	1667		Stellenbosch 60% Tulbagh 61.25% Wolseley 55%		
Lachenalia bulbifera					West coast 100%		
Lachenalia carnosa	0.017	0.0009	1176		Namaqualand 74.38%		
Lachenalia contaminata	0.037	0.0018	545		Swartland 29.38%		
Lachenalia mutabilis	0.027	0.0011	938			Niewoudteville 33.75%	
Lachenalia orchioides var. glaucina	0.02	0.001	1017		Cape Peninsula 77.5%		
Lachenalia pallida	0.012	0.0008	1286		Swartland 66.88%		
Lachenalia purpureo-caerulea	0.01	0.0006	1552		unknown 69.38%		
Lachenalia rubida	0.031	0.0016	638		unknown 75.63%		
Lachenalia viridiflora	0.015	0.001	1023		unknown 56.88%		
Lapeirousia azurea	0.013	0.0004	2368		Malmsbury 78.75%	Malmsbury 74%	
Lapeirousia oreogena							Niewoudteville 50%
Lapeirousia silenoides	0.041	0.002	492	Spoegrivier 16.88%			
Leucadendron album	0.479	0.024	42				Swartberg mountains 1700m 15.71%
Leucadendron spissifolium spp. Fragrans	0.137	0.0069	146				Swartburg 40.71%
Moraea angusta					Heininglilip, hernanus area 66.67%		
Moraea bifida	0.028	0.0014	714	Roggeveld 90.63%			
Moraea bipartita	0.012	0.0006	1714	Dawie 90.63%	Eastern cape 37.5%	Eastern cape 56.25%	
Moraea fugax	0.015	0.0007	1364		unknown 81.25%	unknown 62.5%	
Moraea gigandra	0.011	0.0006	1818	Piketberg 62.14%			
Moraea macronyx				komsberg 26.25%			
Moraea pendula					Kamieskroon 98.44%		
Moraea pritzeliana	0.032	0.0011	928		Komsberg 31.25%	Nieuwoudtville 65.83%	
Moraea ramossisima	0.089	0.0045	225	Baviaans rivier 12.5%		Baviaans rivier 82.5%	
Moraea tripetala	0.021	0.0011	952	Grasberg nieuwoudtville 88.57%	Grasberg, nieuwoudtville 100%	nieuwoudtville 77.5%	
Moraea tulbaghensis	0.035	0.0007	1442			Gouda 69.38%	
Moraea villosa	0.014	0.0007	1395			Tulbagh 71.88%	
Onoxiotis stricta				Somerset West 83.33%			
Ornithogalum corticatum	0.019	0.0005	2069				Bovis River 53.75%
Ornithogalum thyrsoides	0.01	0.0003	4000		Mowbray ridge 85%		
sparaxis elegans	0.101	0.0067	149	Nieuwoudtville 95.83%	Nieuwoudtville 60%	Nieuwoudtville 85.5%	
Sparaxis grandiflora ssp acuticoba						Citrusdal 95.71%	
Sparaxis grandiflora ssp violaceae				Hermanus 85%			
Sparaxis maculosa					unknown 78.75%		
Sparaxis meterlekampiae	0.107	0.0054	187		Clanwilliam 85.63%		
Sparaxis tricolor	0.084	0.0084	119		Nieuwoudtville 90.63%		
Spiloxene capensis						Cape Peninsula 38.5%	
Spiloxene spp. (orange)				Kamieskroon 96.88%		Kamieskroon 35%	
Spiloxene spp. (yellow)				unknown 100%			
Tripteris oppositifolia	0.395	0.0198	51			Springbok 23%	outside Springbok 27.86%
Tritonia deusta	0.028	0.0014	706		unknown 91.88%		unknown 26.25%
Tritonia pallida					Montague 97.5%		
Tritoniopsis spp	0.092 0.144 0.083	0.0061 0.0072 0.0083	163 139 120				Matroosberg north slope 1670m 32.5%; Cold Bokkeveld 1050m 76.88%; Swartberg north slope 1360m 26%
Tritoniopsis triticea	0.265	0.0133	75			Piketberg 64.38%	Piketberg 39.38%
Veltheimia capensis				Kamiesburg 78.13%			
Wachendorfia paniculata	0.152	0.0076	132			Kovebekkeveld 59.38%	
Watsonia aletroides	0.126	0.0063	158		Caledon 32.5%	Napier 89%	
Watsonia borbonica	0.379	0.019	53	unkown 93.75%		Cape Peninsula 11%	Perdaskop 1500m 20% Stellenbosh 34.29%
Watsonia foureadei	0.241	0.012	83		Stellenbosh 32.5%		
Watsonia laccata	0.067	0.0034	297		Napier 100%		
Watsonia marginata	0.159	0.008	126		Stellenbosh 30.63%		
Watsonia marlothii	0.123	0.0062	163		Swatberg 26.88%		Swartberg south slope 1575m 90.63%; Swartberg north slope 1900m 76.25%
Watsonia meriana	0.043	0.0022	465			Somersetwest 93.13%	Somersetwest 35%
Watsonia schlechteri	0.11	0.0055	182			Baviaans rivier 97.33%	Bainskloof 52.5%; Swartberg south slope 1730m 81.88%; Swartberg north slope 1550m 92.5%; Perdaskop west slope 1200m 49.38%
Watsonia spectabilis	0.148	0.0074	135			Paarl mountain 51.25%	
Watsonia 'stanford scarlet'					unkown 16.67%		
Watsonia tabularis					Table Montain 25%	Table Montain 76.5%	
Watsonia 'Tresco Dwarf pink'							unkown 6.25%
Watsonia vanderspuyiae	0.294	0.0147	68			Cedarberg 83.5%	
Watsonia zeyheri	0.211	0.0106	95			Stellenbosch 15%	

3. 4 Discussion

3.4.1 Emergence of Mediterranean South African species from spring sowings

This research tested many species from both inland moutains and coastal areas to explore which species could germinate in spring sowing. When creating sown communities of South African species in practice sowing in spring is a desirable practice in climates which are potentially subject to temperatures that are lethal to the seedlings. Sowing in autumn exposes seedlings to a very high risk of overwintering mortality. Our initial assumption had been that if there were patterns in whether species were restricted to autumn germination only, these patterns would most likely be found in species found in areas subject to more unpredictable or lower rainfall. Similar results were gained from geophyte species with very high germination/emergence (>50%) from spring sowings in genotypes collected from coastal and “wet” mountainous areas with high annual precipitation, such as Cape Peninsula, Table Mountains, Noordaoek, Stellenbosch, Bot River, Caledon, Hermanus, Malmesbury and genotypes from drier more continental inland mountains.

Some of the species that could germinate in spring had lower emergence than in autumn, such as *Aristea confuse, Babiana angustifolia, Babiana villosa, Hesperantha vaginata, Ixia curvata, Moraea fugax.*

Evergreen species of *Aristea* showed high capacity of spring germination (all tested species >30%), even when the species were collected from Nieuwoudtville (Roggeveld-continental inland mountains) (*Aristea inequalis* 70.6%) and Cedarberg (Cedarberg & Clanwilliam-inland moutains) (*Aristea capitata (major)* 69.4%). This may due to their historical distributions were mainly along the west coast and southwest coastal regions, where even in summer rainfall occasionally occurs. Most shrub/forb species were able to emerge from spring sowings when previously subjected to smoke treatment. This treatment over-rode any obligate germination environment behavior related to seed provenance.

3.4.2 Sowing in autumn for Mediterranean SA species

As a general principle all species germinate reliably from autumn sowing so this is the preferred time to maximize emergence in sowings in the field, where winters are sufficiently mild not to risk winter kill of seedlings. Although the horticultural literature (Manning et al., 2002; Smale, 2006) suggests that winter growing and spring flowering geophytes have to be sown in September and October in the Northern Hemisphere to ensure germination, the experience in this research is that sowings can be later than this. Most *Babiana, Bulbinella, Freesia, Geissorhiza, Hesperantha, Ixia, Kniphofia, Lapeirousia, Moraea, Ornithogalum, Romulea, Sparaxis, Spiloxene, Tritonia, Tritoniopsis* and some *Gladiolus, Lachenalia, Watsonia* species were able to germinate during winter period. Species like *Romulea komsbergensis, Romulea sabulosa* and *Romulea eximia* in particular had the ability to emerge in high percentages when sown in the middle of November to middle December. .

Observation revealed that some species responded very differently when derived from different collection locations, for example, *Babiana ringens* from Stellenbosh germinated much later than other populations from elsewhere. *Gladiolus carneus* from Bot River germinated much earlier than the seeds from Paarl Mountain. *Lachenalia aloides* from Wolseley germinated much quicker than seeds from Stellenbosh. These types of variations in germination-emergence response are just an inevitable component of the high inherent genetic variability in wild collected seed.

The overall observation is that when sown in autumn, most South African species and in particular, geophytes have high to very high seedling emergence, making their establishment by field sowing in designed plantings an economically realistic proposal.

3.4.3 Seed dormancy and pre-sown treatment

Some of the seed accession did not germinate under both laboratory and field conditions, *Anisdontea anomala* for instance. This may because these species require certain cues to overcome dormancy before germination is possible. Most species remained viable after sowing for at least one year post sowing till the arrival of the next suitable season for germination. This was the case in the competition experiment (Chapter 5), for all the seeds of spot sown *Romulea komsbergensis*. Fresh seeds of *Gazania heterochaeta* collected in Sheffield from cultivated plants germinated poorly, suggesting a need for an after-ripening or dry storage period prior to germination. These requirements are relatively common in Mediterranean climate forbs and geophytes (Samarah et al., 2004).

In this experiment, smoke treatment successfully improved germination of some species. In natural conditions smoke caused by fynbos fires provide an important cue to promote seed germination, particularly in forbs and shrub species. Germination in these species in the study highly improved by smoke treatment. Species germination that not much improved by smoke treatment may because smoke was only one of the germination cues required (heat, temperatures patterns). Species did not germinate with or without smoke treatment (such as *Anisdontea anomala*, *Erica tumida,* and *Hermannia stricta* clearly required other cues for germination, or complex patterns of heat and smoke produced by a fire that could not be replicated by simple exposure to aqueous smoke compounds.

The seeds of most Cape species are not very long-lived and generally lose viability within a few years (Manning et al., 2002). Soft coated seed usually has shortest life span, while seed with hard and smooth coat usually have longest life span (Manning et al., 2002). Seeds of some *Arctotis campanuflora, Dimorphotheca tragus* were old seeds (>2 years old) from fridge storage, and showed no germination even under smoke treatment, may due to the short longevity of seeds.

3. 5 Conclusion

Following germination-emergent tests on more than 300 genotypes we can conclude the following;

- There were some signs that some winter growing and summer dormant geophyte species from coastal areas had a greater capacity to emerge from spring sowings in comparison with species from inland mountains. Overall however, the general pattern was for their to be no clear geographical pattern between seed provenance and capacity to emerge from spring sowings.

- Many species from *Aristea, Babiana, Geissorhiza, Gladiolus, Hesperantha, Ixia, Lachenalia, Moraea, Sparaxis*, *Romulea* and *Watsonia* can germinate in low winter temperatures even sown as late as November.

- Smoke treatment is effective on many forb and small shrub species from Fynbos and Renosterveld, but much less useful (or necessary) on geophyte species.

CHAPTER 4: EFFECT OF WINTER COLD AND SUMMER WETTNESS ON SOWN WESTERN CAPE SHRUB, FORB AND GEOPHYTE SPECIES

4.1 Introduction

The investigation described in this chapter was to test the range and pattern of variation in winter cold and summer wetness tolerance of species from South African (SA) winter rainfall regions, including shrubs, forbs, evergreen geophytes and summer dormant deciduous geophyte species. Most of the practical experience of growing Western Cape SA in cultivation in the UK has been undertaken in glasshouses where plants are not exposed to low winter temperatures and can be kept drier in summer. Since there is no extensive long term tradition of growing Western Cape out of doors in the UK, many of the amateur growers of these plants, and especially geophytes, have followed the advice of Duncan (2010) that many of these species are highly intolerant of winter cold and winter wet. The nature of these amateur growers-collectors is to cherish their plants and to avoid growing them in situations that might kill them. This is understandable, but has lead to a situation in which a realistic sense of how far Western Cape SA species can be “pushed” before they are damaged has advanced very little. There are however tantalizing contrary narratives in the horticultural literature. Doutt (1994) found that many low altitude SA geophytes tolerated -7^{o}C in California in 1990, and that a wide range of species including *Gladiolus* (particularly *G. tristis*, and *G. floribundus*), *Ixia*, and *Moraea* tolerated much colder temperatures when cultivated outdoors in Verdun in Eastern France.

The winter cold tolerance tests used in Sheffield aimed to provide a baseline for a wide range of species. Species from different geographical regions-provenances, with great contrasts in altitude and habitats in general, were tested to see whether their response to winter cold and summer wetness differed depending on collection locations, and also intrinsic tolerance levels of individual species and genera.

4.1.1 Objectives

Specific research questions associated with this experiment were:

To record the effect of winter cold and summer wetness on damage and mortality of individual species over winters and summers between November 2010 and September 2014, as affected by:

- degree of winter cold experienced
- degree of summer wetness experienced
- life form (summer dormant geophytes or evergreen forbs, shrubs and geophytes)
- collection location in terms of geography, altitude and habitat
- plant age
- spatial location within the experiments

The study generated a number of hypotheses to be tested;

- seedling mortality in test species would be greater when seedlings were uncovered in winter
- genotypes of species collected from colder, more inland and often high altitudes in Western SA would show reduced mortality in Sheffield in response to winter cold.
- summer uncovered (exposed to rainfall) summer deciduous geophytes and evergreen species would show greater mortility than covered plants.
- Species from heavier more moisture retentive soils (shale derived clays in Rennosterveld), or regions with the highest summer rainfall regions, or finally from wet habitats would show the lowest mortality in response to wet summers in Britain.
- older plants would show reduced mortality in response to winter cold than seedlings and young plants

In addition to allowing the testing of these hypotheses, the work also had more prosaic functions; specifically to familiarize the author with the diversity of the flora in question, and to furnish a design platte of relatively cold and wet tolerant plants of western SA for the major competition experiment in the PhD. Any genotypes that survived the study would become available for landscape use and provide a platform for future research into SA Medditeanean planting communities.

4.2 Methodology

Wild collected seeds of these species were purchased from Silverhill Seeds, Cape Town, the main supplier of SA species to researchers, restoration ecology practitioners and amateur gardeners. They also provided us with the approximate location of each collection, as many species have very wide geographical and altitudinal ranges. The experiment site was established in autumn 2011 at a site in Sheffield Botanical Gardens (53°38'N, 1°49'W, altitude 115m) in Northern England to undertaken various Winter Cold Tolerance and Summer Wetness Tolerance tests. In addition to evaluating the cold and wet tolerance of these species, the work allowed for much data to be collected on comparative phenology (see Chapter 7 for Phenology of foliage senescence).

4.2.1 Winter Cold Tolerance Experiment

The site was cleared in mid-October 2011, and materials were ordered. Rough sawn tanalised timber (100 x 25mm) was used to form the margins of the 1.6 x 1.6m treatment blocks that made up the experimental block design (see Figure 4.1). The same material (50 x 25mm) was used to manufacture mobile frames to both moderate the severity of temperatures experienced and also create summer dryness. Bubble wrap fabric and corrugated plastic roofing sheets were purchased to complete the insulated transparent “screens” for winter protection and summer shelter. The experiment was designed as a randomised block experiment with two treatments, involving four replicates of each treatment with a split-pot design in order to minimise the thermal effects of the neighbouring hedge. Each block was coded from B1 to B8. Half of the eight blocks were covered by the insulated transparent "screens" when a frost of -1^{o}C or colder was predicted for the Weston Park Weather station 2km distant. These were removed as soon as the prediction of frost terminated. This was undertaken to provide two temperature steps, to provide a more nuanced understanding of response to winter cold. The other four plots were exposed to the environment without any protection. Seedlings in the experiment were grown in standardised 7x7 cm pots, and separated from other pots by a backfill of the same compost. Each block (1.6 x1.6m) contains a standard layout of 15 x15 pots separated by 30mm of compost (see Fig.4.1-4.2). This was undertaken so as not to expose the root mass contained within the pots to the rapid fluctuations in temperature of uninsulated pots on cold radiation nights, and hence to provide a more accurate picture of how SA species growing in soil might actually respond. Because of pot capacity issues in relation to oxygen levels, a freely drained compost was used in the pots, however given its dominance by granitic materials it had less thermal buffering capacity than typical soil. Research by Sayuti (2013) found that mortality of Eastern African geophytes was much reduced in soil-like, as opposed to grantic sand mineral composts due to much more severe sub surface temperatures in the latter.

In the three years prior to autumn 2011, a wide range of species (150+) had been germinated in 7cm pots in preliminary studies. These seedlings ranged in age from 0 to 3 years old, and are listed in Table 4.1. At the time of commencement of the experiment in December 2011, seeds sown in September 2011 were regarded as 0-year old seedlings; seeds sown in spring 2011 were regarded as 0.5-year old seedlings; seeds sown in autumn 2010 were regarded as 1 year old seedlings; seeds sown in spring 2010, autumn 2009, spring 2009 and autumn 2008 were regarded as 1.5 years old, 2 years old, 2.5 years old and 3 years old plants. Species didn't germinate in spring sowing 2011 while germinated in autumn 2011 were treated as 0-year old seedlings, and grouped together with the new sowing in autumn 2011. In cases of pots containing seeds that partly germinated in spring 2011 and partly germinated in autumn 2011, they were ascribed to mixed ages of 0-0.5 year. The analysis of effect of age was based on these groups.

These seedlings were coded and transferred into each treatment block. The rest of the pots transferred into the experiment consisted of newly sown species in various stages of germination, see Table 4.1.

Species for which 8 pots of seedlings were available (all of the recently sown pots) were present in both covered and uncovered winter cold treatment blocks. Species with only 5-7 pots were allocated preferentially to the four winter uncovered treatments, with the remaineder allocated to the winter covered treatment. Species with four or less pots were used in winter uncovered treatment only.

Table 4.1 Degree of maturity-age of species used in the hardiness study

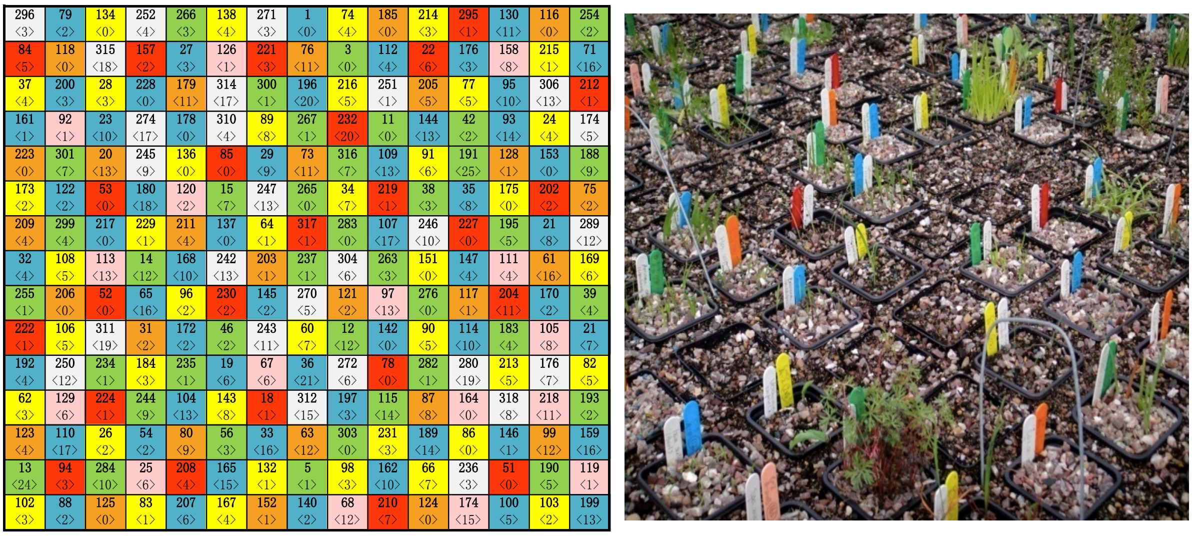
Species Name	Phase One						Phase Two
	3 year seedling	2 year seedling	1.5 year seedling	1 year seedling	0.5 year seedling	autumn 2011 germinated seedling	autumn 2012 germinated seedling
Albuca clanwilliamgloria						X	
Aloinopsis spathulata					X	X	
Amaryllis belladonna			X				
Arctotis acaulos						X	
Arctotis adpressa					X	X	
Arctotis campanuflora (diffusa)						X	
Arctotis gumbletonii						X	
Aristea capitata(major)					X	X	
Aristea confusa					X	X	
Aristea inequalis					X		
Aristea spp.							X
Babiana ambigua				X		X	
Babiana angustifolia					X	X	
Babiana cuneata				X		X	
Babiana dregei							X
Babiana fragrans			X		X	X	
Babiana melaops							X
Babiana ringens				X	X		
Babiana sambucifolia			X				
Babiana thunbergii				X	X	X	
Babiana vanzyliae		X		X		X	
Babiana villosa			X		X	X	
Brynsvigia bosmaniae			X		X		
Bulbinella caudis-felis				X			
Bulbinella eburnifolia				X			X
Bulbinella elata		X				X	
Bulbinella elegans		X		X	X	X	X
Bulbinella latifolia var latifolia		X		X	X	X	
Bulbinella nutans		X		X			X
Bulbinella nutans var. turfosicola							X
Crassula dejecta					X		
Crotalarca humclis							X
Daubenya aurea			X	X	X		
Dimorphotheca cuneata (orange)					X	X	
Dimorphotheca cuneata (white)					X	X	
Dimorphotheca nudicaulis					X	X	X
Dimorphotheca tragus						X	
Dimorphotheca tugax					X		

Species Name	Phase One						Phase Two
	3 year seedling	2 year seedling	1.5 year seedling	1 year seedling	0.5 year seedling	autumn 2011 germinated seedling	autumn 2012 germinated seedling
Erica tumida							X
Esterhuysenia alpina							X
Felicia filifolia							X
Freesia caryophyllacea				X			
Freesia corymbosa				X			
Freesia fergusoniae				X			
Freesia furcata						X	
Gazania heterochaeta						X	
Gazania krebsiana (orange)					X	X	
Gazania leipoldtii							X
Gazania othonites							X
Gazania pectinata						X	
Gazania rigida							X
Geissorhiza aspera		X			X		
Geissorhiza inflexa (red)			X		X		
Geissorhiza splendidissima		X				X	
Geissorhiza tulbaghensis		X			X	X	
Geranium incanum					X		
Gladiolus cardinalis						X	X
Gladiolus carinatus				X			
Gladiolus carneus		X			X		
Gladiolus carneus var. macowan			X				
Gladiolus caryophyllaceus				X		X	
Gladiolus equitans							X
Gladiolus floribundus						X	
Gladiolus floribundus var floribundus					X		
Gladiolus floribundus var rudis		X					
Gladiolus hirsutis			X				
Gladiolus maculatus				X			
Gladiolus marlothii				X			
Gladiolus miniatus			X		X	X	
Gladiolus saccatus						X	
Gladiolus splendens	X						X
Gladiolus tristis		X					
Gladiolus undulatus		X					
Gladiolus venustus					X	X	
Haemantitus cocccineus			X				
Heamatus sagciineus				X			
Hermannia stricta							X
Hesperantha cucullatus						X	
Hesperantha humilis				X			
Hesperantha luticola						X	
Hesperantha pauciflora		X			X	X	
Hesperantha vaginata		X			X	X	
Heterolepis aliena					X		
Ixia curvata			X			X	X
Ixia latifolia					X	X	
Ixia maculata		X				X	
Ixia rapunculoides		X				X	
Ixia scilliaris					X	X	
Ixia thomasiae					X	X	X
Kniphofia sarmentosa						X	
Kniphofia uvaria						X	
Lachenalia aloides					X		
Lachenalia bulbifera					X	X	
Lachenalia carnosa					X	X	
Lachenalia contaminata					X		
Lachenalia mutabilis						X	
Lachenalia orchioides var. glaucina					X		
Lachenalia pallida					X		
Lachenalia purpureo-caerulea					X		
Lachenalia rubida					X	X	
Lachenalia viridiflora					X		

Species Name	Phase One						Phase Two
	3 year seedling	2 year seedling	1.5 year seedling	1 year seedling	0.5 year seedling	autumn 2011 germinated seedling	autumn 2012 germinated seedling
Lapeirousia azurea					X	X	
Lapeirousia oreogena							X
Lapeirousia silenoides				X	X		
Lessertia frutescens							X
Lessertia rigida							X
Leucadendron album							X
Leucadendron spissifolium spp. Fragrans							X
Moraea angusta			X				
Moraea bifida				X		X	
Moraea bipartita			X	X		X	
Moraea fugax			X			X	
Moraea gigandra				X			
Moraea macronyx				X			
Moraea pendula			X				
Moraea pritzeliana			X			X	
Moraea ramossisima		X				X	
Moraea tripetala			X	X		X	
Moraea tulbaghensis						X	
Moraea villosa						X	
Onoxiotis stricta				X			
Ornithogalum corticatum							X
Ornithogalum thyrsoides			X		X		
Podalyria leipoldtii						X	
Romulea amoena				X			
Romulea atrandra				X		X	
Romulea komsbergensis				X			X
Romulea monadelpha							X
Romulea sabulosa				X			
Romulea subtistulosa							X
Ruschia spp.							X
Scabiosa africana					X	X	
sparaxis elegans				X	X	X	
Sparaxis grandiflora ssp acuticoba		X				X	
Sparaxis grandiflora ssp violaceae						X	
Sparaxis maculosa					X	X	
Sparaxis meterlekampiae					X	X	
Sparaxis tricolor						X	
Spiloxene capensis						X	
Spiloxene spp. (orange)		X				X	
Spiloxene spp. (yellow)		X					
Stachys rugosa							X
Syncarpha vestita						X	X
Tripteris oppositifolia						X	X
Tritonia deusta			X		X	X	X
Tritonia pallida			X				
Tritoniopsis spp							X
Tritoniopsis triticea						X	X
Ursina sericea					X	X	
Ursinia spp.							X
Veltheimia capensis		X					
Wachendorfia paniculata						X	
Watsonia aletroides					X	X	
Watsonia borbonica		X			X	X	X
Watsonia foureadei					X	X	
Watsonia laccata			X				
Watsonia marginata					X	X	
Watsonia marlothii					X		X
Watsonia meriana						X	
Watsonia schlechteri						X	X
Watsonia spectabilis						X	
Watsonia 'stanford scarlet'					X		
Watsonia tabularis					X	X	
Watsonia Tresco Dwarf pink							X
Watsonia vanderspuyiae						X	
Watsonia zeyheri						X	X

All experimental pots were then baited with metaldehyde containing pellets to reduce the impact of possible slug predation on mortality assessments. The standard substrate used in all pots was a grit (40%) sand (40%) peat compost (B&Q) (20%).

Fig.4.1 Block arrangement showing the distribution of the two treatments of the experiment. To allow for the expected temperature gradient as a result of the evergreen hedge (photo taken by Ye Hang).



296 〈3〉	79 〈2〉	134 〈0〉	252 〈4〉	266 〈3〉	138 〈4〉	271 〈3〉	1 〈0〉	74 〈4〉	185 〈0〉	214 〈3〉	295 〈1〉	130 〈11〉	116 〈0〉	254 〈2〉
84 〈5〉	118 〈0〉	315 〈18〉	157 〈2〉	27 〈3〉	126 〈1〉	221 〈3〉	76 〈11〉	3 〈0〉	112 〈4〉	22 〈6〉	176 〈3〉	158 〈8〉	215 〈1〉	71 〈16〉
37 〈4〉	200 〈3〉	28 〈3〉	228 〈0〉	179 〈11〉	314 〈17〉	300 〈1〉	196 〈20〉	216 〈5〉	251 〈1〉	205 〈5〉	77 〈5〉	95 〈10〉	306 〈13〉	212 〈1〉
161 〈1〉	92 〈1〉	23 〈10〉	274 〈17〉	178 〈0〉	310 〈4〉	89 〈8〉	267 〈1〉	232 〈20〉	11 〈0〉	144 〈13〉	42 〈2〉	93 〈14〉	24 〈4〉	174 〈5〉
223 〈0〉	301 〈7〉	20 〈13〉	245 〈9〉	136 〈0〉	85 〈0〉	29 〈9〉	73 〈11〉	316 〈7〉	109 〈13〉	91 〈6〉	191 〈25〉	128 〈1〉	153 〈0〉	188 〈9〉
173 〈2〉	122 〈2〉	53 〈0〉	180 〈18〉	120 〈2〉	15 〈7〉	247 〈13〉	265 〈0〉	34 〈7〉	219 〈1〉	38 〈3〉	35 〈8〉	175 〈0〉	202 〈2〉	75 〈2〉
209 〈4〉	299 〈4〉	217 〈0〉	229 〈1〉	211 〈4〉	137 〈0〉	64 〈1〉	317 〈1〉	283 〈0〉	107 〈17〉	246 〈10〉	227 〈0〉	195 〈5〉	21 〈8〉	289 〈12〉
32 〈4〉	108 〈5〉	113 〈13〉	14 〈12〉	168 〈10〉	242 〈13〉	203 〈1〉	237 〈1〉	304 〈6〉	263 〈3〉	151 〈0〉	147 〈4〉	111 〈4〉	61 〈16〉	169 〈6〉
255 〈1〉	206 〈0〉	52 〈0〉	65 〈16〉	96 〈2〉	230 〈2〉	145 〈2〉	270 〈5〉	121 〈2〉	97 〈13〉	276 〈0〉	117 〈1〉	204 〈11〉	170 〈2〉	39 〈4〉
222 〈1〉	106 〈5〉	311 〈19〉	31 〈2〉	172 〈2〉	46 〈2〉	243 〈11〉	60 〈7〉	12 〈12〉	142 〈0〉	90 〈5〉	114 〈10〉	183 〈4〉	105 〈8〉	21 〈7〉
192 〈4〉	250 〈12〉	234 〈1〉	184 〈3〉	235 〈1〉	19 〈6〉	67 〈6〉	36 〈21〉	272 〈6〉	78 〈0〉	282 〈1〉	280 〈19〉	213 〈5〉	176 〈7〉	82 〈5〉
62 〈3〉	129 〈6〉	224 〈1〉	244 〈9〉	104 〈13〉	143 〈8〉	18 〈1〉	312 〈15〉	197 〈3〉	115 〈14〉	87 〈8〉	164 〈0〉	318 〈8〉	218 〈11〉	193 〈2〉
123 〈4〉	110 〈17〉	26 〈2〉	54 〈2〉	80 〈9〉	56 〈3〉	33 〈16〉	63 〈12〉	303 〈0〉	231 〈3〉	189 〈14〉	86 〈0〉	146 〈1〉	99 〈12〉	159 〈16〉
13 〈24〉	94 〈3〉	284 〈10〉	25 〈6〉	208 〈4〉	165 〈15〉	132 〈1〉	5 〈1〉	98 〈3〉	162 〈10〉	66 〈7〉	236 〈3〉	51 〈0〉	190 〈5〉	119 〈1〉
102 〈3〉	88 〈2〉	125 〈0〉	83 〈1〉	207 〈6〉	167 〈4〉	152 〈1〉	140 〈2〉	68 〈12〉	210 〈7〉	124 〈0〉	174 〈15〉	100 〈5〉	103 〈2〉	199 〈13〉

a) b)

Fig.4.2 a) A sample of detailed layout with randomized pots within each treatment block. Different colours indicate different life forms and seedling ages; figures in bold indicate spcies code; figures in brackets indicate number of seedlings in unit pot. b) seedlings in pots on site in each treatment block (photo taken by Ye Hang).

Each pot was ascribed a reference colour coded label, which represented its plant type and age group. Once set up of the experiment was completed in November 2011. There was substantial variation in terms of which species were in leaf or not. Some of the transplanted corms had produced foliage, others had not. This was also the case with the seedlings that had been sown early in autumn 2011. Every pot was counted monthly from middle December 2011 to March 2013 to record how many seedlings were present as plants in leaf.

Rainfall that fell on the four covered plots during periods of low temperature was estimated by 8 tin cans distributed through the experiemnt and applied weekly as irrigation to these four treatment blocks to ensure the less cold plots were of equivalent wetness. A layer of horticultural fleece was used to cover the crowns of seedlings under screens, when air temperatures were predicted to drop to -5℃ to apply extra protection. The exposed treatment with another four blocks was fully exposed even under extraordinary weather conditions such as extremely heavy rainfall or strong wind.

Temperatures at approximately 1cm above the pots and in the centre of the pots were monitored throughout the experiment every half-hour via “Tinytag Plus 2” temperature data loggers to provide a climatic database against which to interpret seedling response to winter cold. Data was downloaded to a laptop with windows program via a USB cable to the Tinytag Explorer software. Two of the winter uncovered treatment and winter covered treatment block, were monitored using Tiny Tag thermistor probes, with one in the center of these treatment block and the other at the edge (200 mm from the block boarder). The concentric arrangement of pots of seedlings within each block was coded from R1 to R7, representing the seven concentric rings of seedlings around the central pot (0) which did not contain seedlings. This approached allowed analysis to explore the effect of geographical position within the raised mass of pots and substrate aross the treatment block on response to cold. One thermistor lay on the surface (one centre (R=0), and one edge (R=7), and one was buried 5cm below the soil surface (one centre, one edge), allowing comparison of minimum temperatures experienced at the interface of shoots with the ground surface and also within the substrate where there corm/bulb structures sat.

Fig.4.3 (left) Screens in place on nights when a frost was forecast; (right) Temperature measurements were recorded by Tinytag data loggers. (photo taken by Ye Hang)

Weeds were removed throughout the study as they appeared. Small weeds were pulled out by eyebrow forceps, while well established ones were cut off at the base just below soil surface. Slug pellets were applied weekly to avoid seedling losses through predation. Leaf cutting of the growth of neibouring plants was used to minimise shading interference during the study. The experimental blocks were covered by wire mesh to prevent fox and squirrel digging.

4.2.1.1 Winter Cold Tolerance Experiment Phase One (winter 2011-2012)

Tolerance of winter cold was assessed through seedling survival, with a count of seedlings in each pot prior to the first frost encountered in December 2011, with subsequent monthly counts to assess mortality. For shrubs, forb, succulents and evergreen geophytes, counts in March 2012 were converted into % in mortality by expressing number of seedlings at this time as a percentage of the maximum number of seedlings present during the previous four months. With winter growing, summer dormant geophyte species, seedlings whose foliage was entirely green and turgid looking, or only showed signs of yellowing at the tip were scored as being alive. Plants whose foliage was no longer turgid or in various stages of necrosis were scored as undetermined in March 2012. Geophytes are difficult to assess without removing the compost from around the roots, as previous experience (Hitchmough and Cummins, 2011) had shown that it is almost impossible to distinguish between undamaged seedlings that are senescing as they enter spring dormany and plants in which the corm or bulb has been killed by cold. The final counting of winter survival of these group of geophyte species was carried out in their next growing season (September 2012-April 2013) post bulb/corm reshooting. In order to maximize the value of this very large and logistically complex experiment, and specifically to shed light on response to summer wetness, in late spring 2012, blocks that were uncovered in winter were covered with screens to exclude summer rainfall in accordance with the protocols shown graphically in Fig. 4.4).

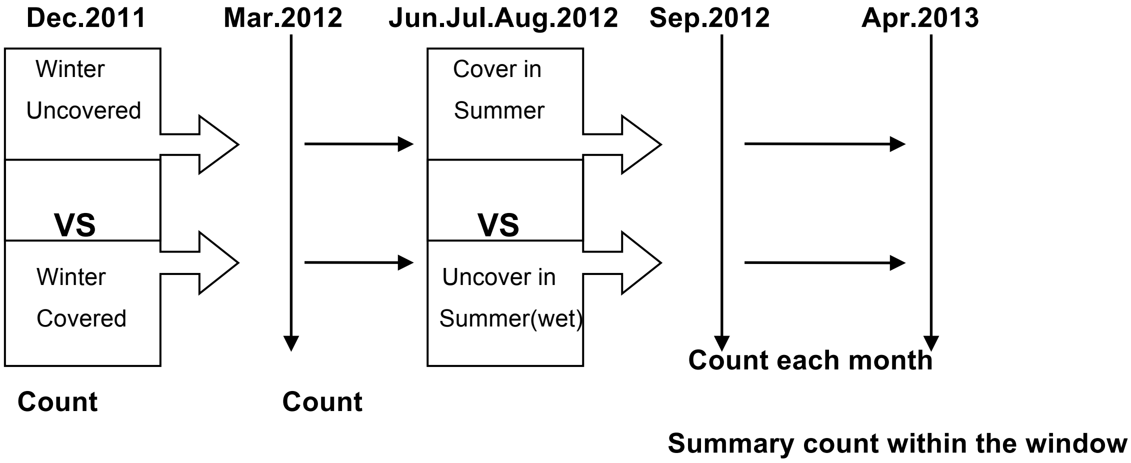


Fig. 4.4 Timing of counts in the experimental process in terms of assessing Phase 1 Winter Cold and Summer Wetness Tolerance Test.

At the end of this time period counts were compared with maximimum count numbers and then converted to percentage mortality values for analysis.

To compare the effect of origins of the genotpyes used in this study to their capacity species to tolerate winter cold an analysis was made that focused on the scale of the geographical region, for example, Stellenbosch to Hermanus (coastal mountain to coast, and more detailed provenance data when this was available, in conjunction with an estimate the cold experienced in the habitat, as shown in Table 4.2. Data on degree of cold experienced in the habitat was derived from Mucina and Rutherford (2006), a GIS based ordination of the South African flora. The provenance of each genotype was related back to the specific bio-region type (46 in total related to test specie) of Mucina and Rutherford (2006). This involved locating the collection locations on the GIS maps, and factoring in approximate altitudes, and then using the mean frost days data modeled from meteorological data in Mucina and Rutherford (number of days when ambient temperature was below 0℃) to calculate frost day values for that genotype. The estimated frost days of each tested genotype was calculated from the following equation:

$$\frac{\text{Mean altitude of collection location of a single species b (m)}}{\text{Altitude of bio-region a (m)}} \times \text{mean frost days (n) days} = \text{estimate frost days (n')}$$

When data on the origins of a genotype was too vague to ascribe to a specific bio-region, mean frost days were calculated for an appropriate altitudinal range for all bioregions in which this species is know to occur and then averaged to give a value for use in calculation.

Expressed as an equation:

$$\text{Calculated Mean Frost days for region} \quad \frac{a+b+c+\ldots+z}{n} = \text{Calculated Frost Days}$$

(where bioregions >1, bioregion a-z, correct to 1 decimal)

4.2.1.2 Winter Cold Tolerance Experiment Phase Two (winter 2013-2014)

The process of data collection for winter cold and summer wetness in this time period is illustrated in Fig. 4.5) and replicates that undertaken in phase 1.

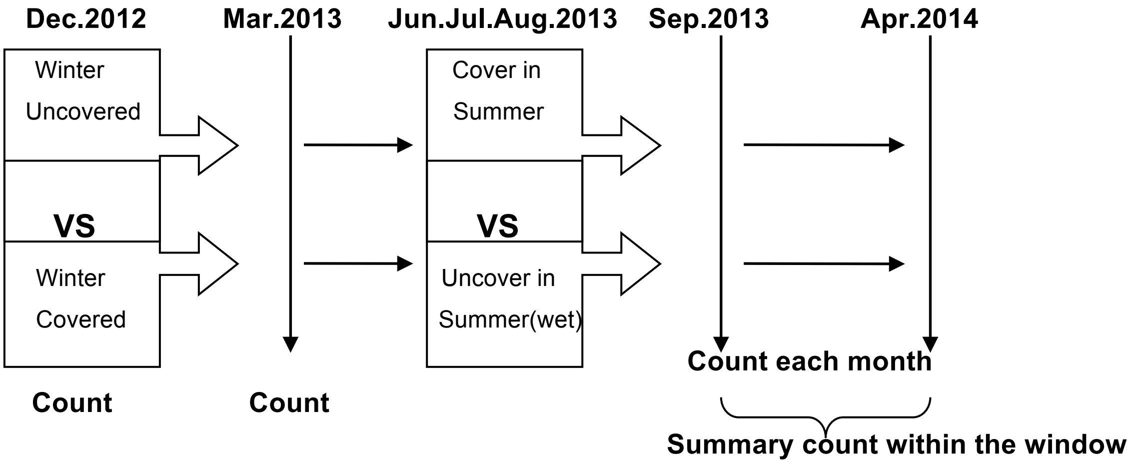


Fig.4.5 Timing of counts in the experimental process in terms of assessing Phase 2 Winter Cold and Summer Wetness Tolerance Test.

Table 4.2 Estimated frost days (final column) for each genotype in the winter cold hardiness experiment. (Data derived from Mucina and Rutherford, 2006)

	Provenance	"Bio-region type" code	Altitute of Bio-region	Relative habitat coldness as mean days p.a. with frost	South Africa "Bio-region type"	Mean average precipitation (mm)	Altitute of collection location (m)	Species	Estimated frost days	Average of estimated frost days
	Cape Peninsula									
2	Scarborough	FFg3 (p.168)	0-450	2-3 d	Granite Fynbos	960	40-260	Babiana ambigua	2-2.5d	2.25d
								Dimorphotheca nudicaulis	2-2.5d	2.25d
3	Noordaoek	FFs9 (p.107)	20-1086	2-3 d	Sandstone Fynbos	780	150-400	Gladiolus angustus	2-2.5d	2.25d
								Gladiolus carneus	2-2.5d	2.25d
1	Cape Peninsula (no specific location)	FFs9 (p.107)	20-1086	2-3 d	Sandstone Fynbos	780	20-1086	Babiana ambigua	2-3d	2.5d
								Geissorhiza aspera	2-3d	2.5d
								Lachenalia orchioides var. glaucina	2-3d	2.5d
								Scabiosa africana	2-3d	2.5d
								Spiloxene capensis	2-3d	2.5d
								Watsonia borbonica	2-3d	2.5d
4	Table Mountain	FFs9 (p.107)	20-1086	2-3 d	Sandstone Fynbos	780	400	Aristea capitata(=A.major)	2.5d	2.5d
							200-1086	Crassula coccinea	2-3d	2.5d
								Ornithogalum thyrsoides	2-3d	2.5d
							1000	Bulbinella nutans var. turfosicola	3d	3d
								Watsonia tabularis	3d	3d
	Stellenbosch to Hermanus (coastal mountain to coast)									
8	Bot River	FFs11(p.109)	20-1590	2-3 d	Sandstone Fynbos	1330	100-500	Gladiolus carneus	2.1-2.4d	2.25d
								Gladiolus floribundus var. floribundus	2.1-2.4d	2.25d
								Roella ciliata	2.1-2.5d	2.26d
5	Stellenbosch	FFg2(p.167)/ FFh5(p.149)/ FFs11(p.109)	150-650 0-700 20-1590	2-3 d 2-3 d 2-3 d	Granite Fynbos/ Shale Fynbos/ Sandstone Fynbos	985 865 1330	100-600	Aristea bakeri(=A.confusa, A. macrocarpa)	2-2.7d	2.35d
								Babiana fragrans	2-2.7d	2.35d
								Babiana ringens	2-2.7d	2.35d
								Babiana sambucifolia	2-2.7d	2.35d
								Crassula perfoliata var. minor	2-2.7d	2.35d
								Freesia caryophyllacea	2-2.7d	2.35d
								Freesia fergusoniae	2-2.7d	2.35d
								Gladiolus carneus var. macowan	2-2.7d	2.35d
								Gladiolus maculatus	2-2.7d	2.35d
								Lachenalia aloides	2-2.7d	2.35d
								Watsonia borbonica	2-2.7d	2.35d
								Watsonia fourcadei	2-2.7d	2.35d
								Watsonia marginata	2-2.7d	2.35d
								Watsonia zeyheri	2-2.7d	2.35d
57	Franschhoek	FFg2(p.167)/	150-850	2-3 d	Boland Granite Fynbos	985	850	Ruschia spp.	3d	3d
7	Villiersdorp	FFh6 (p.150)	200-450	2-3 d	Shale Fynbos	830	200-450	Freesia fucata	2-3d	2.5d
9	Caledon	FRs11(p.184)	60-450	3d	Shale Renosterveld	490	100-400	Watsonia aletroides	3d	3d
11	Hermanus	FFb2(p.155)	50-1800	2-10 d	Coastal Shale Band Vegetation	1070	100-500	Gladiolus miniatus	2.2-4.1d	3.15d
								Moraea angusta	2.2-4.1d	3.15d
								Sparaxis grandiflora ssp violaceae	2.2-4.1d	3.15d
10	Betty's Bay	FFb2(p.155)	50-1800	2-10 d	Coastal Shale Band Vegetation	1070	50-900	Moraea ramosissima	2-5d	3.5d
6	Somerset West	FRs9 (p.181)	50-350	3-4 d	Shale Renosterveld	430	100-350	Berkheya herbacea	3.2-4d	3.6d
								Onixotis stricta	3.2-4d	3.6d
								Watsonia meriana	3.2-4d	3.6d
55	Perdaskop	FFs10(p.108)	250-1800	3-20d	Sandstone Fynbos	1200	1200	Watsonia borbonica	13.4d	13.4d
							800-900	Aristea spp.	9.6d	9.6d
							940	Aristea spp.	10.6d	10.7d
							1200/1250	Aristea spp.	13.4d	13.4d
							800	Peucedanum spp.	9.6d	9.6d
							1200	Watsonia schlecteri	13.4d	13.4d
							1500	Wachendorfia paniculata	16.7d	16.7d
							1200	Heterolepis aliena	13.4d	13.4d
	Swartland (lower altitude to inland mountains)									
20	Gouda	FFa3(p.164)/ FRs9(p.181)	60-250/ 50-350	0d/ 3-4d	Alluvium Fynbos/Shale Renosterveld	655	100-200	Arctotis acaulos	1.6-1.8d	1.7d
						430		Moraea tulbagensis	1.6-1.8d	1.7d
17	Wolseley	FFa2(p.163)/ FRs8 (p.180)	200-350/ 100-650	0d/ 3-8d	Alluvium Fynbos/Shale Renosterveld	480 370	200-300	Lachenalia aloides	2-2.4d	2.2d
12	Paarl mt	FFg2(p.167)	150-650	2-3 d	Granite Fynbos	985	150-500	Ixia scillaris	2-2.7d	2.35d
								Watsonia spectabilis	2-2.7d	2.35d
13	Malmesbury	FRg2(p.190)	50-350	3d	Granite Renosterveld	520	100-200	Geissorhiza aspera	3d	3d
								Ixia maculata	3d	3d
								Lapeirousia azurea	3d	3d
							200-400	Lachenalia contaminata	3d	3d
								Lachenalia pallida	3d	3d
								Lapeirousia azurea	3d	3d
							250-500	Babiana angustifolia	3d	3d
21	Piketberg	FFs6 (p.104)	100-1458	2-4d	Sandstone Fynbos	510	800-1000	Moraea gigandra	3-3.3d	3.15d
								Tritoniopsis triticea	3-3.3d	3.15d
19	Tulbagh	FRs8 (p.180)	100-650	3-8d	Shale Renosterveld	370	100-200	Babiana melanops	3-3.9d	3.45d
								Babiana villosa	3-3.9d	3.45d
								Geissorhiza inflexa (red)	3-3.9d	3.45d
								Geissorhiza tulbaghensis	3-3.9d	3.45d
								Lachenalia aloides	3-3.9d	3.45d
								Romulea eximia	3-3.9d	3.45d

	Provenance	"Bio-region type" code	Altitute of Bio-region	Relative habitat coldness as mean days p.a. with frost	South Africa "Bio-region type"	Mean average precipitation (mm)	Altitute of collection location (m)	Species	Estimated frost days	Average of estimated frost days
14	Bainskloof	FFs10(p.108)	250-1800	3-20d	Sandstone Fynbos	1200	300-600	Babiana fragrans	3.6-6.8d	5.2d
								Crassula dejecta	3.6-6.8d	5.2d
								Gladiolus hirsutus (= G.punctulatus)	3.6-6.8d	5.2d
								Gladiolus undulatus	3.6-6.8d	5.2d
								Lapeirousia neglecta	3.6-6.8d	5.2d
							500-1000	Moraea ramosissima	5.7-11.2d	8.45d
							800	Bulbinella elata	9d	9d
							1700	Watsonia schlecteri	18.9d	18.9d
15	Hex river Mountains	FFs8(p.106)/ FFs7(p.105)/ FFb1(p.154)	400-1800/ 500-1800/ 400-1650	10-30d/ 10-50d/ 10-30d/	Sandstone Fynbos/Shale Band Vegetation	955 750 590	1000	Euryops othonoides	22.9d	22.9d
18	Ceres	FRs4 (p.177)	500-1300	10-40d	Shale Renosterveld	430	800-900	Ixia latifolia	21.3-25d	23.15d
52	Kovebekkeveld (Prince Albert Hamlet)	FRs4 (p.177)	500-1300	10-40d	Shale Renosterveld	430	1000	Kniphofia uvaria	28.8d	28.8d
								Wachendorfia paniculata	28.8d	28.8d
58	Cold Bokkeveld	FRs4 (p.177)	500-1300	10-40d	Shale Renosterveld	430	1050	Tritoniopsis spp	30.6d	30.6d
16	Matroosberg	FFs30(p.127)	1800-2250	65-74d	Shale Renosterveld	1385	1799	Erica tumida	65d	65d
							1900	Esterhuysenia alpina	67d	67d
							1913	Erica tumida	67.5d	67.5d
							1925	Gladiolus cardinalis	67.5d	67.5d
							1670	Tritoniopsis spp	65d	65d
	West coast (coastal plain)									
22	West coast	FS2 (p.199)	0-180	0d	Granite Strandveld	north 250 south 350	0-100	Babiana thunbergii	0d	0d
								Lachenalia bulbifera	0d	0d
							100	Moraea angusta	0d	0d
	Cedarberg & Clanwilliam (inland mountains)									
25	Clanwilliam	FFd2 (p.137) FFs2 (p.100)	50-350 100-650	3-4d 3-4d	Sand Fynbos Sandstone Fynbos	260 355	300-600	Albuca clanwilliamgloria	3.6-4d	3.8d
								Gladiolus venustus	3.6-4d	3.8d
								Ornithogalum maculatum	3.6-4d	3.8d
								Podalyria leipoldtii	3.6-4d	3.8d
								Sparaxis meterlekampiae	3.6-4d	3.8d
23	Citrusdal	FFs3 (p.100)/ SKk7 (p.275)	200-1200/ 180-700	3-10d/ 3-5d	Fynbos/ Vygieveld	450 316	600-800	Sparaxis grandiflora ssp acuticoba	5.2-6.3d	5.75d
								Gladiolus brevifolius	5.2-6.3d	5.75d
27	Gifberg	FFs1(p.99)	200-1000	3-10d	Sandstone Fynbos	290	1000	Aristea inequalis	10d	10d
26	Pakhuis Pass	FFs4 (p.101)	300-1800	3-30d	Sandstone Fynbos	395	800-1000	Arctotis gumbletonii	12-15.6d	13.8d
								Bulbinella elata	12-15.6d	13.8d
24	Cedarberg	FFs4 (p.101)	300-1800	3-30d	Sandstone Fynbos	395	1000-1500	Aristea capitata(=A.major)	15.6-24.6d	20.1d
								Bulbinella caudis-felis	15.6-24.6d	20.1d
								Heterolepis aliena	15.6-24.6d	20.1d
								Ursinia sericea	15.6-24.7d	20.2d
								Watsonia vanderspuyiae	15.6-24.6d	20.1d
	Namaqualand (coastal plain to inland mountains)									
30	Spoegrivier Namaqualand	SKn1 (p.251)	120-1260	8d	Klipkoppe Shrubland	160	200-300	Lapeirousia silenoides	8d	8d
33	Namaqualand	SKn1 (p.251)	120-1260	8d	Klipkoppe Shrubland	160	1000-1200	Arctotis gumbletonii	8d	8d
								Dimorphotheca cuneata orange	8d	8d
							600-700	Dimorphotheca tugax	8d	8d
								Dimorphotheca tragus	8d	8d
							1000-1200	Gazania krebsiana (orange)	8d	8d
								Lachenalia carnosa	8d	8d
								Lachenalia violacea	8d	8d
34	Springbok	SKn1(p.251)	120-1260	8d	Klipkoppe Shrubland	160	1300	Tripteris oppositifolia	8d	8d
29	Garies	SKn3 (p.255)	460-1080	13d	Blomveld	145	800	Arctotis campanuflora (=A.diffusa)	13d	13d
							200-300	Gazania heterochaeta	13d	13d
32	Kamiesberg (Kamieskroon)	FRg1 (p.189)	1100-1450	10-30d	Granite & Dolerite Renosterveld	235	1000-1200	Arctotis campanuflora (=A.diffusa)	10-15.7d	12.85d
								Arctotis spp.	10-15.7d	12.85d
								Brunsvigia bosmaniae	10-15.7d	12.85d
								Bulbinella latifolia var. latifolia	10-15.7d	12.85d
								Dimorphotheca cuneata orange	10-15.7d	12.85d
								Gazania leipoldtii	10-15.7d	12.85d
								Gazania pectinata	10-15.7d	12.85d
								Gladiolus equitans	10-15.7d	12.85d
								Lessertia frutescens	10-15.7d	12.85d
								Moraea pendula	10-15.7d	12.85d
								Ornithogalum multiflorum	10-15.7d	12.85d
								Spiloxene spp. (orange, yellow)	10-15.7d	12.85d
								Veltheimia capensis	10-15.7d	12.85d
							1100-1300	Babiana dregei	10-21.4d	15.7d
31	Leliefontein	FRg1(p.189)	1100-1450	10-30d	Granite Renosterveld	235	1300-1400	Gladiolus equitans	21.4-27.1d	24.25d
	Roggeveld (continental inland mountains)									
42	Tanqua Karoo	SKv5 (p.284)	240-960	15d	Tanqua Karoo	40-112	900	Moraea speciosa	15d	15d
28	Nieuwoudtville	FRd1(p.192)	740-1500	10-50d	Dolerite Renosterveld	290	800-1000	Anisdontea anomala	13.2-23.7d	18.45d
								Aristea inequalis	13.2-23.7d	18.45d
								Babiana cuneata	13.2-23.7d	18.45d
								Babiana vanzyliae	13.2-23.7d	18.45d
								Brunsvigia bosmaniae	13.2-23.7d	18.45d
								Bulbinella eburnifolia	13.2-23.7d	18.45d
								Bulbinella elegans	13.2-23.7d	18.45d
								Bulbinella latifolia var. doleritica	13.2-23.7d	18.45d
								Bulbinella nutans	13.2-23.7d	18.45d
								Dimorphotheca nudicaulis	13.2-23.7d	18.45d
								Geissorhiza splendidissima	13.2-23.7d	18.45d

	Provenance	"Bio-region type" code	Altitute of Bio-region	Relative habitat coldness as mean days p.a. with frost	South Africa "Bio-region type"	Mean average precipitation (mm)	Altitute of collection location (m)	Species	Estimated frost days	Average of estimated frost days
28	Nieuwoudtville	FRd1(p.192)	740-1500	10-50d	Dolerite Renosterveld	290	800-1000	Gladiolus caryophyllaceus	13.2-23.7d	18.45d
								Hesperantha cucullata	13.2-23.7d	18.45d
								Hesperantha pauciflora	13.2-23.7d	18.45d
								Hesperantha vaginata	13.2-23.7d	18.45d
								Ixia rapunculoides	13.2-23.7d	18.45d
								Lachenalia mutabilis	13.2-23.7d	18.45d
								Lapeirousia oreogena	13.2-23.7d	18.45d
								Moraea pritzeliana	13.2-23.7d	18.45d
								Moraea tripetala	13.2-23.7d	18.45d
								Romulea sabulosa	13.2-23.7d	18.45d
								sparaxis elegans	13.2-23.7d	18.45d
								sparaxis tricolor	13.2-23.7d	18.45d
54	loeriesfontein	SKt2 (p.278)	400-1280	20-40d	Hantamkaroo	190-2550	500	Gladiolus saccatus	22.3d	22.3d
35	Calvinia	FRd2 (p193)	550-1672	10-40d	Dolerite Renosterveld	250	900	Dimorphotheca cuneata white	19.4d	19.4d
53	Rooiwal	FRd1 (p.192)	740-1500	10-50d	Dolerite Renosterveld	290	1100	Anisdontea spp.	28.9d	28.9d
								Bulbinella elegans	28.9d	28.9d
								Crotalarca humclis	28.9d	28.9d
								Dimorphotheca cuneata white	28.9d	28.9d
								Felicia filifolia	28.9d	28.9d
								Gazania krebsiana (orange)	28.9d	28.9d
								Gazania othonites	28.9d	28.9d
								Gladiolus splendens	28.9d	28.9d
								Romulea monadelpha	28.9d	28.9d
37	Roggeveld	FRs3 (p.177) FRd1 (p.192)	1200-1900 740-1500	30-70d 10-50d	Shale Renosterveld/ Dolerite Renosterveld	305 290	900-1300	Bulbinella elegans	24.2-37.6d	30.9d
								Daubenya aurea	24.2-37.6d	30.9d
								Hesperantha luticola	24.2-37.6d	30.9d
								Ixia thomasiae	24.2-37.6d	30.9d
								Lessertia frutescens	24.2-37.6d	30.9d
								Lessertia rigida	24.2-37.6d	30.9d
								Moraea bifida	24.2-37.6d	30.9d
								Moraea pritzeliana	24.2-37.6d	30.9d
								Romulea atrandra	24.2-37.6d	30.9d
								Romulea komsbergensis	24.2-37.6d	30.9d
								Romulea monadelpha	24.2-37.6d	30.9d
								Romulea subfistulosa	24.2-37.6d	30.9d
								Romulea syrengodoeflora	24.2-37.6d	30.9d
36	Hantamsberg	FRd2 (p193)	550-1672	10-40d	Dolerite Renosterveld	250	1500	Haemanthus coccineus	35.4d	35.4d
38	near Middelpos	SKt3 (p.279)	1040-1680	56d	Roggeveld Karoo	230	1400	Ursinia spp.	56d	56d
								Dimorphotheca nudicaulis	56d	56d
39	Middelpos	SKt3 (p.279)	1040-1680	56d	Roggeveld Karoo	230	1100	Gladiolus marlothii	56d	56d
							1000	Gladiolus splendens	56d	56d
								Ixia thomasiae	56d	56d
								Romulea unifolia	56d	56d
								Babiana cuneata	56d	56d
								Tritonia karooicum	56d	56d
40	Sutherland	SKt3 (p.279)	1040-1680	56d	Roggeveld Karoo	230	1450	Hesperantha humilis	56d	56d
								Ixia curvata	56d	56d
								Kniphofia sarmentosa	56d	56d
41	Komsberg	SKt3 (p.279)	1040-1680	56d	Roggeveld Karoo	230	1600-1680	Aloinopsis spathulata	56d	56d
								Arctotis adpressa	56d	56d
								Arctotis campanuflora (diffusa)	56d	56d
								Cheiridopsis namaquensis	56d	56d
								Gazania rigida	56d	56d
								Gladiolus breviflorus	56d	56d
								Ixia curvata	56d	56d
								Leysseria gnaphaloides	56d	56d
								Moraea macronyx	56d	56d
								Moraea pritzeliana	56d	56d
								Stachys rugosa	56d	56d
46	Groot Swartberg mountains	FFs23 (p.122) FFs24 (p.123) FFs31 (p.128)	700-1800 550-1800 1800-2325	10-40d 10-30d 10-30d	Sandstone Fynbos	375 475 585	1830	Elegia vaginaga	11.14d	11.14d
							1820	Elegia vaginaga	10.76d	10.76d
							1500+	Erica cerinthoides	26.8d	26.8d
							1845	Erica cerinthoides	11.71d	11.71d
							1700	Leucadendron album	37.27d	37.27d
							1500	Leucadendron spissifolium spp. Fragrans	20.9d	20.9d
							1360	Tritoniopsis spp	23d	23d
							2325	Ruschia spp.	30d	30d
							1575	Watsonia marlothii	26.4d	26.4d
							1900	Watsonia marlothii	13.8d	13.8d
							1550	Watsonia schlecteri	26d	26d
							1730	Watsonia schlecteri	28.9d	28.9d
							1000	Watsonia marlothii	17.7d	17.7d
	Southern valleys & mountains									
45	McGregor	FRs8 (p.180)	100-650	3-8d	Shale Renosterveld	370	250-500	Gladiolus floribundus var. rudis	4.4-6.6d	5.5d
43	Little Karoo	SKv8 (p.288)	160-1060	14d	Little Karoo	230	200-500	Ursina sericea	14d	14d
44	Montagu	SKv8 (p.288)	160-1060	14d	Little Karoo	230	200-500	Erica densifolia	14d	14d
								Tritonia pallida	14d	14d
	Eastern Cape									
47	Arniston	FS7 (p.204)	0-100	0d	Dune Renosterveld	400-600	100-200	Gladiolus miniatus	0d	0d
50	Oyster Bay	AZs1 (p.687)	0-100	0d	Dune Renosterveld	680	0-100	Ornithogalum dubium	0d	0d

	Provenance	"Bio-region type" code	Altitute of Bio-region	Relative habitat coldness as mean days p.a. with frost	South Africa "Bio-region type"	Mean average precipitation (mm)	Altitute of collection location (m)	Species	Estimated frost days	Average of estimated frost days
51	Napier	FRs12 (p.184)	20-340	3d	Shale Renosterveld	380	200-500	Gladiolus brevifolius	3d	3d
								Gladiolus teretifolius	3d	3d
								Watsonia aletroides	3d	3d
								Watsonia laccata light purple	3d	3d
48	Mossel Bay	FFs13 (p.113)	150-1600	7-10d	Sandstone Fynbos	605	100-200	Geranium incanum	7-7.1d	7.05d
	Ex hort or Specific Location Unknown									
56	E. Cape						100-500	Freesia corymbosa		
								Gladiolus floribundus var. floribundus		
								Gladiolus floribundus		
								Gladiolus tristis		
								Moraea bipartita		
	Northern Cape							Hermannia stricta		
	Ex hort							Amaryllis belladonna		
								Babiana vanzyliae		
								Geissorhiza tulbaghensis		
								Geissorhiza splendidissima		
								Gladiolus breviflorus		
								Gladiolus carinatus		
								Heamatus sagciineus		
								Hesperantha pauciflora		
								Lachenalia purpureo-caerulea		
								Lachenalia rubida		
								Lachenalia viridiflora		
								Moraea bipartita		
								Moraea elegans		
								Moraea fugax		
								Moraea villosa		
								Ornithogalum ex Pisa		
								Romulea amoena		
								Sparaxis maculosa		
								Tritonia deusta		
								Watsonia marginata		
								Watsonia 'stanford scarlet'		
								Watsonia stokoei		
	Dawie							Moraea bipartita		
								Moraea elegans		
	Dunlop						1400	Gladiolus cardinalis		
	smac							Watsonia borbonica		
								Syncarpha vestita		

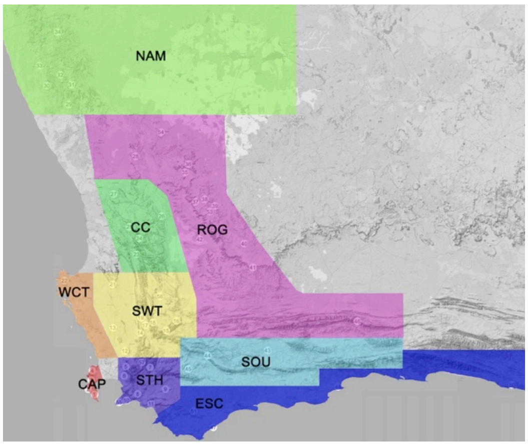


Fig.4.6 The map illustrates the different geographical regions categoried in Table 4.1 above. Cape Peninsula (CAP for short), Stellenbosch to Hermanus (coastal mountain to coast) (STH for short), Swartland (lower altitude to inland mountains) (SWT for short), West coast (coastal plain) (WCT for short), Cedarberg & Clanwilliam (inland mountains) (CC for short), Namaqualand (coastal plain to inland mountains) (NAM for short), Roggeveld (continental inland mountains) (ROG for short), Southern valleys & mountains (SOU for short) and Eastern Cape (ESC for short).

Fig.4.7 The map illustrats different Provenances categoried in Table 4.2 above.

4.2.2 Summer Wetness Tolerance Experiment

As shown in Figure 4.4 and 4.5 the four winter covered blocks which experienced less cold damage were subjected to summer rainfall, where as the four winter uncovered blocks with higher winter mortality were covered by ventilated and transparent “screens” from the end of May until 15th August 2012. Given rainfall in summer mainly comes from northwest, the eastern and southern sides where removed whilst the western and northern sides were retained to prevent unintential re-wetting on these edges (Fig. 4.8). Evergreen geophytes, forbs, shrubs and succulents were removed from the experimental blocks and placed in trays adjacent to the main experiment and exposed to ambient rainfall during the summer months.

Fig.4.8 Transparent “screen” with two sides cut off to keep ventilation.

4.2.3 Statistical Analysis

Analysis of the hardiness and wetness experiment was problematic because of variables such as the number of pots of each species that were available, different provenances, and ages of the plant material. Mortality during each of the previously described experimental phases was coverted into percentages and analysis of variance (ANOVA) was applied. Following statistical advice, ANOVA was chosen because of its robustness to violation of its core assumptions.

4.3 Results

4.3.1 Climatic conditions in Sheffield during the study time period

In the UK, winter 2010/2011 was recorded as an extremely cold winter, which experienced the coldest December in 100 years, and -8.9 °C on the 21th December in Sheffield (Met Office 2015). In Sheffield, following -7.2°C being recorded on 28th November, at the Western Park Met Station, on 1st December 2010, 38cm of snow (the deepest in any month since 1958 (BBC Weather Sheffield 2010). Winter 2010/2011 was also very wet, and two-month rainfall in December and January was upto 1019.7mm (SWP 2015). The 30-years (1981-2000) average rainfall in these two months in Sheffield is 167.9mm (SWP 2015). March 2011 was the driest March (average for UK) since 1953, however Sheffield had relatively normal rainfall. April to October 2011 was warmer than average, but with regular rainfall.

During phase 2 of the hardiness study, between December 2011 and January 2012 conditions were relatively mild with the minimum air temperature -3.3 °C. This droped down to -6.2 °C in early Febuary, and the total frost days in Sheffield was 42 days. The summer of 2012 was very wet, the fourth wettest since1882 at The Sheffield Weston Park Station. Therefore, summer 2012 was extremely challenging for species from a Meditteranean climate, and in particular geophytes. January 2013 saw 18cm of snow in the Sheffield Btanical Gardens on 21th January (see Figure 4.9 below). Winter 2012/2013 was very extremely long and cold, starting from the first snow at the end of October stretching to the end of March 2013. The minimum air temperature at The Sheffield Weston Park Station was close to -5 °C in January and March 2013.

Fig.4.9 (right) Really thick snow carpets were covered on the winter uncovered 4 blocks. (pics were both taken on 21th January 2013 by Ye Hang)

The minimum temperatures on experimental sites recorded by Tingtag sensors are shown in Fig. 4.10, Fig. 4.11 and Fig. 4.12 during winter months in the research window.

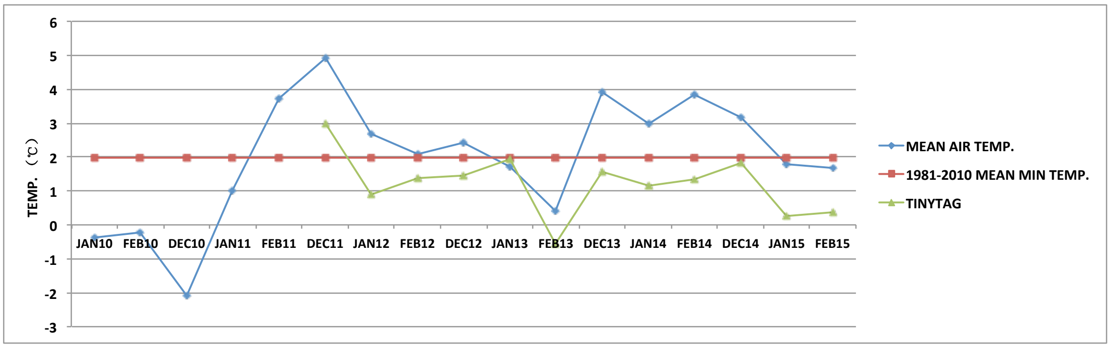


Fig. 4.10 December, January and Febuary temperatures during the experimental period (December 2010- Febuary 2015). The blue line indicates mean minimum air tempertures (Sheffield Western Park Weather Station, SWP, 2015). The red line indicates 30-year (1981-2010) average mean minimum temperatures during this period (Met Office, 2015). The green line indicates the mean minimum soil surface temperatures collected by Tinytag temperature recorders in winter on uncovered blocks on experimental site, and normally 1-2 °C lower than mean air temperature.

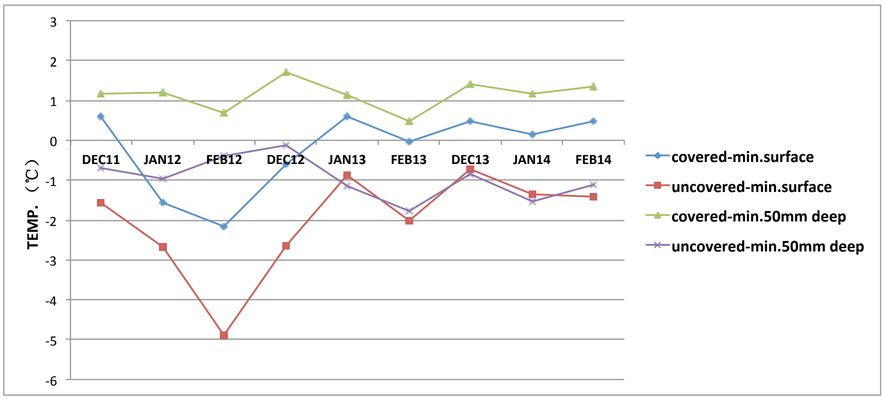


Fig.4.11 The minimum temperatures of Winter cold Tolerance Test recorded by Tinytag temperature loggers on the experimental site.

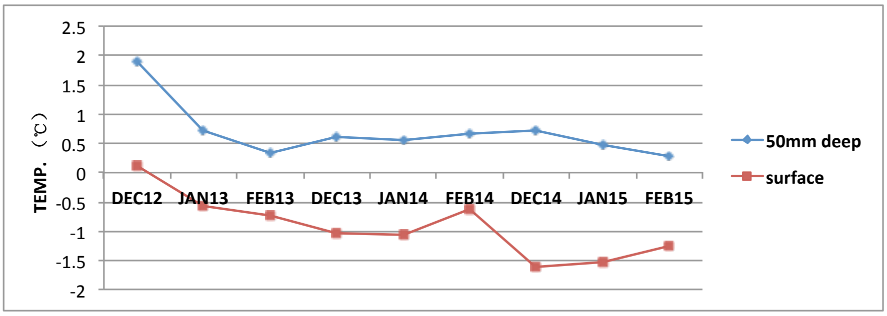


Fig.4.12 The minimum temperatures within the Competition Experiment recorded by Tinytag temperature loggers on site at 50mm deep compared to at the soil surface.

4.3.2 Winter Cold Tolerance Experiment Phase 1 (December 2011-April 2013)

As recorded, the hardiness experimental blocks experienced 42 ground frost days between 16th December 2011 and 16th April 2012. The minimum ground surface temperature measured by tiny tags close to pot soil surface of winter uncovered treatment was -5°C, with -2.2°C in the same block at 50mm depths. This compared with -1.1°C on soil surface and -0.6°C as 50mm deep in the covered treatment. Transparent "screens" made 2-3°C difference on ground temperature generally, and extra double layers of horticultural fleece could main the surface another 1-2°C warmer.

There were 1232 pots of (79.6%) deciduous geophytes and 315 pots of (20.4%) forbs and evergreen geophytes under the phase 1 study.

From Table 4.3 below, the Univariate ANOVA revealed that there was highly significant difference (P<0.01) in mortality between winter covered and uncovered treatments. This indicates that relatively small difference in minimum temperature had a major impact in relation to winter mortality. There was highly significant difference (P<0.01) in mortality between various collection locations (Provenanance and Geograpical Regions). Collection locations combined winter cover condition significantly (P<0.01) influenced species mortality. But the concentric arrangement within each block did not significantly affect species mortality (P>0.05).

Table. 4.3 General picture as mean of all species of the main factors affecting winter mortality in relation to 2011-2012.

Tests of Between-Subjects Effects

Dependent Variable: 2011-2012 Witer mortality

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1544506.678a	292	5289.406	6.049	0.000
Intercept	616407.136	1	616407.136	704.93	0.000
Location	202321.234	44	4598.21	5.259	0.000
Winter.cover.condition	159391.402	1	159391.402	182.282	0.000
Concentric.arragement	3647.838	6	607.973	0.695	0.653
Location * Concentric.arragement	162726.846	193	843.144	0.964	0.620
Winter.cover.condition * Concentric.arragement	12659.61	6	2109.935	2.413	0.025
Location * Winter.cover.condition	185351.104	42	4413.122	5.047	0.000
Error	1093029.311	1250	874.423		
Total	4865324	1543			
Corrected Total	2637535.99	1542			

a R Squared = .586 (Adjusted R Squared = .489)

Winter cover/non-cover and location emerge as key main factors significantly influencing species winter mortality. A large majority (>200 genotypes) of forbs and geophytes tolerate -1.1°C soil surface temperatures. Approximately 180 tested genotypes tolerated -5°C soil surface temperature.

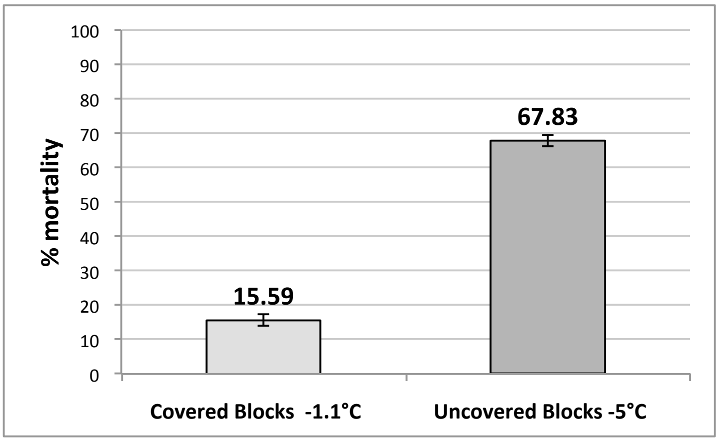


Fig. 4.13 Mortality as mean of all the species in covered and uncovered treatments over winter 2011-2012. There were 716 pots tested in winter-covered treatment and 831 pots tested in winter uncovered treatment (error bars indicate standard error).

4.3.2.1 Winter mortality comparison between evegreen forbs/shrubs/geophytes and summer deciduous geophytes in Phase 1

There were 656 of summer deciduous geophytes tested in winter uncovered treatment, and 576 pots in winter covered treatment. For forbs, shrubs, evergreen geophytes 175 pots were tested in winter uncovered treatment, and 140 pots in winter covered treatment. Winter cover highly significantly affected the mortality of both deciduous geophytes (P<0.01) and shrubs/forbs/ evergreen geophytes (P<0.01) in winter 2011/2012. However, summer deciduous geophytes had 11.5% lower mortality at -1.1°C, and 10% higher mortality at -5°C compared to the shrubs/frobs/ evergreen geophytes group.

Table. 4.4 Winter cover condition as a factor in relation to 2011-2012 winter mortality of deciduous geophytes and frobs/evergreen geophytes.

Tests of Between-Subjects Effects

Dependent Variable: 2011-2012 Winter mortality

Life.form	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
deciduous geophytes	Corrected Model	817025.339a	1	817025.339	777.323	0.000
	Intercept	1608020.569	1	1608020.569	1529.881	0.000
	Winter.cover.condition	817025.339	1	817025.339	777.323	0.000
	Error	1292822.882	1230	1051.076		
	Total	3877626	1232			
	Corrected Total	2109848.221	1231			
forbs and evergreen geophytes	Corrected Model	71602.400b	1	71602.4	48.254	0.000
	Intercept	426717.27	1	426717.27	287.574	0.000
	Winter.cover.condition	71602.4	1	71602.4	48.254	0.000
	Error	464445.016	313	1483.85		
	Total	1008323	315			
	Corrected Total	536047.416	314			

a R Squared = .387 (Adjusted R Squared = .387)

b R Squared = .134 (Adjusted R Squared = .131)

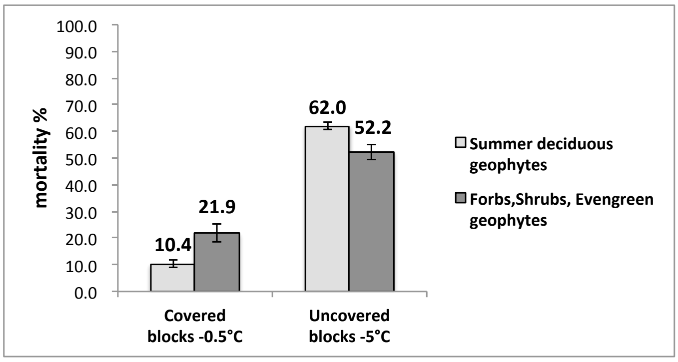


Fig. 4.14 Comparison of winter mortality between evegreen forbs/shrubs/geophytes and summer deciduous geophytes in both covered and uncovered treatments (error bars indicate standard error).

4.3.2.2 The effect of collection locations on winter mortality of Phase 1

(1) Geographical region

In this analysis, species were grouped into 9 groups. Species whose wild collection locations were unknown or seeds collected from a horticultural environment (also see Table 4.2). Cape Peninsula (CAP for short) included 142 pots, Stellenbosch to Hermanus (coastal mountain to coast) (STH for short) included 166 pots, Swartland (lower altitude to inland mountains) (SWT for short) included 281 pots, West coast (coastal plain) (WCT for short) included 24 pots, Cedarberg

& Clanwilliam (inland mountains) (CC for short) included 82 pots, Namaqualand (coastal plain to inland mountains) (NAM for short) included 140 pots, Roggeveld (continental inland mountains) (ROG for short) included 445 pots, Southern valleys & mountains (SOU for short) included 20 pots and Eastern Cape (ESC for short) included 32 pots.

From Figure 4.15 it is clear that, species from Roggeveld region, where including very cold and high altitute inland plateaus and high mountains, such as Sutherland, Middelpos, Komsberg and Nieuwoudtville (see Table 4.2), stood out with the lowest winter mortality (25.33%). The highest mortality occurred in SOU and CC with the figures closed to 60%. Species from Southern Valleys and mountains region were mainly collected at relatively low altitutes (200-500m), thus winter mortality was exected to be higher in comparison. The SOU result may however be due to the relatively low number of samples (20), because some areas within this region experienced as many as 14 days of frost. Compared with the Cape Peninsula with only 2-3 days of frost, Southern Valleys and mountains region had 20% more in winter mortality. This is because many species under test were from CAP were collected from high mountains of the Table Mountain plateau at up to 1086m. Cedarberg & Clanwilliam (inland mountains) surprisely turned out to have the second highest mortality figures, uncertain reason (refer to Table 4.2). Results of WCT and ESC may not very accurate both due to the small number of species.

The patterns of winter uncovered treatment in Figure 4.16 was similar to the pattern in Figure 4.15. In the pairwise comparison of SPSS (Appendix 1), no matter in winter covered or uncovered treatment, many coastal regions showed significant difference from inland mountain regions.

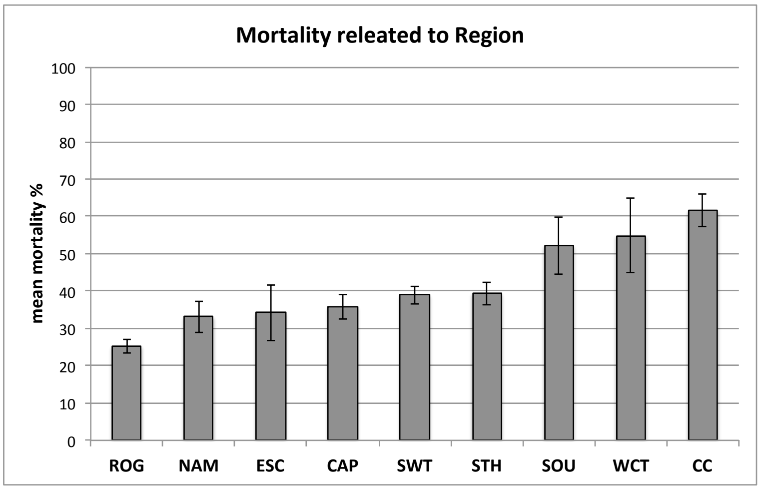


Fig. 4.15 Mean mortality of species from different geographical regions in all treatments over winter 2011-2012 (error bars indicate standard error).

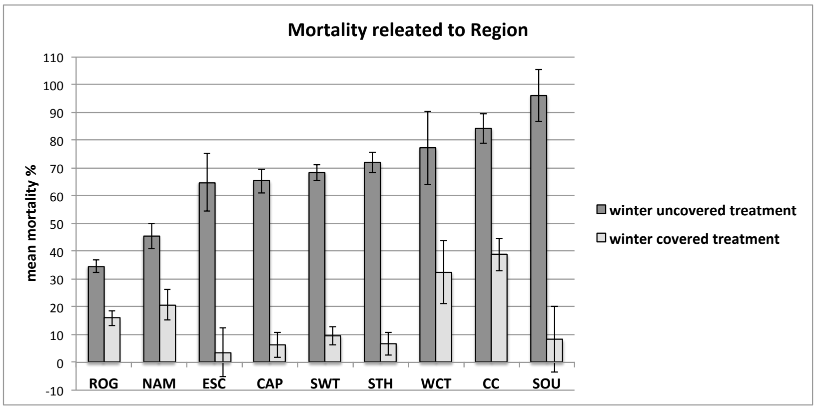


Fig. 4.16 Comparison of over wintering mortality of species in both covered and uncovered treatments in different geographical regions (error bars indicate standard error).

(2) Provenance

Because within each region listed above, it sometimes combined low plains and high plateaus or tall mountains, a more detailed collection location comparison was used to produce more authentic results. As shown in Table 4.2, each region was divided into sub-sections with more typical collection locations. In SPSS analysis, ‘Univariate Analysis of Variance’ was used to investigate the effect of winter cover on mortality of species from different collection locations in order to test the hypothesis of ‘genotypes of species collected from colder, more inland and often high altitudes in Western SA would show reduced mortality in Sheffield in response to winter cold.

Table 4.3 and Table 4.5 below is a summary of ‘Test of Between-Subject Effects’ from through the ‘General Liner Model-Univariate’. Rooiwal (P-value=0.938) and Kovebekkeveld (Prince Albert Hamlet) (P-value=0.879) were close to P= 1.000 showing no significant difference of winter mortality in covered (-1.1 ^{o}C) and uncovered (-5^{o}C) treatments. Both of these two locations are high in altitude (1100 and 1000m repectively), with long frost periods (28.9days and 28.8days respectively). This suggests the species from these two areas could survive at -5^{o}C or even lower temperature, therefore, there was no significangt difference with or without covers. In winter uncovered treatment (see Table 4.6), populations from very cold provenances Sutherland (7.6%), Rooiwal (13.67%) and Groot Swartberg mountains (20.5%) had the least mortality. Populations from Roggeveld (28.92%), Komsberg (33.84%), Nieuwoudtville (36.99%), Namaqualand (40.67%), Kamiesberg (41.19%), Ceres (44.50%) and Kovebekkeveld (50%) all had no more than 50% mortality. Most of genotypes were all from relatively cold provenances.

Table 4.5 Analysis of ‘General Liner Model- Univariate’ to investigate the effect of winter cover on mortality of species from different provenances.

Location	**Winter.cover.condition**	**Mean winter mortality %**	**Std. Error**	**Sig.**
Cape Peninsula	winter uncovered blocks	67.57	5.766	
	winter covered blocks	7.50	6.505	**0.000**
Scarborough	winter uncovered blocks	57.08	7.669	
	winter covered blocks	4.50	9.392	**0.000**
Noordaoek	winter uncovered blocks	66.00	7.325	
	winter covered blocks	1.25	7.325	**0.000**
Table Mountain	winter uncovered blocks	78.96	4.717	
	winter covered blocks	4.75	4.717	**0.000**
Stellenbosch	winter uncovered blocks	73.00	4.2	
	winter covered blocks	5.19	4.674	**0.000**
Somerset West	winter uncovered blocks	73.88	12.719	
	winter covered blocks	4.25	17.987	**0.010**
Villiersdorp	winter uncovered blocks	95.00	2.37	
	winter covered blocks	2.75	2.37	**0.000**
Bot River	winter uncovered blocks	63.13	11.582	
	winter covered blocks	3.25	16.38	**0.014**
Caledon	winter uncovered blocks	66.00	15.971	
	winter covered blocks	0.00	15.971	**0.027**
Hermanus	winter uncovered blocks	84.00	5.819	
	winter covered blocks	16.63	5.819	**0.000**
Paarl mt	winter uncovered blocks	75.33	5.413	
	winter covered blocks	3.33	5.413	**0.000**
Malmesbury	winter uncovered blocks	72.59	4.218	
	winter covered blocks	7.27	4.218	**0.000**
Bainskloof	winter uncovered blocks	66.20	5.952	
	winter covered blocks	14.65	6.324	**0.000**
Wolseley	winter uncovered blocks	100.00	3.889	
	winter covered blocks	5.50	3.889	**0.000**
Ceres	winter uncovered blocks	44.50	7.73	
	winter covered blocks	19.50	7.73	0.062
Tulbagh	winter uncovered blocks	71.11	4.884	
	winter covered blocks	1.67	5.275	**0.000**
Gouda	winter uncovered blocks	83.75	4.68	
	winter covered blocks	6.67	4.68	**0.000**
Piketberg	winter uncovered blocks	83.00	8.348	
	winter covered blocks	6.71	8.924	**0.000**
West coast	winter uncovered blocks	76.83	7.799	
	winter covered blocks	23.25	7.799	**0.000**
Citrusdal	winter uncovered blocks	88.00	3.95	
	winter covered blocks	0.00	3.421	**0.000**
Cedarberg	winter uncovered blocks	81.53	8.869	
	winter covered blocks	41.29	9.18	**0.004**
Clanwilliam	winter uncovered blocks	93.00	8.066	
	winter covered blocks	45.47	8.066	**0.000**
Pakhuis Pass	winter uncovered blocks	65.00	11.765	
	winter covered blocks	22.50	11.765	**0.023**
Nieuwoudtville	winter uncovered blocks	36.99	2.728	
	winter covered blocks	9.50	2.919	**0.000**
Garies	winter uncovered blocks	77.50	15.681	
	winter covered blocks	69.67	18.106	0.757
Spoegrivier	winter uncovered blocks	100.00	3.651	
Namaqualand	winter covered blocks	6.67	4.216	**0.000**
Kamiesberg	winter uncovered blocks	41.19	5.212	
	winter covered blocks	12.57	5.572	**0.000**
Namaqualand	winter uncovered blocks	40.67	9.049	
	winter covered blocks	29.80	12.14	0.479
Springbok	winter uncovered blocks	100.00	10.398	
	winter covered blocks	66.50	10.398	0.063
Hantamsberg	winter uncovered blocks	75.00	15.023	
	winter covered blocks	33.25	15.023	0.097
Roggeveld	winter uncovered blocks	28.92	5.168	
	winter covered blocks	7.92	6.202	**0.012**
Middelpos	winter uncovered blocks	69.08	11.369	
	winter covered blocks	41.17	11.369	0.096
Sutherland	winter uncovered blocks	7.60	4.001	
	winter covered blocks	18.78	4.218	0.062
Komsberg	winter uncovered blocks	33.84	9.993	
	winter covered blocks	22.23	12.081	0.465
Montagu	winter uncovered blocks	95.00	7.906	
	winter covered blocks	10.00	7.906	**0.000**
McGregor	winter uncovered blocks	90.00	7.071	
	winter covered blocks	0.00	7.071	**0.000**
Groot Swartberg	winter uncovered blocks	20.50	7.377	
mountains	winter covered blocks	10.50	7.377	0.375
Arniston	winter uncovered blocks	87.50	9.021	
	winter covered blocks	10.00	9.021	**0.001**
Napier	winter uncovered blocks	85.13	6.061	
	winter covered blocks	4.13	6.061	**0.000**
Kovebekkeveld(	winter uncovered blocks	50.00	18.194	
Albert Hamlet)	winter covered blocks	46.00	18.194	0.879
Rooiwal	winter uncovered blocks	13.67	4.79	
	winter covered blocks	14.29	6.271	0.938

Table 4.6 2011-2012 Winter mortality associated with various provenances compared with altitude and frost day characteristics. Altitude: high represents >1000m elevation, medium represents 400-1000m elevation, low represents <400m elevation; frost days: long represents mean annual frost days >25 days, medium represents 10-25 days, short represents <10 days.

Location	Mean winter mortality %	Std. Error	collection loction information	
			altitude	frost days
Sutherland	7.60	4.001	high	long
Rooiwal	13.67	4.79	high	long
Groot Swartberg mountains	20.50	7.377	high	long
Roggeveld	28.92	5.168	high	long
Komsberg	33.84	9.993	high	long
Nieuwoudtville	36.99	2.728	medium-high	medium
Namaqualand	40.67	9.049	medium-high	short
Kamiesberg	41.19	5.212	high	medium
Ceres	44.50	7.73	medium	medium
Kovebekkeveld	50.00	18.194	high	long
Scarborough	57.08	7.669	low	short
Bot River	63.13	11.582	low	short
Pakhuis Pass	65.00	11.765	medium-high	medium
Noordaoek	66.00	7.325	low	short
Caledon	66.00	15.971	low	short
Bainskloof	66.20	5.952	low-high	short-medium
Cape Peninsula	67.57	5.766	low-high	short
Middelpos	69.08	11.369	high	long
Tulbagh	71.11	4.884	low	short
Malmesbury	72.59	4.218	low	short
Stellenbosch	73.00	4.2	low-medium	short
Somerset West	73.88	12.719	low	short
Hantamsberg	75.00	15.023	high	long
Paarl moutain	75.33	5.413	low	short
West coast	76.83	7.799	low	short
Garies	77.50	15.681	low-medium	medium
Table Mountain	78.96	4.717	low-high	short
Cedarberg	81.53	8.869	high	medium
Piketberg	83.00	8.348	low	short
Gouda	83.75	4.68	low	short
Hermanus	84.00	5.819	low	short
Napier	85.13	6.061	low	short
Arniston	87.50	9.021	low	short
Citrusdal	88.00	3.95	medium	short
McGregor	90.00	7.071	low	short
Clanwilliam	93.00	8.066	low-medium	short
Villiersdorp	95.00	2.37	low	short
Montagu	95.00	7.906	low	medium
Wolseley	100.00	3.889	low	short
Spoegrivier Namaqualand	100.00	3.651	low	short
Springbok	100.00	10.398	high	short

In some case, Springbok, for instance, the provenance only involved two genotypes raising questions about the comparisons. In the pairwise comparison of SPSS (Appendix 2), no matter in winter covered or uncovered treatment, many provenances from coastal regions showed significantly increased mortality compared to provenances from inland mountain regions.

4.3.2.3 Effect of age on winter mortality in Phase 1

All the tested genotypes could be divided into 9 age groups as shown in Fig. 4.17. Two genotypes were represented by 8 pots in the winter uncovered treatment and 4 pots of one genotype in winter covered treatment of 0-1 mixed age group tested, in winter 2011/2012. These sorts of variations resulted in larger standard error bars, and hence a lack of significant differences between the different age categories within the same treatment type (for example uncovered). As demonstrated in Table 4.7 below, most age groups showed significant difference in winter mortality between the two treatments except the 0-1 mixed and 3 years old age groups. For the remaining seven age groups, the mean mortality were all between 55-67%, with one year old and two years old groups slightly less in figures. Overall age appears to play a relatively unimportant role in the cold tolerance of Western SA species.

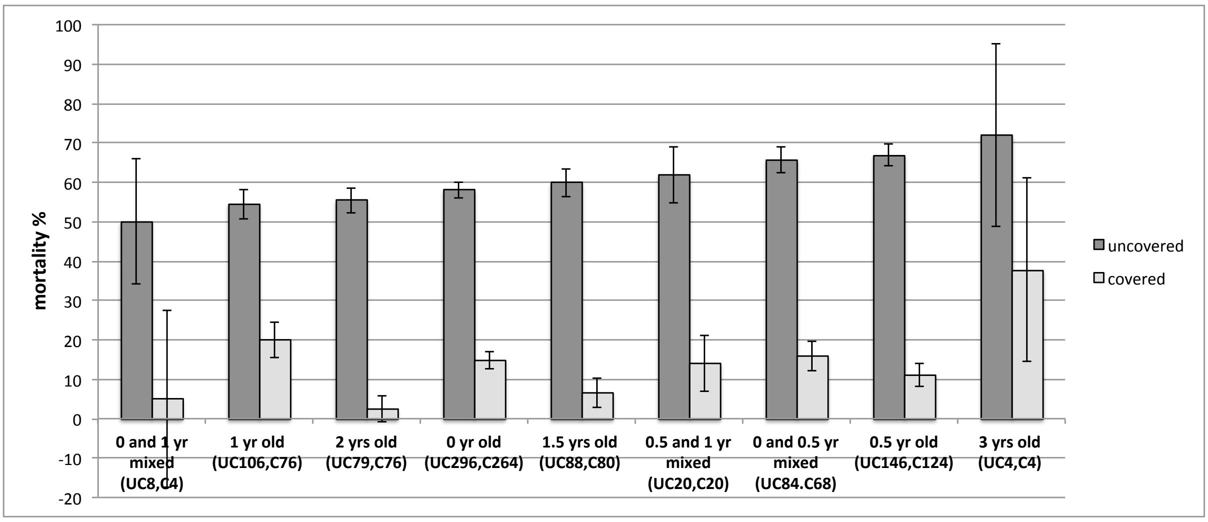


Fig. 4.17 Mortality of all the species over winter 2011-2012 of different age groups (error bars indicate standard error; “UC8” means there were 8 pots tested in uncovered treatment, “C4” means there were 4 pots tested in covered treatment) .

Table 4.7 Univariate ANOVA pairwise comparisons between different age groups in winter mortality 2011/2012.

Dependent Variable: 2011-2012 Winter mortality

Age	(I) Winter.cover.condition	(J) Winter.cover.condition	Mean Difference (I-J)	Std. Error	Sig.b
0 yr seedling (newly sown seed)	winter uncovered blocks	winter covered blocks	43.241*	2.948	**0.000**
0 yr and 0.5 yr mixed seedlings (sown in autumn and spring 2011)	winter uncovered blocks	winter covered blocks	49.877*	5.003	**0.000**
0 yr and 1 yr mixed seedlings (sown in autumn 2011 and autumn 2010)	winter uncovered blocks	winter covered blocks	45.000	27.591	0.134
0.5 yr seedlings (sown in spring 2011)	winter uncovered blocks	winter covered blocks	55.773*	3.949	**0.000**
0.5 yr and 1 yr mixed seedlings (sown in spring 2011 and autumn 2010)	winter uncovered blocks	winter covered blocks	47.700*	10.037	**0.000**
1 yr old plants (sown in autumn 2010)	winter uncovered blocks	winter covered blocks	34.505*	5.811	**0.000**
1.5 yrs old plants (sown in spring 2010)	winter uncovered blocks	winter covered blocks	53.308*	5.179	**0.000**
2 yrs old plants (sown in autumn 2009)	winter uncovered blocks	winter covered blocks	52.944*	4.560	**0.000**
3 yrs old plants (sown in autumn 2008)	winter uncovered blocks	winter covered blocks	34.250	32.814	0.337

Based on estimated marginal means
* The mean difference is significant at the
b Adjustment for multiple comparisons: Sidak.

4.3.2.4 Experimental location effects on winter mortality in Phase 1

Tinytag measurements showed blocks closer to the backing hedges were warmer than the blocks further away. Fig.4.18 showed a clear pattern of the influence of hedges on winter mortality within the uncovered treatment. Block 5 located at the corner with the best micro-climate condition suffered the least mortality (48%), whilst the block furthest from the hedge (4) (70%). Covered blocks showed no additional effects of the hedge microclimate.

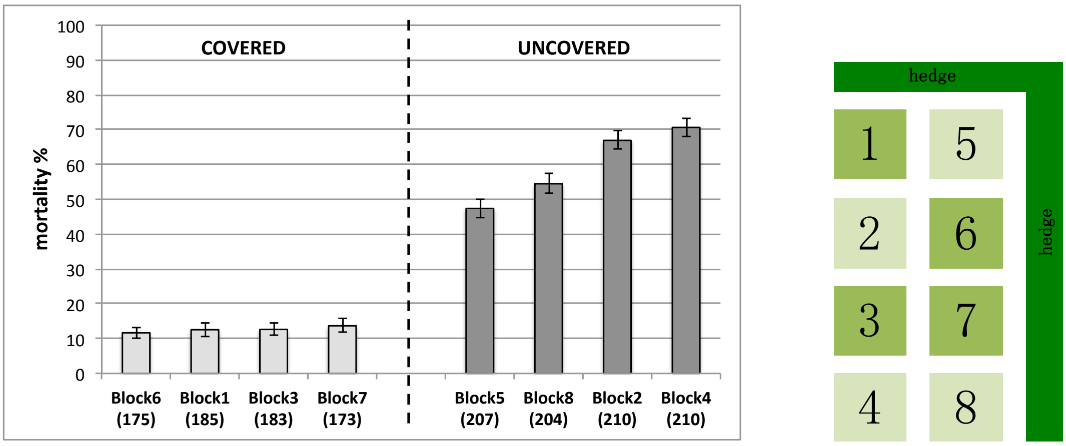
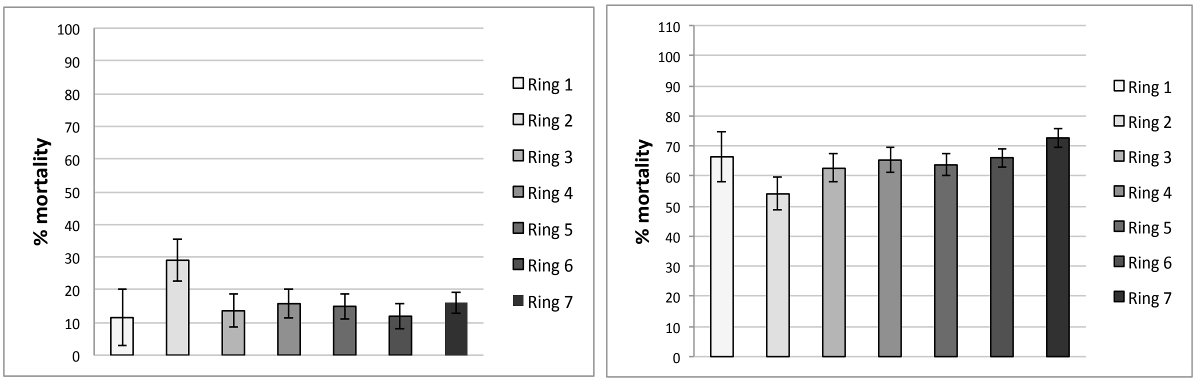


Fig. 4.18 Effect of location of experimental blocks on total species mortality. With the bar chart error bars indicate standard error (figures in bracket indicates pot numbers in each block).

4.3.2.5 Pot position within the block effects on mortality in Phase 1

Concentric arrangement within each block was coded from 1 to 7, with 0 the central pot, and 7=the ring of pots along the outer edge of each experiment block. Ring 1 to ring 7 included 42, 94,157, 209, 283, 341,417 pots respectively). By using ‘concentric arragements’ as factor in univariate ANOVA, it was possible to confirm that winter mortality of tested species was statistically independent of position within the block. .



a) b)

Fig. 4.19 Effect of concentric arrangements on mean mortality. a) Mean mortality of species in winter covered blocks over winter 2011/2012; (b) mean mortality of species in winter uncovered blocks over winter 2011/2012 (error bars indicate standard error).

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4.3.2.6 Mean individual winter mortality of part one

There were 210 genotypes from different provenances (represented by more than 3 pots, with most genotypes were represented by 8 pots) tested during winter 2011/2012. The overall mortality of these species in uncovered treatment in all replicates was 60.38%. 32 provenances of 25 species (15.24%) tolerated -5°C as soil surface temperature with less than 15% mortality. 26 populations of 21 species (12.38%) had less than 10% over winter mortality. Amongst the 25 species (<15% mortality), 9 (34.4%) were shrub/forb/evergreen geophyte species and 16 (65.6%) deciduous geophyte species. Most of these species were naturally distributed in high altitude continental climate mountains such as the Roggeveld (Komsberg, Sutherland, Nieuwoudtville, Roggeveld, Rooiwal), the Namaqualand mountains (Kamiesberg). The geophyte *Romulea komsbergensis* from these regions showed no frost damage whatsoever.

Only *Geranium incanum* (Mossel Bay) and *Babiana sambucifolia* (Stellenbosch) were from relatively low altitude and or coastal areas. Most of the populations that suffered more than 75% mortality were from coastal regions or low altitude region, such as Cape Peninsula, and the environs around Cape Town. The species that were most cold sensitive species to low temperature were: *Freesia fergusoniae, Ornithogalum thyrsoides, Syncarpha vestita, Crassula spp., Aristea spp., Albuca clanwilliamgloria*, *Gladiolus saccatus* and *Brunsvigia bosmaniae.* These were the first species to show senescence and foliage loss. *Gazania heterochaeta, Heterolepis aliena, Tripteris oppositifolia* and *Podalyria leipoldtii* were affected by what appeared to be root rot pathogens about 3 months after sowing. *Bulbinella* seedlings were recorded as extremely attractive to slugs and snails early in the growing season, when the first new and tender leaves were eaten completely.

In many geophytes sub zero temperatures caused leaf browning at tips and margins of the leaves. In most forbs sub-lethal damage involved dark spots on the leaves. In certain cases, foliage was severely damaged, such as in *Scabiosa africana* and *Geranium incanum*, but plants recovered new healthy shoots in the following spring when temperatures rose. *Dimorphotheca cuneata* was the most cold hardy forb species without any damage across the winter.

Species for which multiple provenances were available allowed comparison of how this affected mortality. The evergreen geophyte *Aristea capitata (*syn*. A. major)* provenance from the Cedarberg had 80.75% mortality, which was 19.25% less than the population collected from Table Mountain (100% mortality). Forb *Dimorphotheca nudicaulis* from the coast at Scarborough near Cape Town had mean mortality at 52%, the population from 1000m near Nieuwoudtville (2.5%). Although in the overall comparisions, age of corms etc did not improve cold tolerance it did in some individual species; for example, *Babiana villosa from the same provenance* showed 50% mortality as 3 year old corms, 85% of half-year old seedlings and 73% of newly germinated seedlings. Detailed comparisions of mortality for all species and provenances are given in Table 4.8.

Table 4.8 Mean mortality of individual species in winter uncovered treatment over winter 2011-2012.

Species Name	collection location	Winter.cover.condition				Sig.b (I-J)	Altitute of collection location	Estimated frost days in collection location
		winter uncovered blocks (I)		winter covered blocks (J)				
		Mean winter mortality %	Std. Error	Mean winter mortality %	Std. Error			
Arctotis adpressa	Komsberg	0.000	15.733	22.250	15.733	0.356	high	long
Ixia curvata	Sutherland	0.000	0.000	0.000	0.000	.	high	long
Moraea tripetala	Nieuwoudtville	0.000	0.000	0.000	0.000	.	medium-high	medium
Geranium incanum	Mossel Bay	0.000	0.000	0.000	0.000	.	low	short
Kniphofia uvaria	Kovebekkeveld	0.000	0.000	0.000	0.000	.	high	long
Bulbinella elegans	Nieuwoudtville	0.000	3.801	4.250	3.292	0.437	medium-high	medium
Gazania krebsiana (orange)	Namaqualand	0.000	3.005	4.250	3.005	0.356	medium-high	short
Spiloxene spp. (yellow)	Kamiesberg	0.000	0.000	0.000	0.000	.	high	long
Dimorphotheca cuneata (white)	Rooiwal	0.000	0.000	.a	.	.	high	long
Bulbinella nutans	Nieuwoudtville	0.000	0.000	50.000	0.000	.	medium-high	medium
Bulbinella elata	Bainskloof	0.000	0.000	0.000	0.000	.	low-high	short-medium
Romulea atrandra	Roggeveld	0.000	0.000	0.000	0.000	.	high	long
Bulbinella elegans	Roggeveld	0.000	4.217	15.750	4.217	**0.038**	high	long
Romulea sabulosa	Nieuwoudtville	0.000	0.000	10.000	0.000	.	medium-high	medium
Dimorphotheca cuneata (orange)	Kamiesberg	2.500	5.534	17.000	5.534	0.113	high	long
Dimorphotheca nudicaulis	Nieuwoudtville	2.500	2.196	2.750	2.196	0.938	medium-high	medium
Dimorphotheca cuneata (orange)	Kamiesberg	2.750	3.147	3.500	3.147	0.872	high	long
Bulbinella latifolia var latifolia	Kamiesberg	3.250	2.298	0.000	2.298	0.356	high	long
Moraea tripetala	Nieuwoudtville	3.750	3.413	5.250	3.413	0.766	medium-high	medium
Romulea komsbergensis	Roggeveld	4.250	3.005	0.000	3.005	0.356	high	long
Hesperantha humilis	Sutherland	8.250	12.776	41.750	12.776	0.113	high	long
Hesperantha luticola	Roggeveld	8.250	5.834	0.000	5.834	0.356	high	long
Ixia curvata	Sutherland	8.500	6.788	8.250	6.788	0.980	high	long
Gazania krebsiana (orange)	Namaqualand	9.250	3.614	.a	.	.	medium-high	short
Hesperantha vaginata	Nieuwoudtville	9.250	3.801	0.000	3.801	0.136	medium-high	medium
Kniphofia sarmentosa	Sutherland	9.500	3.617	26.500	3.617	**0.016**	high	long
Hesperantha cucullatus	Nieuwoudtville	10.250	3.987	5.250	3.987	0.409	medium-high	medium
Ixia curvata	Sutherland	11.750	10.182	16.000	14.399	0.821	high	long
Ixia rapunculoides	Nieuwoudtville	12.000	4.975	0.000	4.975	0.139	medium-high	medium
Babiana sambucifolia	Stellenbosch	12.500	8.839	0.000	8.839	0.356	low-medium	short
Dimorphotheca cuneata (white)	Rooiwal	13.000	7.913	11.750	7.913	0.915	high	long
Sparaxis tricolor	Nieuwoudtville	15.000	5.000	0.000	5.000	0.078	medium-high	medium
Spiloxene spp. (orange)	Kamiesberg	16.750	11.844	0.000	11.844	0.356	high	long
Scabiosa africana	Cape Peninsula	18.750	10.364	0.000	14.658	0.355	high	long
Gladiolus tristis	Unknown	19.000	7.890	0.000	7.890	0.139		
Bulbinella nutans	Nieuwoudtville	20.000	10.000	0.000	10.000	0.207	medium-high	medium
Watsonia marlothii	Groot Swartberg mountains	20.500	7.377	10.500	7.377	0.375	high	long
Moraea tripetala	Nieuwoudtville	22.500	13.150	.a	.	.	medium-high	medium
Hesperantha vaginata	Nieuwoudtville	22.750	7.358	7.250	7.358	0.187	medium-high	medium
Lachenalia mutabilis	Nieuwoudtville	23.750	9.638	6.250	9.638	0.247	medium-high	medium
Arctotis adpressa	Komsberg	25.000	25.000	.a	.	.	high	long
Babiana vanzyliae	Nieuwoudtville	25.000	17.678	0.000	17.678	0.356	medium-high	medium
Hesperantha luticola	Roggeveld	25.000	25.000	.a	.	.	high	long
Moraea pritzeliana	Roggeveld	25.000	25.000	.a	.	.	high	long
Ixia rapunculoides	Nieuwoudtville	25.250	4.694	0.000	4.694	**0.009**	medium-high	medium
Gazania krebsiana (orange)	Rooiwal	28.000	8.794	17.667	10.154	0.476	high	long
Bulbinella elegans	Nieuwoudtville	28.250	6.034	3.500	6.034	**0.027**	medium-high	medium
Ixia maculata	Malmesbury	29.750	9.761	4.000	9.761	0.111	low	short
Spiloxene spp. (orange)	Kamiesberg	31.250	13.975	6.250	13.975	0.253	high	long
Geissorhiza splendidissima	Unknown	32.000	5.123	0.000	5.123	**0.004**		
Ixia thomasiae	Roggeveld	32.750	7.382	13.500	7.382	0.115	high	long
sparaxis elegans	Nieuwoudtville	33.000	4.699	0.000	4.699	**0.003**	medium-high	medium
Dimorphotheca tugax	Namaqualand	33.333	16.667	.a	.	.	medium-high	short
Hesperantha pauciflora	Nieuwoudtville	34.000	8.439	5.500	8.439	0.054	medium-high	medium
Watsonia tabularis	Table Mountain	34.750	15.597	0.000	15.597	0.166	low-high	short
Bulbinella latifolia var latifolia	Kamiesberg	35.000	8.416	0.000	8.416	**0.026**	high	long
Watsonia schlecterii	Bainskloof	36.000	21.229	0.000	21.229	0.297	low-high	short-medium
Hesperantha pauciflora	Unknown	37.500	10.110	0.000	10.110	**0.039**		
Bulbinella elata	Pakhuis Pass	38.250	5.515	0.000	5.515	**0.002**	medium-high	medium
Babiana thunbergii	West coast	39.250	14.203	27.250	14.203	0.572	low	none
Babiana vanzyliae	Nieuwoudtville	41.750	21.675	0.000	30.653	0.328	medium-high	medium
Bulbinella eburnifolia	Nieuwoudtville	41.750	25.028	.a	.	.	medium-high	medium
Geissorhiza aspera	Malmesbury	43.000	15.218	0.000	15.218	0.093	low	short
Gladiolus maculatus	Stellenbosch	43.750	15.095	0.000	15.095	0.086	low-medium	short
Ixia latifolia	Ceres	44.500	7.730	19.500	7.730	0.062	medium	medium

Species Name	collection location	Winter.cover.condition				Sig.b (I-J)	Altitute of collection location	Estimated frost days in collection location
		winter uncovered blocks (I)		winter covered blocks (J)				
		Mean winter mortality %	Std. Error	Mean winter mortality %	Std. Error			
Watsonia 'stanford scarlet'	Unknown	45.667	13.740	.a	.	.		
Geissorhiza inflexa (red)	Tulbagh	45.750	12.856	0.000	12.856	**0.046**	low	short
Dimorphotheca nudicaulis	Scarborough	46.500	17.197	.a	.	.	low	short
Moraea macronyx	Komsberg	47.667	7.881	0.000	13.650	0.094	high	long
Babiana cuneata	Nieuwoudtville	48.000	15.676	0.000	15.676	0.074	medium-high	medium
Romulea amoena	Unknown	48.000	4.975	0.000	4.975	**0.000**		
Tritonia deusta	Unknown	49.250	10.311	5.250	10.311	**0.023**		
Arctotis campanuflora (diffusa)	Kamiesberg	50.000	28.868	.a	.	.	high	long
Babiana villosa	Tulbagh	50.000	28.868	.a	.	.	low	short
Gladiolus carneus var. macowan	Stellenbosch	50.000	20.142	0.000	20.142	0.134	low-medium	short
Moraea bipartita	Unknown	50.000	20.412	0.000	20.412	0.134		
sparaxis elegans	Nieuwoudtville	50.000	15.245	0.000	15.245	0.060	medium-high	medium
Watsonia schlecterii	Bainskloof	50.000	11.713	56.750	11.713	0.698	low-high	short-medium
Bulbinella latifolia var doleritica	Nieuwoudtville	50.000	28.868	.a	.	.	medium-high	medium
Bulbinella caudis-felis	Cedarberg	50.000	18.672	0.000	26.405	0.197	high	medium
Scabiosa africana	Cape Peninsula	50.250	18.841	2.500	18.841	0.123	low-high	short
Gladiolus carneus	Noordaoek	50.500	9.349	3.750	9.349	**0.012**	low	short
sparaxis elegans	Nieuwoudtville	51.750	11.481	1.250	11.481	**0.021**	medium-high	medium
Ixia rapunculoides	Nieuwoudtville	52.500	9.629	0.000	9.629	**0.008**	medium-high	medium
Babiana fragrans	Stellenbosch	54.250	14.884	0.000	14.884	**0.042**	low-medium	short
Geissorhiza aspera	Cape Peninsula	55.000	10.989	3.000	10.989	**0.015**	low-high	short
Gladiolus carneus	Bot River	56.750	16.347	3.250	16.347	0.060	low	short
Watsonia borbonica	Unknown	56.750	10.620	0.000	10.620	**0.009**		
Babiana vanzyliae	Unknown	57.000	6.640	0.000	6.640	**0.001**		
Watsonia tabularis	Table Mountain	57.000	7.623	8.250	7.623	**0.004**	low-high	short
Dimorphotheca nudicaulis	Scarborough	58.000	7.906	9.000	7.906	**0.005**	low	short
Lapeirousia azurea	Malmesbury	61.250	11.629	19.500	11.629	**0.044**	low	short
Gladiolus caryophyllaceus	Nieuwoudtville	61.750	15.779	40.750	15.779	0.383	medium-high	medium
Moraea pendula	Kamiesberg	62.250	6.003	0.000	6.003	**0.000**	high	long
Gladiolus carneus	Noordaoek	62.500	16.925	0.000	16.925	**0.040**	low	short
Lapeirousia azurea	Malmesbury	63.000	11.132	23.000	11.132	**0.044**	low	short
Babiana cuneata	Nieuwoudtville	63.500	15.716	3.250	15.716	**0.035**	medium-high	medium
Watsonia spectabilis	Paarl moutain	63.500	15.019	4.250	15.019	**0.032**	low-medium	short
Watsonia marginata	Stellenbosch	63.750	26.192	50.000	37.042	0.777	low-medium	short
Watsonia aletroides	Caledon	66.000	15.971	0.000	15.971	**0.027**	low	short
Geissorhiza tulbaghensis	Tulbagh	66.500	13.104	0.000	13.104	**0.012**	low	short
Babiana ambigua	Scarborough	66.750	16.667	0.000	16.667	**0.030**	low	short
Freesia corymbosa	Unknown	66.750	19.543	25.000	19.543	0.182		
Moraea tulbaghensis	Gouda	66.750	7.653	3.250	7.653	**0.001**	low	short
Gladiolus floribundus var floribundus	Unknown	67.250	14.767	10.750	14.767	**0.035**		
Babiana cuneata	Middelpos	67.500	8.369	0.000	8.369	**0.001**	high	long
Gladiolus marlothii	Middelpos	67.750	13.984	85.750	13.984	0.398	high	long
Gladiolus floribundus var floribundus	Bot River	69.500	18.241	.a	.	.	low	short
Dimorphotheca tragus	Namaqualand	69.667	8.077	83.500	9.892	0.358	medium-high	short
Freesia caryophyllacea	Stellenbosch	70.750	15.058	12.500	15.058	**0.034**	low-medium	short
Gladiolus splendens	Middelpos	72.000	23.203	37.750	23.203	0.337		
Gladiolus undulatus	Bainskloof	72.000	23.203	3.250	23.203	**0.006**	low-high	short-medium
Watsonia meriana	Somerset West	72.750	15.044	4.250	15.044	**0.018**	low	short
Babiana villosa	Tulbagh	73.000	12.580	0.000	12.580	**0.006**	low	short
Babiana fragrans	Bainskloof	73.250	11.245	0.000	11.245	**0.004**	low-high	short-medium
Moraea angusta	Hermanus	75.000	10.206	0.000	10.206	**0.002**	low	short
Moraea ramossisima	Bainskloof	75.000	25.000	.a	.	.	low-high	short-medium
Onoxiotis stricta	Somerset West	75.000	25.000	.a	.	.	low	short
Watsonia borbonica	Cape Peninsula	75.000	25.000	.a	.	.	low-high	short
Haemantitus cocccineus	Hantamsberg	75.000	15.023	33.250	15.023	0.097	high	long
Moraea pritzeliana	Nieuwoudtville	75.250	2.262	0.000	2.262	**0.000**	medium-high	medium
Moraea bifida	Roggeveld	75.250	8.203	0.000	8.203	**0.001**	high	long
Ixia scilliaris	Paarl moutain	76.750	5.548	1.000	5.548	**0.000**	low	short
Gazania heterochaeta	Garies	77.500	15.681	69.667	18.106	0.757	low-medium	medium
Moraea villosa	Unknown	77.500	3.900	0.000	3.900	**0.000**		
Lachenalia purpureo-caerulea	Unknown	77.750	15.769	1.500	15.769	**0.014**		
Geissorhiza splendidissima	Nieuwoudtville	79.250	7.193	12.500	7.193	**0.001**	medium-high	medium
Brynsvigia bosmaniae	Nieuwoudtville	79.250	14.672	0.000	14.672	**0.009**	medium-high	medium
Geissorhiza tulbaghensis	Unknown	80.000	14.577	5.000	14.577	**0.011**		
Gladiolus floribundus	Unknown	80.500	6.658	12.250	6.658	**0.000**		
Aristea capitata(major)	Cedarberg	80.750	13.786	10.750	13.786	**0.011**	high	medium
Babiana ambigua	Cape Peninsula	81.250	6.502	0.000	6.502	**0.000**	low-high	short
Gladiolus miniatus	Hermanus	81.250	12.220	22.500	12.220	**0.015**	low	short

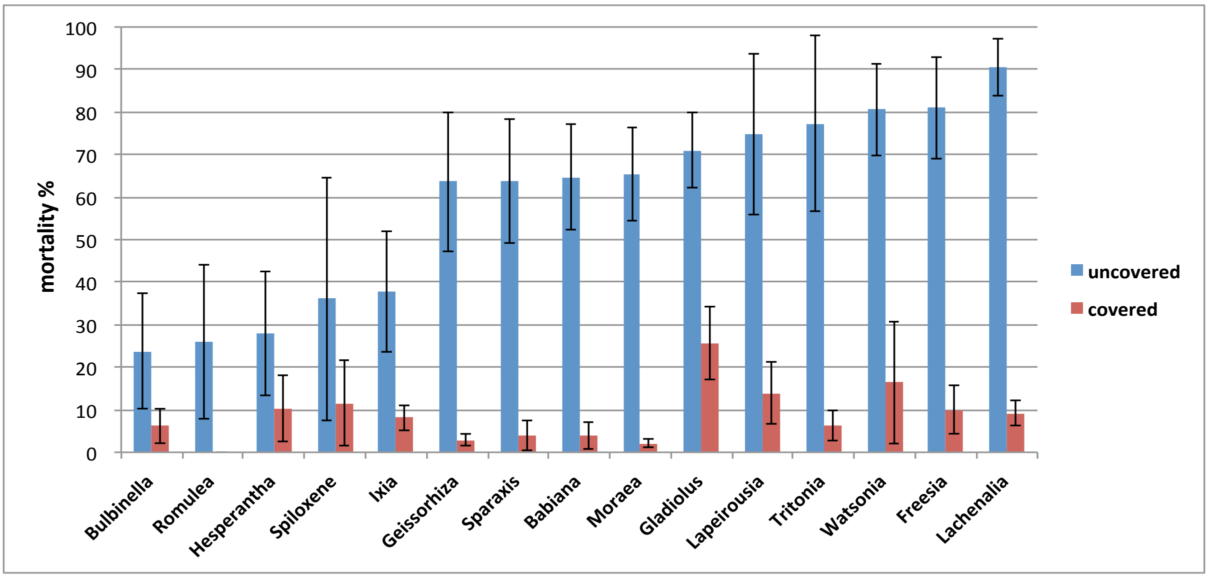
Species Name	collection location	Winter.cover.condition				Sig.b (I-J)	Altitute of collection location	Estimated frost days in collection location
		winter uncovered blocks (I)		winter covered blocks (J)				
		Mean winter mortality %	Std. Error	Mean winter mortality %	Std. Error			
Moraea gigandra	Piketberg	81.250	15.724	11.000	18.156	**0.033**	medium-high	short
Gladiolus caryophyllaceus	Nieuwoudtville	82.250	13.006	87.500	13.006	0.785	medium-high	medium
Gladiolus cardinalis	Unknown	82.750	5.086	0.000	5.086	**0.000**		
Watsonia aletroides	Napier	82.750	9.259	8.250	9.259	**0.001**	low	short
Aristea confusa	Stellenbosch	83.250	9.486	6.500	9.486	**0.001**	low-medium	short
Babiana angustifolia	Malmesbury	83.250	6.827	0.000	6.827	**0.000**	low	short
Gladiolus hirsutis	Bainskloof	83.250	18.671	50.000	18.671	0.255	low-high	short-medium
Geissorhiza inflexa (red)	Tulbagh	84.000	7.141	0.000	7.141	**0.000**	low	short
Moraea tulbagensis	Gouda	84.500	8.626	8.250	8.626	**0.001**	low	short
Tritoniopsis triticea	Piketberg	84.750	9.534	3.500	9.534	**0.001**	medium-high	short
Babiana villosa	Tulbagh	85.000	8.773	3.500	8.773	**0.001**	low	short
Gladiolus carneus	Noordaoek	85.000	10.607	0.000	10.607	**0.001**	low	short
Gladiolus venustus	Clanwilliam	85.000	12.067	81.750	12.067	0.855	low-medium	short
Ixia scilliaris	Paarl moutain	85.750	4.776	4.750	4.776	**0.000**	low	short
Ixia maculata	Malmesbury	86.750	8.174	8.250	8.174	**0.000**	low	short
Ornithogalum thyrsoides	Table Mountain	87.000	8.399	12.500	8.399	**0.001**	low-high	short
Gladiolus miniatus	Arniston	87.500	9.021	10.000	9.021	**0.001**	low	none
Tritonia deusta	Unknown	87.500	8.839	0.000	8.839	**0.000**		
Watsonia laccata	Napier	87.500	8.839	0.000	8.839	**0.000**	low	short
Babiana ringens	Stellenbosch	87.500	9.050	2.750	9.050	**0.001**	low-medium	short
Geissorhiza tulbaghensis	Unknown	87.750	5.859	5.500	5.859	**0.000**		
Gladiolus miniatus	Hermanus	88.000	12.631	42.500	12.631	**0.044**	low	short
Sparaxis grandiflora ssp acuticoba	Citrusdal	88.000	3.950	0.000	3.421	**0.000**	medium	short
Moraea bipartita	Unknown	89.250	4.347	.a	.	.		
Moraea bipartita	Unknown	89.250	5.503	0.000	5.503	**0.000**		
Daubenya aurea	Roggeveld	89.750	6.933	20.250	6.933	**0.000**	high	long
Gladiolus floribundus var rudis	McGregor	90.000	7.071	0.000	7.071	**0.000**	low	short
Gazania pectinata	Kamiesberg	90.500	7.961	47.000	7.961	**0.008**	high	long
Gladiolus carinatus	Unknown	91.667	8.333	0.000	14.434	**0.032**		
Arctotis gumbletonii	Pakhuis Pass	91.750	14.564	45.000	14.564	0.064	medium-high	medium
Freesia fergusoniae	Stellenbosch	91.750	5.834	0.000	5.834	**0.000**	low-medium	short
Sparaxis grandiflora ssp violaceae	Hermanus	91.750	5.929	1.500	5.929	**0.000**	low	short
Lachenalia orchioides var. glaucina	Cape Peninsula	92.750	4.121	4.250	4.121	**0.000**	low-high	short
Sparaxis meterlekampiae	Clanwilliam	93.000	7.943	18.000	7.943	**0.001**	low-medium	short
Lachenalia aloides	Tulbagh	93.500	4.031	6.500	4.031	**0.000**	low	short
Sparaxis maculosa	Unknown	93.750	6.250	.a	.	.		
Lachenalia viridiflora	Unknown	94.250	2.780	5.750	2.780	**0.000**		
Podalyria leipoldtii	Clanwilliam	94.333	8.750	89.000	8.750	0.689	low-medium	short
Lachenalia bulbifera	West coast	94.750	2.759	11.000	2.759	**0.000**	low	short
Freesia furcata	Villiersdorp	95.000	2.370	2.750	2.370	**0.000**	low	short
Ornithogalum thyrsoides	Table Mountain	95.000	3.536	0.000	3.536	**0.000**	low-high	short
Tritonia pallida	Montagu	95.000	7.906	10.000	7.906	**0.000**	low	short
Amaryllis belladonna	Unknown	95.000	9.502	20.750	9.502	**0.001**		
Lachenalia aloides	Stellenbosch	95.750	3.005	0.000	3.005	**0.000**	low-medium	short
Lachenalia rubida	Unknown	95.750	10.279	23.500	10.279	**0.003**		
Watsonia foureadei	Stellenbosch	95.750	4.250	.a	.	.	low-medium	short
Lachenalia carnosa	Namaqualand	96.500	8.139	28.500	8.139	**0.001**	medium-high	short
Babiana thunbergii	West coast	96.500	8.206	31.500	8.206	**0.001**	low	short
Moraea fugax	Unknown	98.000	1.414	0.000	1.414	**0.000**		
Moraea ramossisima	Bainskloof	98.750	2.628	3.500	2.628	**0.000**	low-high	short-medium
Albuca clanwilliamgloria	Clanwilliam	100.000	2.000	4.000	2.000	**0.000**	low-medium	short
Aloinopsis spathulata	Komsberg	100.000	20.412	50.000	20.412	0.134	high	long
Arctotis acaulos	Gouda	100.000	3.577	8.500	3.577	**0.000**	low	short
Aristea capitata(major)	Table Mountain	100.000	4.187	3.500	4.187	**0.000**	low-high	short
Aristea confusa	Stellenbosch	100.000	4.187	7.750	4.187	**0.000**	low-medium	short
Aristea inequalis	Nieuwoudtville	100.000	8.226	65.000	8.226	**0.024**	medium-high	medium
Babiana angustifolia	Malmesbury	100.000	0.000	0.000	0.000	.	low	short
Crassula coccinea	Table Mountain	100.000	3.005	4.250	3.005	**0.000**	low-high	short
Crassula dejecta	Bainskloof	100.000	0.000	0.000	0.000	.	low-high	short-medium
Hesperantha vaginata	Nieuwoudtville	100.000	0.000	0.000	0.000	.	medium-high	medium
Heterolepis aliena	Cedarberg	100.000	8.472	59.750	8.472	**0.015**	high	medium
Lachenalia aloides	Wolseley	100.000	3.889	5.500	3.889	**0.000**	low	short
Lachenalia contaminata	Malmesbury	100.000	3.536	5.000	3.536	**0.000**	low	short
Lachenalia pallida	Malmesbury	100.000	1.414	2.000	1.414	**0.000**	low	short
Moraea fugax	Unknown	100.000	0.000	0.000	0.000	.		
Spiloxene capensis	Cape Peninsula	100.000	5.358	31.500	5.358	**0.000**	low-high	short
Syncarpha vestita	Unknown	100.000	15.309	37.500	15.309	**0.028**		

Species Name	collection location	Winter.cover.condition				Sig.b (I-J)	Altitute of collection location	Estimated frost days in collection location
		winter uncovered blocks (I)		winter covered blocks (J)				
		Mean winter mortality %	Std. Error	Mean winter mortality %	Std. Error			
Ursina sericea	Little Karoo	100.000	0.000	.a	.	.	low	medium
Wachendorfia paniculata	Kovebekkeveld	100.000	2.466	92.000	2.466	0.062	high	long
Watsonia vanderspuyiae	Cedarberg	100.000	7.492	74.000	6.488	**0.047**	high	medium
Watsonia zeyheri	Stellenbosch	100.000	0.000	.a	.	.	low-medium	short
Gladiolus saccatus	loeriesfontein	100.000	0.000	.a	.	.	medium	medium
Veltheimia capensis	Kamiesberg	100.000	5.834	8.250	5.834	**0.000**	high	long
Tripteris oppositifolius	Springbok	100.000	10.398	66.500	10.398	0.063	high	short
Lapeirousia silenoides	Spoegrivier Namaqualand	100.000	3.651	6.667	4.216	**0.000**	low	short
Brunsvigia bosmaniae	Kamiesberg	100.000	0.000	100.000	0.000	.	high	long
Heamanthus coccineus	Unknown	100.000	8.839	87.500	8.839	0.356		

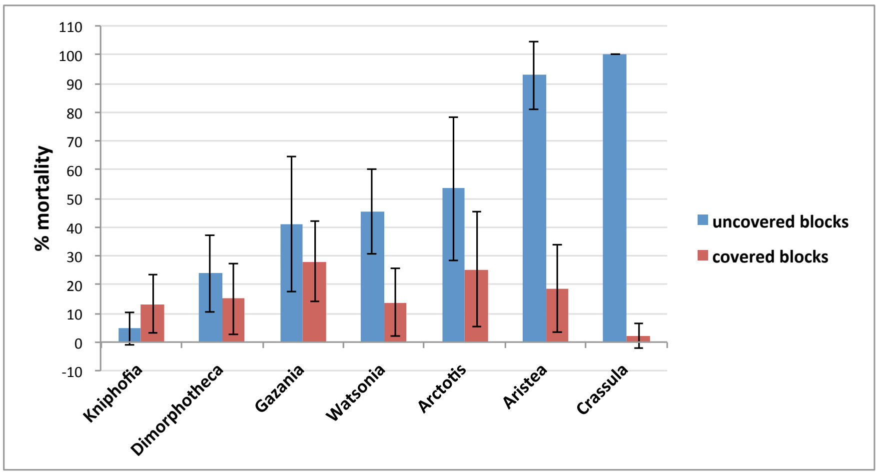
Estimates a This level combination of factors is not observed, thus the corresponding population marginal mean is not estimable.
Pairwise Comparisons Based on estimated marginal means
* The mean difference is significant at the
b Adjustment for multiple comparisons: Sidak.
c This pairwise comparison table cannot be constructed because Winter.cover.condition, the factor being compared, has one level.

4.3.2.7 A comparison of mean mortality of Genera in Phase 1

Mortality of the main genera (mean of all tested species for summer deciduous geophytes and shrubs/forbs/succulents are listed in Fig.4.20. Among summer deciduous geophytes *Bulbinella, Romulea* and *Hesperantha* were the most cold hardy genera in winter 2011/2012, followed by *Spiloxene* and *Ixia*. The highest mortality were recorded (in decreasing order of sensitivity) in *Lachenalia, Freesia* and summer deciduous *Watsonia*. Overall *Romulea* showed close to zero mortality, the best performance in all the genera. Moraea, Geissorhiza, Sparaxis, Babiana, Tritonia and Bulbinella were the next genera with the lowest mortality. These results suggest that some genera are significant more cold tolerant than others, presumably because of their distribution in past climatic epochs.



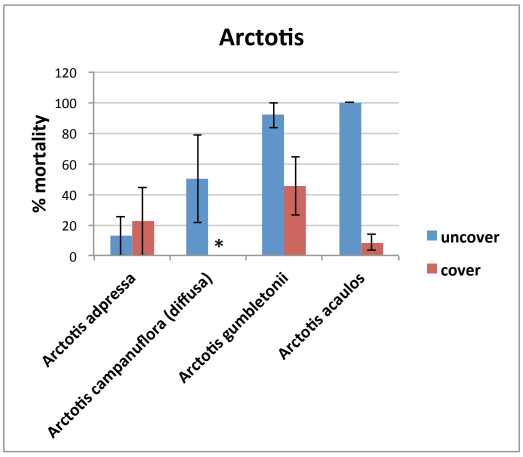
(a)

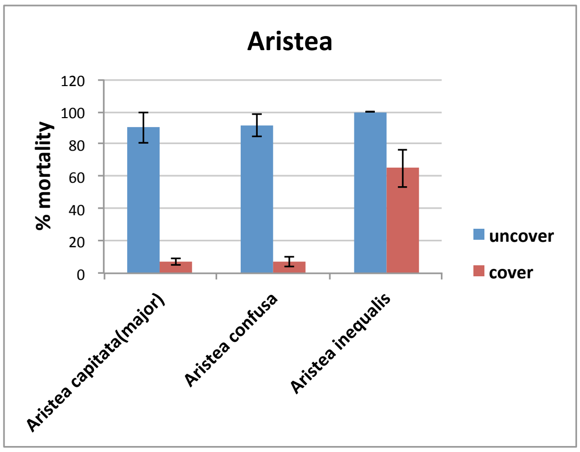


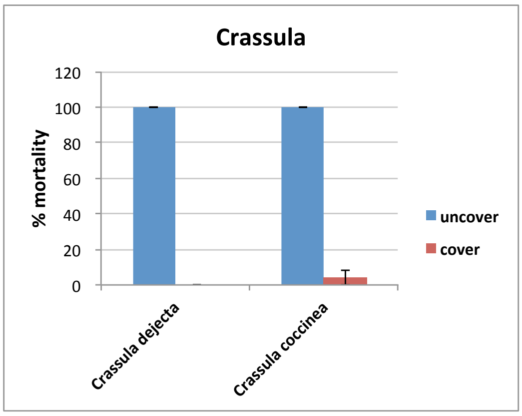
(b)

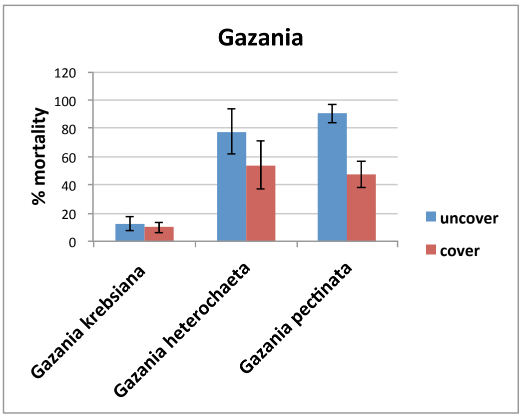
Fig.4.20 Mean mortality of genera (as mean of all species) in winter uncovered and covered treatments over winter 2011-2012 (a) summer deciduous geophytes group (b) evergreen geophytes/shrubs/forbs/succulents group.

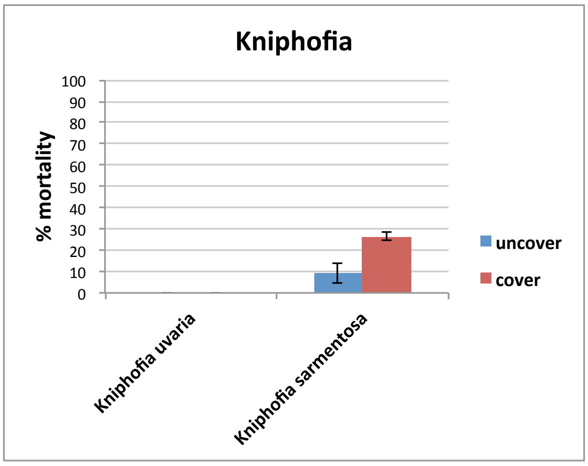
Within each genus there were clear patterns of cold tolerance. In Kniphofia, *K. uvaria* was more hardy than *Kniphofia sarmentosa*. *Aristea capitata* and *Aristea confusa* were much hardy than *Aristea inequalis* at -1.1^{o}C but suffered the similar mortality at -5^{o}C. *Arctotis adpressa* was relatively hardy compared to the other Arctotis species tested. *Gazania krebsiana* provenances were hardier than *Gazania heterochaeta* and *Gazania pectinata*. Both white and orange forms of *Dimorphotheca cuneata* showed very low mortality, 30% less than *Dimorphotheca nudicaulis* and over 60% less than *Dimorphotheca tragus*. The most cold tolerant evergreen *Watsonia* was *Watsonia marlothii*, a high altitude species (up to 1900m) in the Swartberg Range. Its mortality was 20% less than *W. schlecterii, W.* 'Stanford Scarlet', and *W. tabularis.* These results show how that even though some genera are more likely to be cold tolerant than others, generalisations on these average mortalities are fundamentally unsound.

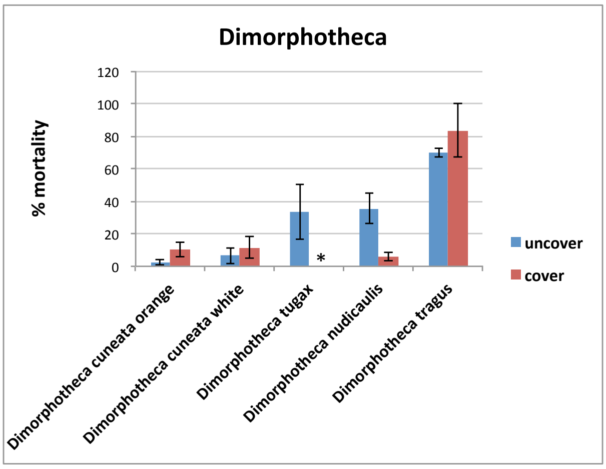












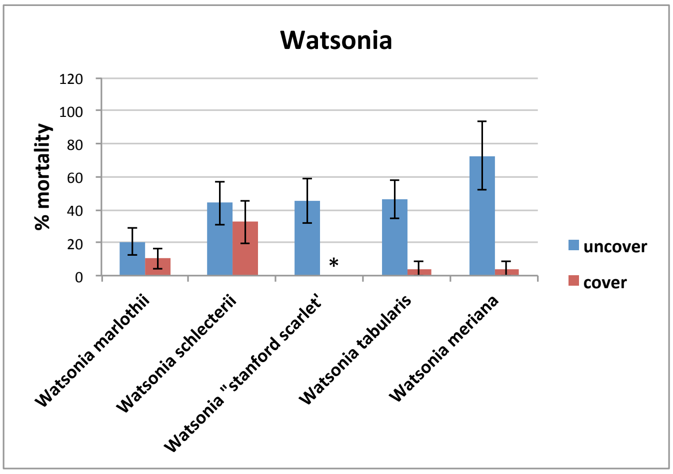
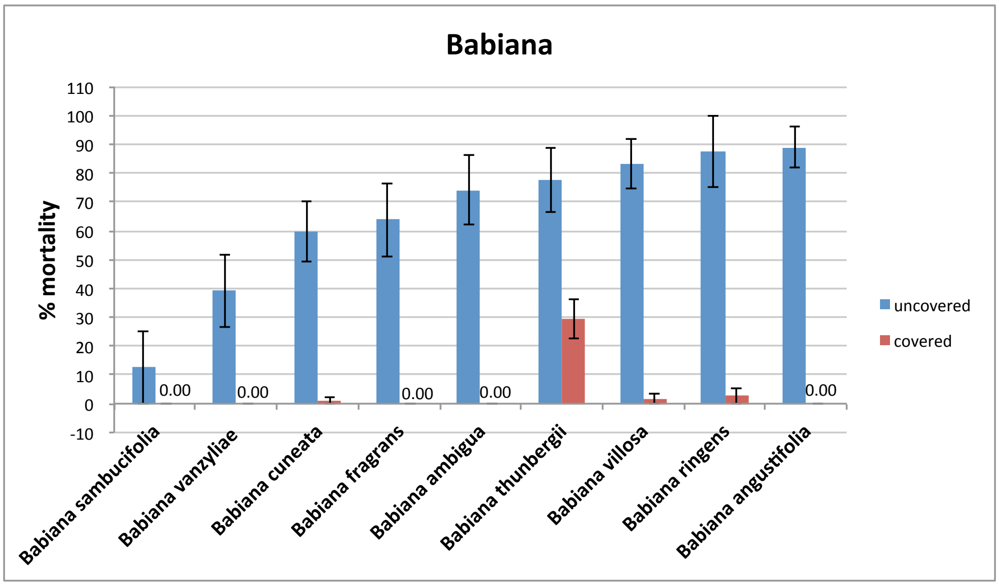
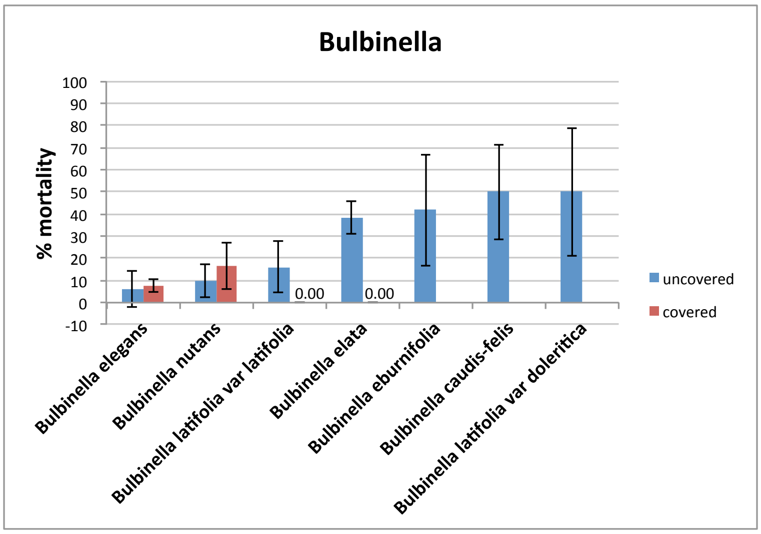
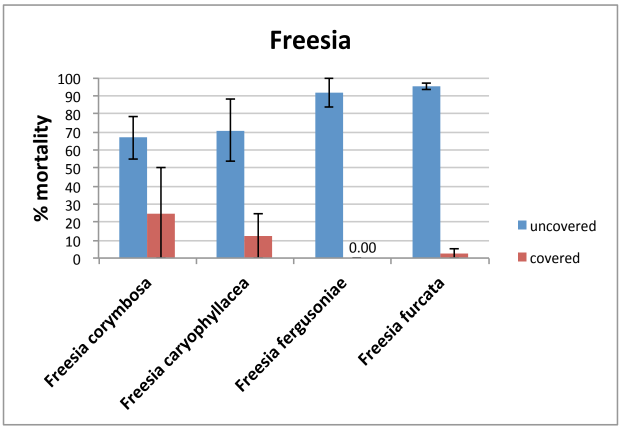


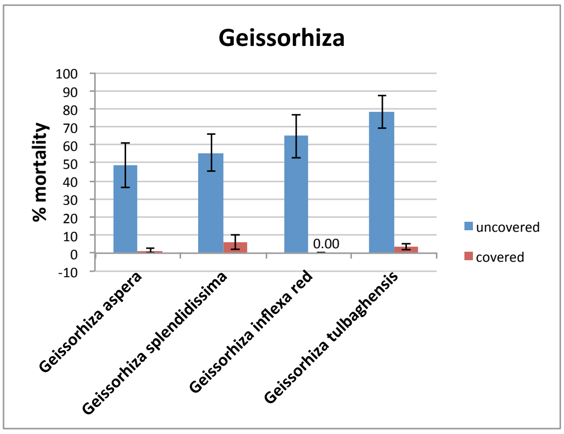
Fig.4.21 Mean mortality of individual evergreen geophytes/forbs/shrubs over winter 2011-2012. Bars with * means there was no sample tested for that treatment for that species).

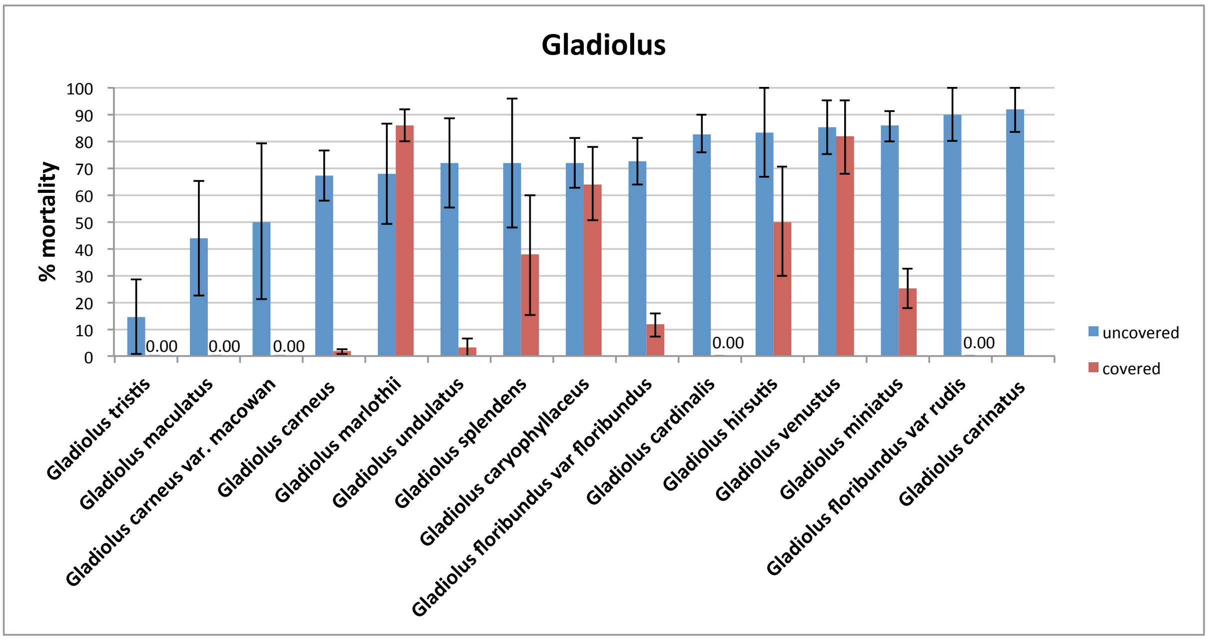
Babiana sambucifolia was the hardiest species, and *Babiana angustifolia, Babiana ringens* and *Babiana villosa* were the three least hardy species. *Bulbinella elegans, Bulbinella nutans* and *Bulbinella latifolia var. latifolia* were much hardier than the other four species. In total 15 Gladiolus species were tested, and only 3 had less than 50% mortality at -5^{o}C, and the rest were all near or over 70% in mortality at the same temperature. In general whilst an important genus, Gladiolus is less cold tolerant (in terms of Western Cape species) than many other genera, with the conspicuous exception of *Gladiolus tristis.* It was the hardiest species in these 15 species and 5 of them had no mortality at -1.1 ^{o}C. *Ixia curvata* was a very hardy species even at -5 ^{o}C, and *Ixia rapunculoides* and *Ixia thomasiae* also showed low mortality at -5$^{.o}$C. In Moraea, it is clear that *Moraea tripetala* was a much hardier species compared to others. *Sparaxis tricolor* and *S. elegans* suffered less mortality at -5^{o}C while the rest four species were all nearly all died at the same temperature. Summer deciduous Watsonia were generally less hardy than evergreen *Watsonia*. All 8 tested species suffered more than 60% mortality at -5^{o}C, with *Watsonia spectaiblis* and *Watsonia marginata* surviving better than the other 6 species.

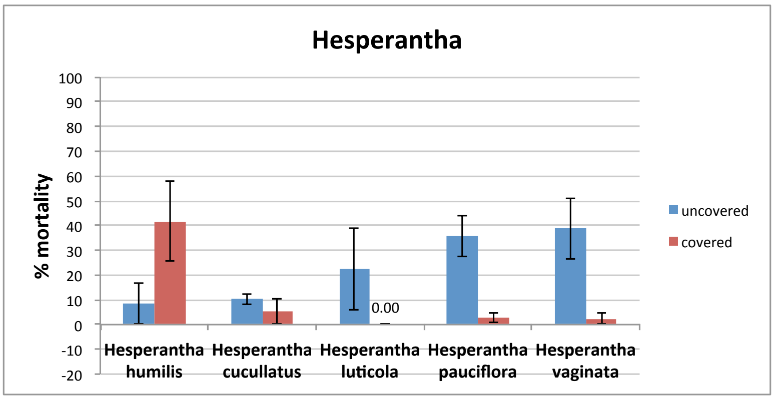

Babiana
% mortality
110
100
90
80
70
60
50
40
30
20
10
0
-10
0.00
0.00
0.00
0.00
0.00
Babiana sambucifolia
Babiana vanzyliae
Babiana cuneata
Babiana fragrans
Babiana ambigua
Babiana thunbergii
Babiana villosa
Babiana ringens
Babiana angustifolia
uncovered
covered

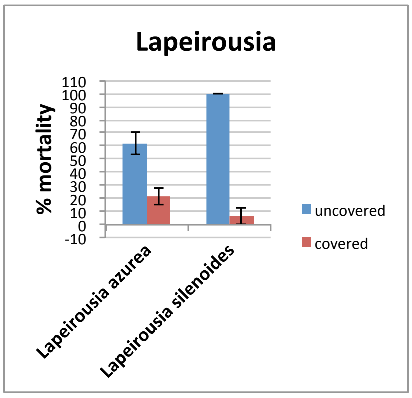

Bulbinella
% mortality
100
90
80
70
60
50
40
30
20
10
0
-10
0.00
0.00
Bulbinella elegans
Bulbinella nutans
Bulbinella latifolia var latifolia
Bulbinella elata
Bulbinella eburnifolia
Bulbinella caudis-felis
Bulbinella latifolia var doleritica
uncovered
covered

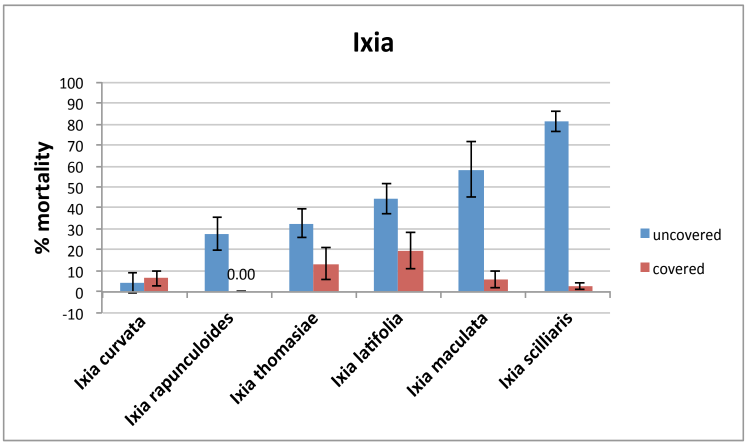

Freesia
% mortality
100
90
80
70
60
50
40
30
20
10
0
0.00
Freesia corymbosa
Freesia caryophyllacea
Freesia fergusoniae
Freesia furcata
uncovered
covered

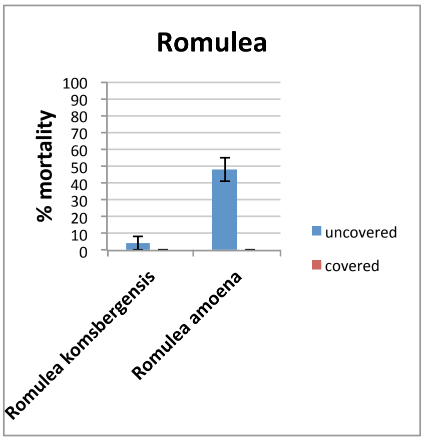

Geissorhiza
% mortality
100
90
80
70
60
50
40
30
20
10
0
-10
0.00
Geissorhiza aspera
Geissorhiza splendidissima
Geissorhiza inflexa red
Geissorhiza tulbaghensis
uncovered
covered

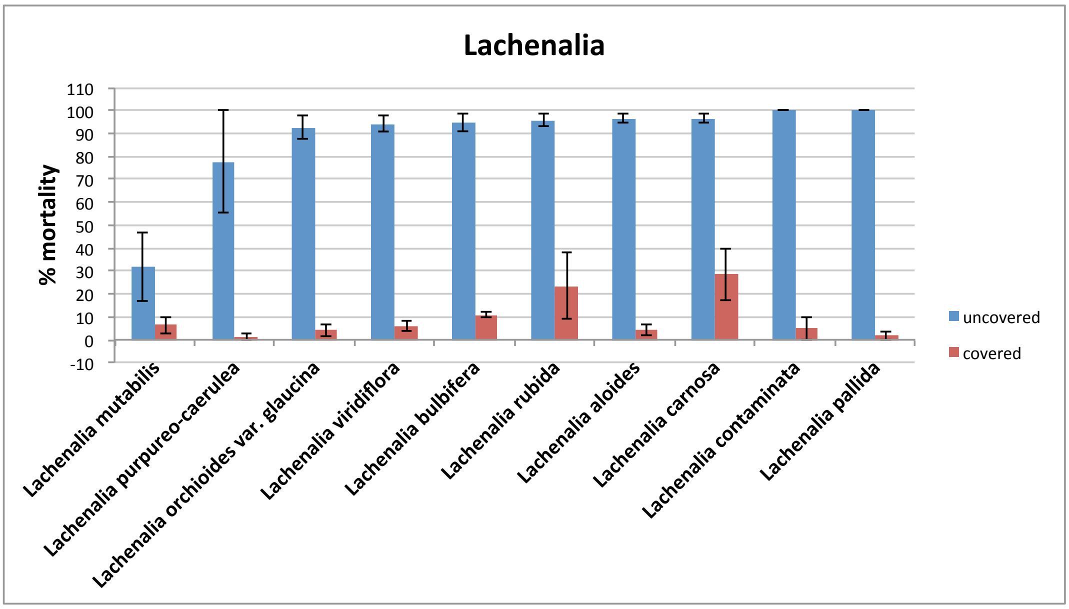

Gladiolus
% mortality
0
10
20
30
40
50
60
70
80
90
100
0.00
0.00
0.00
0.00
0.00
Gladiolus tristis
Gladiolus maculatus
Gladiolus carneus var. macowan
Gladiolus carneus
Gladiolus marlothii
Gladiolus undulatus
Gladiolus splendens
Gladiolus caryophyllaceus
Gladiolus floribundus var floribundus
Gladiolus cardinalis
Gladiolus hirsutis
Gladiolus venustus
Gladiolus miniatus
Gladiolus floribundus var rudis
Gladiolus carinatus
uncovered
covered

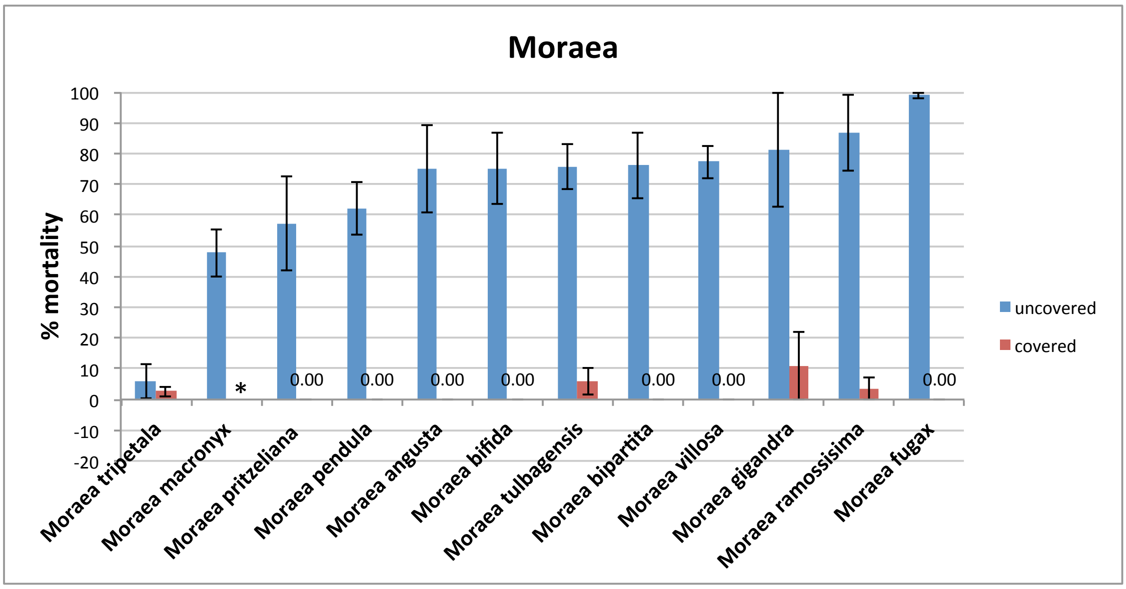

Hesperantha
% mortality
-20
-10
0
10
20
30
40
50
60
70
80
90
100
0.00
Hesperantha humilis
Hesperantha cucullatus
Hesperantha luticola
Hesperantha pauciflora
Hesperantha vaginata
uncovered
covered

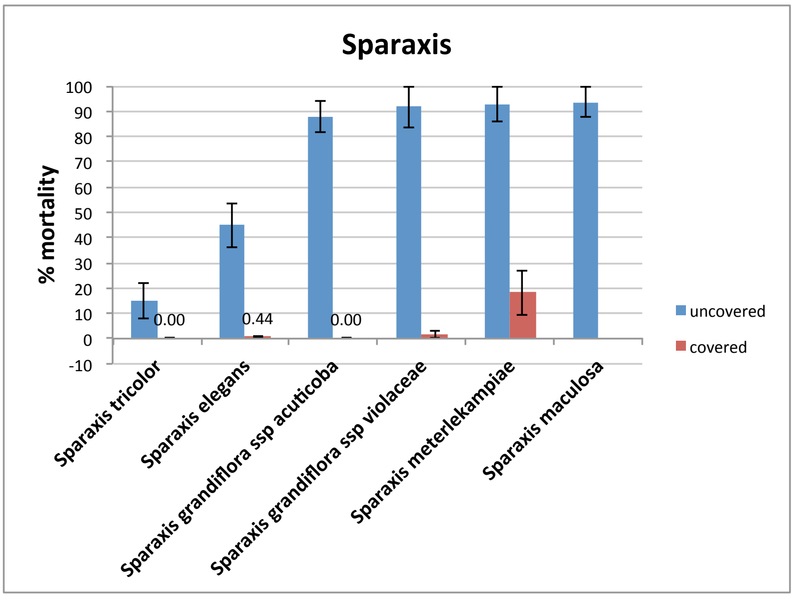

Lapeirousia
% mortality
-10
0
10
20
30
40
50
60
70
80
90
100
110
Lapeirousia azurea
Lapeirousia silenoides
uncovered
covered


Ixia
% mortality
-10
0
10
20
30
40
50
60
70
80
90
100
0.00
Ixia curvata
Ixia rapunculoides
Ixia thomasiae
Ixia latifolia
Ixia maculata
Ixia scilliaris
uncovered
covered


Romulea
% mortality
0
10
20
30
40
50
60
70
80
90
100
Romulea komsbergensis
Romulea amoena
uncovered
covered


Lachenalia
% mortality
110
100
90
80
70
60
50
40
30
20
10
0
-10
Lachenalia mutabilis
Lachenalia purpureo-caerulea
Lachenalia orchioides var. glaucina
Lachenalia viridiflora
Lachenalia bulbifera
Lachenalia rubida
Lachenalia aloides
Lachenalia carnosa
Lachenalia contaminata
Lachenalia pallida
uncovered
covered


Moraea
% mortality
100
90
80
70
60
50
40
30
20
10
0
-10
-20
*
0.00
0.00
0.00
0.00
0.00
0.00
0.00
Moraea tripetala
Moraea macronyx
Moraea pritzeliana
Moraea pendula
Moraea angusta
Moraea bifida
Moraea tulbagensis
Moraea bipartita
Moraea villosa
Moraea gigandra
Moraea ramossisima
Moraea fugax
uncovered
covered


Sparaxis
% mortality
100
90
80
70
60
50
40
30
20
10
0
-10
0.00
0.44
0.00
Sparaxis tricolor
Sparaxis elegans
Sparaxis grandiflora ssp acuticoba
Sparaxis grandiflora ssp violaceae
Sparaxis meterlekampiae
Sparaxis maculosa
uncovered
covered

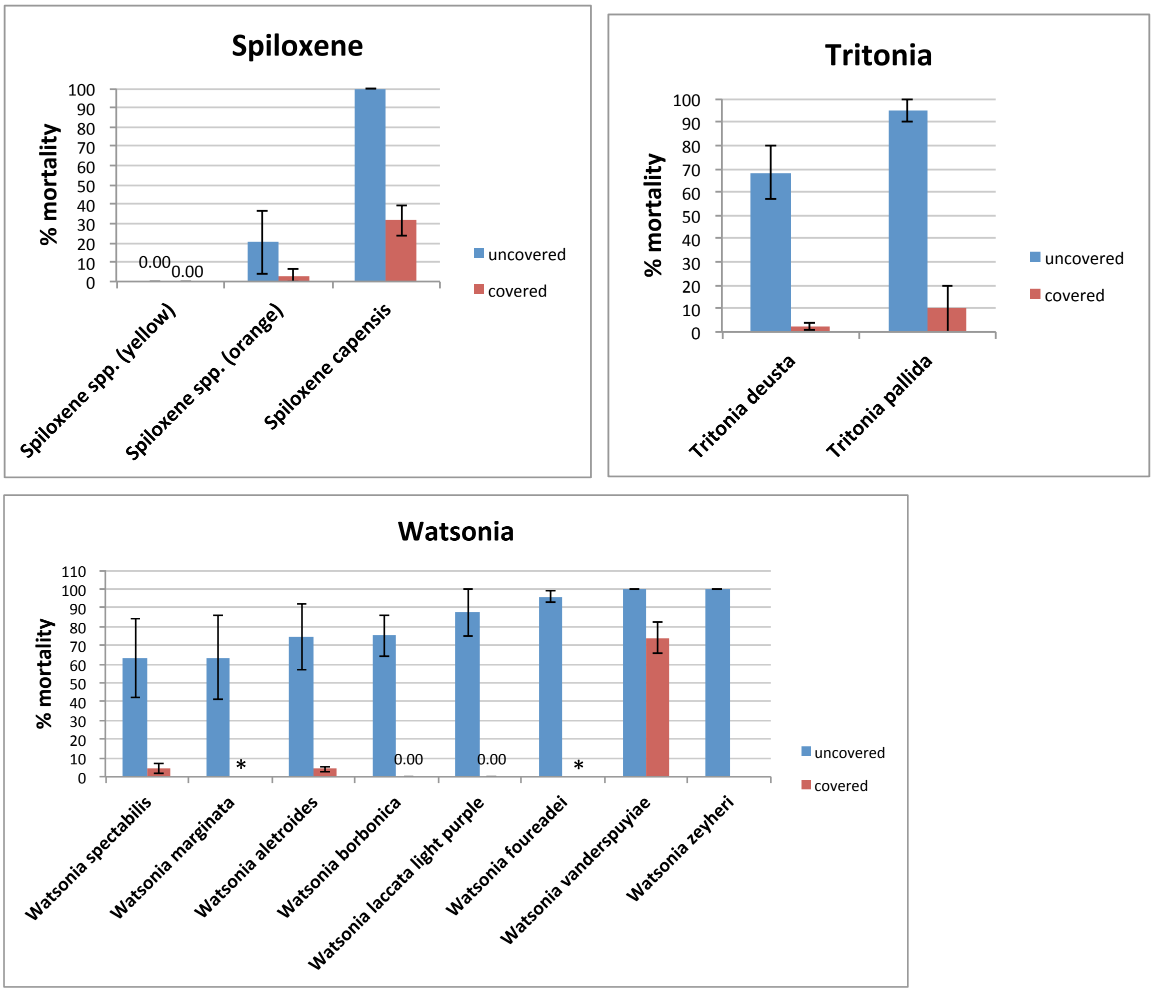


Fig.4.22 Mean mortality of individual deciduous geophyte species within important genera. * means no sample of this species was tested in this treatment).

4.3.3 Winter Cold Tolerance Experiment, Phase 2 (Dec. 2012-April 2014)

Most of the test species in Phase 2 were collected from high altitude in inland mountains in cold geographical regions which naturally experienced more frost days during winters.

4.3.3.1 General mortality

Table 4.9 shows that whilst mortality was significantly lower in covered blocks (P = 0.025), the differences were reduced, (covered 41%; uncovered 50%) as a result of the less extreme temperatures experienced in 2012-13. In 2011-12, the mortality differences between the treatments were much greater.

Table. 4.9 Effect of cover vs no cover on winter mortality in 2012-2013 as mean of all species.

Tests of Between-Subjects Effects

Dependent Variable: 2012-2013 Part Two Winter mortality %

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	8122.132a	1	8122.132	5.086	0.025
Intercept	829794.225	1	829794.225	519.604	0.000
covered	8122.132	1	8122.132	5.086	0.025
Error	641983.843	402	1596.975		
Total	1482524.08	404			
Corrected Total	650105.975	403			

a R Squared = .012 (Adjusted R Squared = .010)

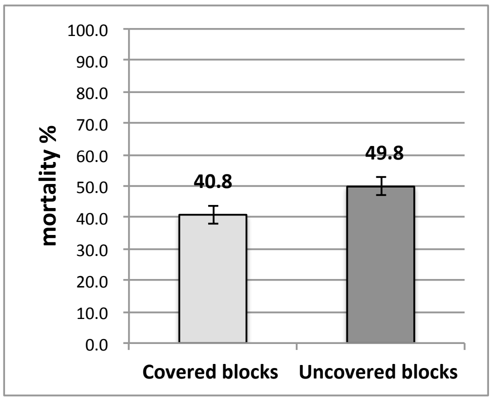


Fig. 4.23 Average mortality (mean of all species) in covered and uncovered treatments over winter 2012-2013. There were 199 pots tested in the covered treatment and 205 pots tested in the uncovered treatment (error bars indicate standard error).

4.3.3.2 Winter mortality comparison between evegreen forbs/shrubs/geophytes and summer deciduous geophytes in Phase 2.

Winter cover significantly reduced the mortality of shrubs/forbbs/evergreen geophytes (P =0.009) in winter 2011/2012, but not in deciduous geophytes (P =0.542). Group of summer deciduous geophytes had similar mortality in both treatments, suggesting the geophytes used were more cold tolerant than the shrubs, forbs, and evergreen geophytes.

Table. 4.10 Effect of winter cover on 2012-2013 winter mortality of deciduous geophytes and frobs/evergreen geophytes.

Tests of Between-Subjects Effects

Dependent Variable: 2012-2013 Part Two Winter mortality %

Life.form	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
deciduous geophytes	covered	508.224	1	508.224	0.372	0.542
	Error	274313.426	201	1364.743		
	Total	967153.65	203			
	Corrected Total	274821.65	202			
forbs and evergreen geophytes	covered	10291.538	1	10291.54	6.92	0.009
	Error	295958.599	199	1487.229		
	Total	515370.43	201			
	Corrected Total	306250.137	200			

a R Squared = .002 (Adjusted R Squared = -.003)

b R Squared = .034 (Adjusted R Squared = .029)

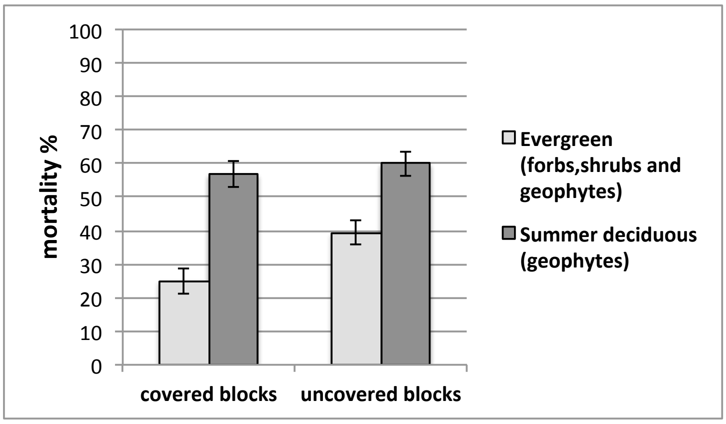


Fig. 4.24 Comparison of over winter mortality between Evergreen Forbs/Shrubs/Geophytes and Summer Deciduous Geophytes in both covered and uncovered treatments (error bars indicate standard error).

4.3.3.3 The effect of collection locations on Winter Mortality in Phase 2

(1) Geographical Region

The geographical regions species were derived from, only Stellenbosch to Hermanus (STH) showed significant difference (P=0.003) in winter mortality in 2012-2013 between winter covered and uncovered treatments. These reduced number of significant differences are probably largely a result of the less severe temperatures experienced in this winter.

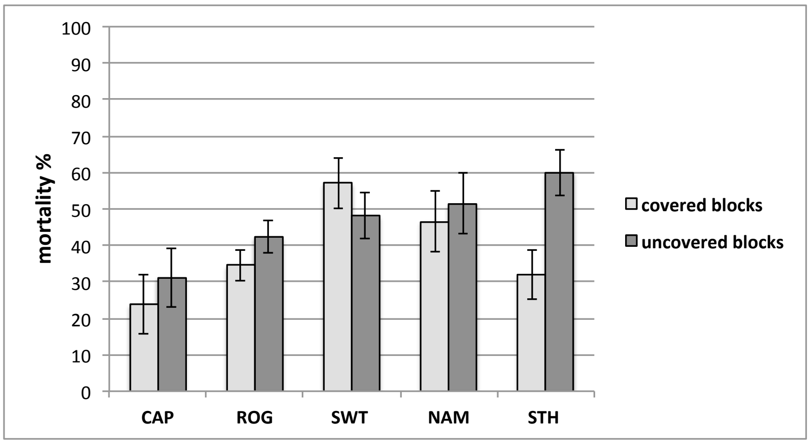


Fig. 4.25 Comparison of over winter mortality of species of different geographical areas in response to covered and uncovered treatments (error bars indicate standard error).

(2) Provenance

The same approach as in Phase 1 was applied to analise provenances within each geographical region. Because most of the tested species in part two were collected from high altitudes, their capacity of cold tolerance was assumed to be higher. The Univariate test found no significant difference, except Perdaskop (P =0.002) (Table 4.11). In winter un-covered treatment (see Table 4.12), populations from cold, high altitudes provenances such as near Middelpos with many frost days had less mortality. Coastal populations had much higher mortality.

Table 4.11 'General Linear Model- Univariate analysis into the effect of winter cover on mortality of species from different provenances.

Provenance	winter cover condition	Mean winter mortality %	Std. Error	Sig.
Table Mountain	winter uncovered blocks	31.25	8.13	0.539
	winter covered blocks	23.75	8.13	
Stellenbosch	winter uncovered blocks	82.94	10.23	0.663
	winter covered blocks	75.86	12.23	
Bainskloof	winter uncovered blocks	70.45	23.87	.
Matroosberg	winter uncovered blocks	33.10	10.02	0.171
	winter covered blocks	53.54	10.43	
Tulbagh	winter uncovered blocks	57.53	14.11	0.669
	winter covered blocks	66.48	14.11	
Piketberg	winter uncovered blocks	79.53	8.86	0.190
	winter covered blocks	61.00	8.86	
Nieuwoudtville	winter uncovered blocks	87.33	5.46	0.451
	winter covered blocks	93.55	5.46	
Leliefontein	winter uncovered blocks	100.00	4.42	0.356
	winter covered blocks	93.75	4.42	
Kamiesberg (Kamieskroon)	winter uncovered blocks	39.36	7.84	0.685
	winter covered blocks	34.83	7.84	
Calvinia	winter covered blocks	0.00	0.00	.

Provenance	winter cover condition	Mean winter mortality %	Std. Error	Sig.
Roggeveld	winter uncovered blocks	54.18	19.09	0.180
	winter covered blocks	19.37	14.43	
near Middelpos	winter uncovered blocks	12.50	9.68	0.437
	winter covered blocks	0.00	11.18	
Middelpos	winter uncovered blocks	57.95	11.15	0.415
	winter covered blocks	44.07	12.33	
Komsberg	winter uncovered blocks	44.77	13.54	0.626
	winter covered blocks	34.69	15.14	
Groot Swartberg mountains	winter uncovered blocks	25.47	5.56	0.287
	winter covered blocks	16.87	5.75	
Rooiwal	winter uncovered blocks	51.01	8.94	0.473
	winter covered blocks	42.28	8.10	
loeriesfontein	winter covered blocks	100.00	0.00	.
Perdaskop	winter uncovered blocks	55.64	7.12	**0.002**
	winter covered blocks	22.92	7.12	
Franschhoek	winter uncovered blocks	25.00	10.61	0.147
	winter covered blocks	0.00	10.61	
Cold Bokkeveld	winter uncovered blocks	33.60	14.37	0.342
	winter covered blocks	54.55	14.37	

Table 4.12 2012-2013 Winter mortality of species drawn from various provenances on uncovered blocks . Numbers in parentheses represent number of genotypes tested.

Provenance	Mean winter mortality %	Std. Error	collection loction information	
			altitude	frost days
near Middelpos (4)	12.50	9.68	high	long
Franschhoek (4)	25.00	10.61	medium	short
Groot Swartberg mountains (30)	25.47	5.56	high	long
Table Mountain (4)	31.25	8.13	low-high	short
Matroosberg (13)	33.10	10.02	high	long
Cold Bokkeveld (4)	33.60	14.37	high	long
Kamiesberg (16)	39.36	7.84	high	medium
Komsberg (10)	44.77	13.54	high	long
Rooiwal (23)	51.01	8.94	high	long
Roggeveld (4)	54.18	19.09	high	long
Perdaskop (20)	55.64	7.12	high	medium
Tulbagh (4)	57.53	14.11	low	short
Middelpos (11)	57.95	11.15	high	long
Bainskloof (4)	70.45	23.87	low-high	short-medium
Piketberg (4)	79.53	8.86	low	short
Stellenbosch (10)	82.94	10.23	low-medium	short
Nieuwoudtville (4)	87.33	5.46	medium-high	medium
Leliefontein (4)	100.00	4.42	high	medium-long

4.3.3.4 Mean individual species winter mortality in Phase 2

There were 57 species (all as 8 pots) being tested during winter 2012/2013. The overall mortality of these species in uncovered blocks was 50.06%. Ten species (17.54%) had less than 10% mortality, and 13 species (22.8%) had less than 15% mortality. Amongst the 13 species (<15% mortality), there were 9 shrub/forb/succulent/evergreen geophyte species and 4 deciduous geophyte species. Most of these species were collected from high altitude continental inland mountains Roggeveld, Rooiwal, Middelpos, Kamiesberg, Groot Swartberg mountains and Matroosberg. It was surprising that *Tritoniopsis spp.* from Groot Swartberg mountains (1360m), *Bulbinella eburnifolia* from Nieuwoudtville (800-1000m), *Bulbinella elegans* from Rooiwal (1100m), *Gladiolus splendens* from both Rooiwal (1100m) and Middelpos (1000m), and *Gladiolus equitans* from Leliefontein (1300-1400m) which all experience more than 20-56 days frost days in their habitats all suffered high mortality only at -2°C. Winter 2012-13 was very wet and it may be that some of the recorded mortality is due to this factor, and rainfall in winter is typically relatively low in these inland continental mountains, with total annual rainfall generally <300mm pa.

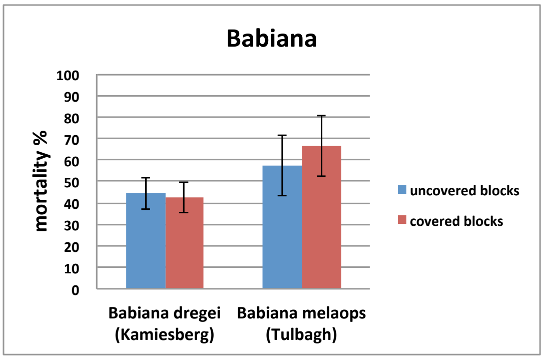
Table 4.13 Mean mortality of individual species in winter uncovered treatment over winter 2012-2013.

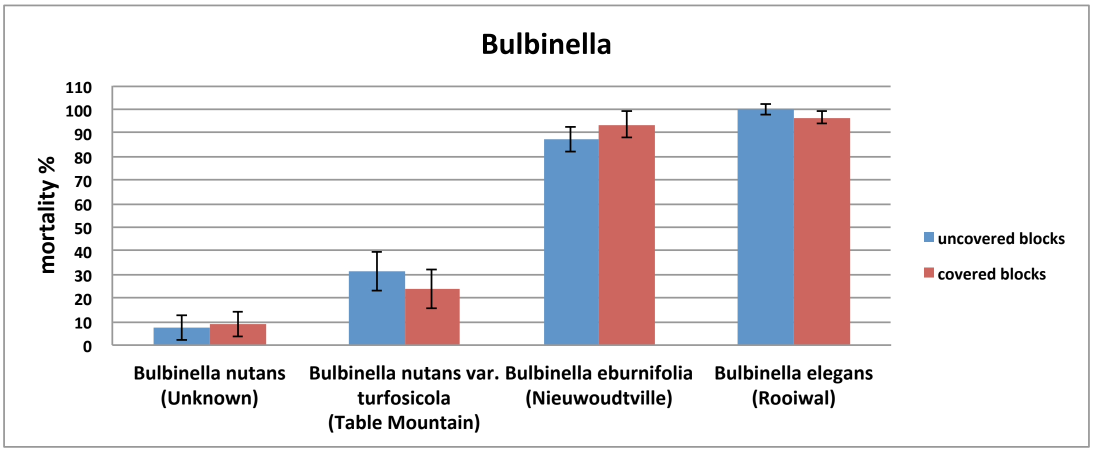
		Winter.cover.condition						
		winter uncovered blocks (I)		winter covered blocks (J)				
Species Name	**collection location**	**Mean winter mortality %**	**Std. Error**	**Mean winter mortality %**	**Std. Error**	**Sig.b (I-J)**	**Altitute of collection location**	**Estimated frost days in collection location**
Romulea komsbergensis	Roggeveld	0.000	8.456	8.900	4.228	0.416	high	long
Erica tumida	Matroosberg	0.000	.	.	.	.	high	long
Esterhuysenia alpina	Matroosberg	0.000	5.103	12.500	5.103	0.134	high	long
Gazania leipoldtii	Kamiesberg	0.000	5.887	8.325	5.887	0.356	high	medium
Gazania othonites	Rooiwal	0.000	22.361	25.000	19.365	0.437	high	long
Watsonia marlothii	Groot Swartberg mountains south slope 1575m	0.000	0.937	1.325	0.937	0.356	high	long
Watsonia schlecteri	Groot Swartberg mountains south slope 1730m	1.475	1.441	4.200	1.441	0.230	high	long
Bulbinella nutans	Ex hort or Specific Location Unknown	7.300	5.167	8.750	5.167	0.849		
Romulea subtistulosa	Ex hort or Specific Location Unknown	7.750	8.354	24.400	8.354	0.208		
Watsonia marlothii	Groot Swartberg mountains north slope 1900m	8.025	3.229	4.600	3.229	0.482	high	long
Leucadendron album	Groot Swartberg mountains	11.100	7.849	0.000	7.849	0.374	high	long
Dimporphotheca nudicaulis	near Middelpos	12.500	9.682	0.000	11.180	0.437	high	long
Watsonia Tresco Dwarf pink	Ex hort or Specific Location Unknown	12.500	8.839	0.000	8.839	0.356		
Watsonia schlecteri	Groot Swartberg mountains north slope 1550m	15.900	9.386	17.100	9.386	0.931	high	long
Watsonia borbonica	Perdaskop	18.750	16.732	25.000	16.732	0.801	high	medium
Ursinia spp.	Middelpos	20.000	16.330	0.000	20.000	0.495	high	long
Crotalarca humclis	Rooiwal	20.825	8.837	0.000	8.837	0.147	high	long
Ruschia spp.	Franschhoek	25.000	10.607	0.000	10.607	0.147	medium	short
Leucadendron spissifolium spp. Fragrans	Groot Swartberg mountains	29.567	7.225	5.000	6.257	0.050	high	long
Bulbinella nutans var. turfosicola	Table Mountain	31.250	8.133	23.750	8.133	0.539	low-high	short
Gazania rigida	Komsberg	33.333	33.333	50.000	28.868	0.721	high	long
Tritoniopsis spp	Cold Bokkeveld	33.600	14.366	54.550	14.366	0.342	high	long
Watsonia schlecteri	Perdaskop	35.000	13.189	27.500	13.189	0.702	high	medium
Romulea monadelpha	Rooiwal	39.575	15.096	0.000	15.096	0.113	high	long
Babiana dregei	Kamiesberg	41.100	5.047	36.975	5.047	0.584	high	medium
Felicia filifolia	Rooiwal	43.750	9.547	81.250	9.547	**0.032**	high	long
Ixia curvata	Komsberg	45.250	16.734	.	.	.	high	long
Gladiolus cardinalis	Matroosberg	46.425	15.276	54.475	15.276	0.722	high	long
Babiana dregei	Kamiesberg	47.600	9.432	48.200	9.432	0.966	high	medium
Ixia thomasiae	Middelpos	49.625	8.505	41.650	8.505	0.532	high	long
Ruschia spp.	Groot Swartberg mountains	51.775	16.275	70.850	16.275	0.439	high	long
Stachys rugosa	Komsberg	55.567	21.120	19.375	18.290	0.252	high	long
Aristea spp.	Perdaskop	56.250	13.476	8.325	13.476	**0.046**	high	medium
Babiana melaops	Tulbagh	57.525	14.108	66.475	14.108	0.669	low	short
Tritoniopsis spp	Matroosberg	61.150	7.256	93.650	7.256	**0.019**	high	long
Watsonia borbonica	Stellenbosch	61.900	18.759	43.667	21.661	0.553	low-medium	short
Lessertia frutescens	Kamiesberg	68.750	22.293	45.825	22.293	0.495	high	medium
Watsonia schlecteri	Bainskloof	70.450	23.872	.	.	.	low-high	short-medium
Lessertia rigida	Roggeveld	72.233	25.759	33.333	25.759	0.346	high	long
Arctotis campanuflora (diffusa)	Ex hort or Specific Location Unknown	75.000	25.000	.	.	.		
Tritoniopsis triticea	Piketberg	79.525	8.861	61.000	8.861	0.190	low	short
Aristea spp.	Perdaskop	81.250	15.347	26.350	15.347	**0.045**	high	medium
Tritoniopsis spp	Groot Swartberg mountains	83.350	9.613	60.000	19.226	0.357	high	long
Aristea spp.	Perdaskop	86.925	10.806	27.400	10.806	**0.008**	high	medium
Bulbinella eburnifolia	Nieuwoudtville	87.325	5.460	93.550	5.460	0.451	medium-high	medium
Gladiolus splendens	Rooiwal	89.150	7.453	76.625	7.453	0.280	high	long
Watsonia zeyheri	Stellenbosch	90.900	9.100	.	.	.	low-medium	short
Gladiolus splendens	Middelpos	94.725	12.997	76.667	15.008	0.405	high	long
Gladiolus equitans	Ex hort or Specific Location Unknown	95.825	3.688	96.875	3.688	0.847		
Ornithogalum corticatum	Ex hort or Specific Location Unknown	96.875	2.210	100.000	2.210	0.356		
Syncarpha vestita	Ex hort or Specific Location Unknown	100.000	0.000	100.000	0.000	.		
Tritonia deusta	Ex hort or Specific Location Unknown	100.000	3.536	95.000	3.536	0.356		
Bulbinella elegans	Rooiwal	100.000	2.528	96.425	2.528	0.356	high	long
Gladiolus equitans	Leliefontein	100.000	4.419	93.750	4.419	0.356	high	medium-long
Hermannia stricta	Ex hort or Specific Location Unknown	100.000	.	.	.	.		
Lapeirousia oreogena	Stellenbosch	100.000	.	.	.	.	low-medium	short
Tripteris oppositifolia	Stellenbosch	100.000	0.000	100.000	0.000	.	low-medium	short

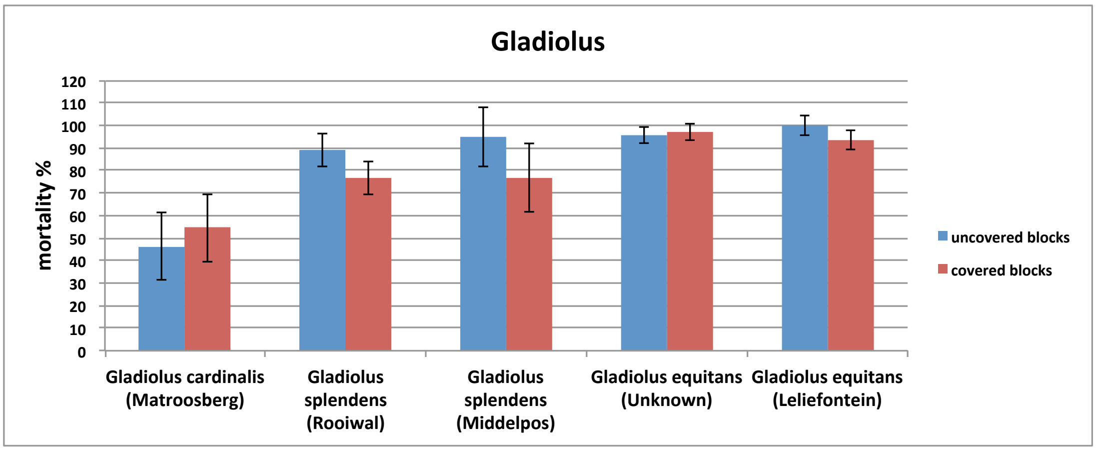
4.3.3.5 Winter mortality of key genera in Phase 2.

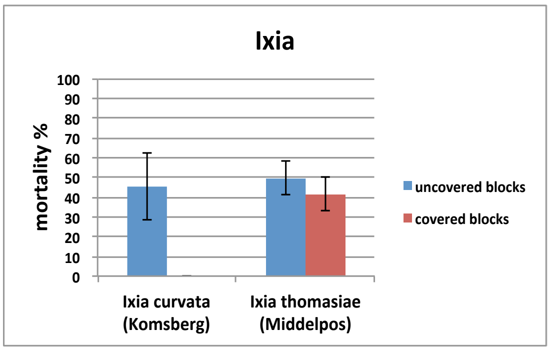
The following within genus comparisons illustrate the levels of winter cold tolerance between test species. *Romuleas* were the most hardy geophyte species in Phase 2, and the *Romulea komsbergensis* was still the best performer within the genus. This colonial species grows in high altitude seasonal wetlands. Similar results were seen in Phase 1, *Romuleas* from the Roggeveld suffer 0% winter mortality even in very wet or cold winters. *Bulbinella nutans* and *B. nutans var. turfosicola* were much more hardy than *B. eburnifolia* and *B. elegans.* In the case of *B. eburnifolia* this is not surprising as it is restricted to altitudes of 800-900m altitude. *Bublinella elegans,* is however, generally a very cold tolerant species*.* *Gladiolus* continue to be damaged at temperatures as which they should not be damaged, for example, *G. cardinalis* collected from Matroosberg (1925m) with 67.5 frost days was the most cold tolerant species in this genus in phase two, but the mortality figure was still near 50%. *Tritoniopsis* seemed to be a sensitive genus, even they origined in high altitude moutains, they have proved to be very difficult to grow in cultivation. Some of the *Watsonia* tested seem to have great potential, particularly the *W. marlothii* provenances from the Groot Swartberg mountains all had less than 16% mortality, much less than the other species tested.

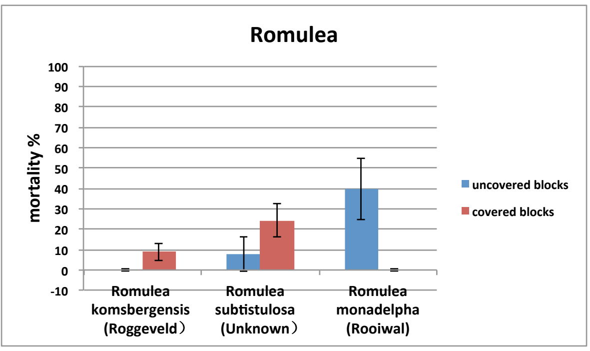
Wetness and humidty seem to have been an issue in some of the shrubs and forbs. *Lessertia* was the most sensitive genus to wetness. *Gazania* was the most-cold tolerant genus, but proved to be very intolerant of the more humid atmosphere within the covered plots, with evidence of fungal pathogen damage. Mortality was always greater when covered. Amougst *Gazania*, *G. rigida* was the most prone to mortality.

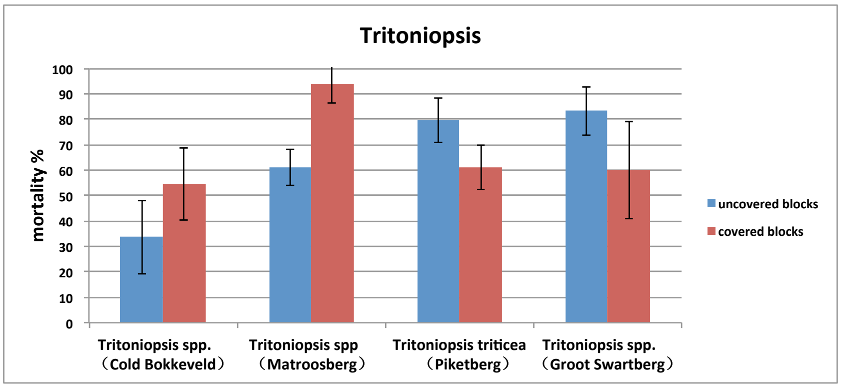



Bulbinella
mortality %
0
10
20
30
40
50
60
70
80
90
100
110
Bulbinella nutans (Unknown)
Bulbinella nutans var. turfosicola (Table Mountain)
Bulbinella eburnifolia (Nieuwoudtville)
Bulbinella elegans (Rooiwal)
uncovered blocks
covered blocks


Gladiolus
mortality %
0
10
20
30
40
50
60
70
80
90
100
110
120
Gladiolus cardinalis (Matroosberg)
Gladiolus splendens (Rooiwal)
Gladiolus splendens (Middelpos)
Gladiolus equitans (Unknown)
Gladiolus equitans (Leliefontein)
uncovered blocks
covered blocks


Ixia
mortality %
0
10
20
30
40
50
60
70
80
90
100
Ixia curvata (Komsberg)
Ixia thomasiae (Middelpos)
uncovered blocks
covered blocks


Romulea
mortality %
-10
0
10
20
30
40
50
60
70
80
90
100
Romulea komsbergensis（Roggeveld）
Romulea subtistulosa（Unknown）
Romulea monadelpha (Rooiwal)
uncovered blocks
covered blocks


Tritoniopsis
mortality %
0
10
20
30
40
50
60
70
80
90
100
Tritoniopsis spp.（Cold Bokkeveld）
Tritoniopsis spp（Matroosberg）
Tritoniopsis triticea（Piketberg）
Tritoniopsis spp.（Groot Swartberg）
uncovered blocks
covered blocks

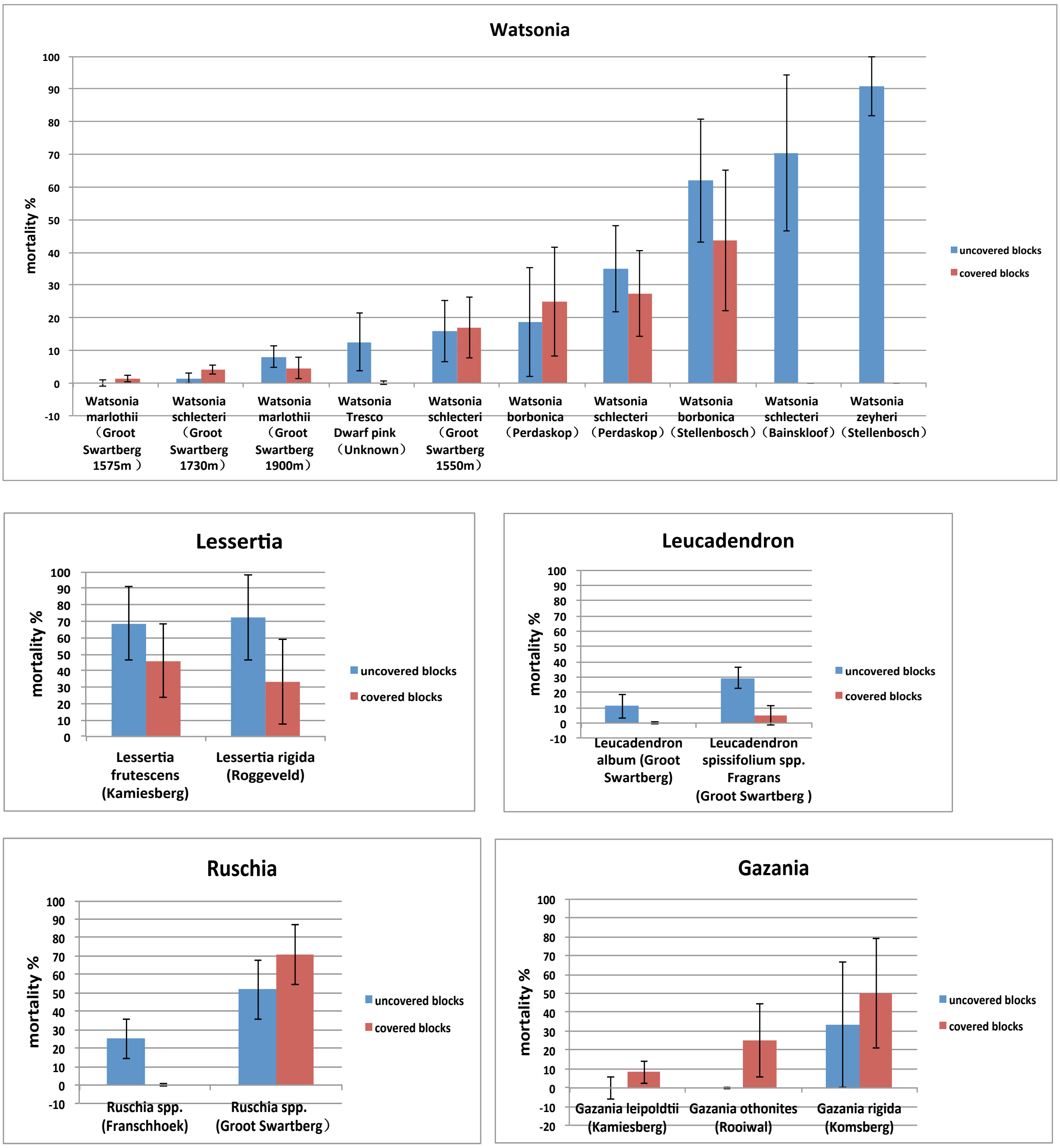


Fig.4.26 Mean mortality of individual species within important genera. * means no sample of this species was tested in this treatment).

4.3.4 Summer Wetness Tolerance Experiment, Phase 1 (summer 2012)

4.3.4.1 General summer mortality of phase 1

There were 560 summer deciduous geophytes pot units tested in summer uncovered treatment over the historical wettest summer 2012, and 528 pot units tested in summer covered treatment. Test samples of evergreen (forbs, shrubs and geophytes) were 140. Mortality was not significantly different between covered and uncovered deciduous geophytes (P =0.074). All evergreen species were taken out of the blocks before summer covered treatment were covered on screens.

Table 4.14 Effect of summer cover on 2012 summer mortality of deciduous geophytes. Forbs/evergreen geophytes were not subjected to this summer covered, droughting treatment.

Tests of Between-Subjects Effects

Dependent Variable: 2012 Summer mortality %

Life.form	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Summer deciduous (geophytes)	Corrected Model	4726.229a	1	4726.229	3.197	0.074
	Intercept	2070632.791	1	2070632.791	1400.702	0.000
	cover	4726.229	1	4726.229	3.197	0.074
	Error	1605414.326	1086	1478.282		
	Total	3676746	1088			
	Corrected Total	1610140.555	1087			
Evergreen (forbs, shrubs and geophytes)	Corrected Model	.000b	0	.	.	.
	Intercept	119019.457	1	119019.457	92.863	0.000
	cover	0	0	.	.	.
	Error	178152.543	139	1281.673		
	Total	297172	140			
	Corrected Total	178152.543	139			

a R Squared = .003 (Adjusted R Squared = .002)
b R Squared = .000 (Adjusted R Squared = .000)

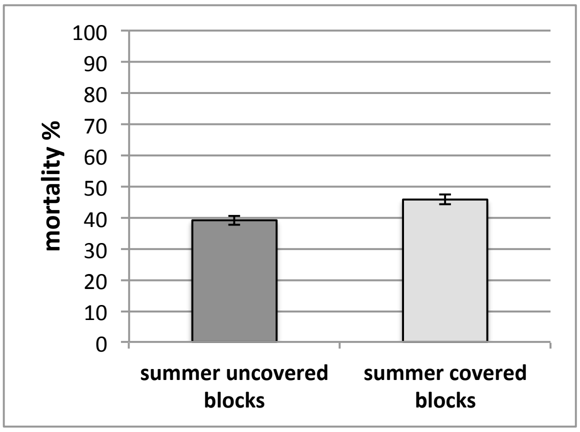


Fig. 4.27 Mean mortality of all the summer dormant geophyte species in covered and uncovered treatments over summer 2012. There were 700 pots tested uncovered and 528 unit pots tested covered . Error bars indicate standard error.

4.3.4.2 Summer mortality comparison between evegreen forbs/shrubs/geophytes and summer deciduous geophytes over summer 2012

Mortality of uncovered shrubs/frobs/evergreen geophytes group was significantly less (P = 0.000) than uncovered summer deciduous geophytes.

Table. 4.15 Effect of life form (summer deciduous geophytes v evergreen forbs/shrubs/geophytes) on 2012 summer mortality.

Tests of Between-Subjects Effects

Dependent Variable: 2012 Summer mortality

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	17226.080a	1	17226.08	12.627	0.000
Intercept	560085.429	1	560085.429	410.555	0.000
Life.form	17226.08	1	17226.08	12.627	0.000
Error	952222.598	698	1364.216		
Total	2038443	700			
Corrected Total	969448.679	699			

a R Squared = .018 (Adjusted R Squared = .016)

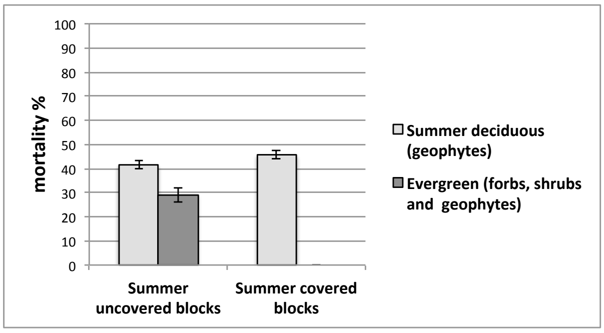


Fig. 4.28 Comparison of over summer mortality between Eevegreen Forbs/Shrubs/Geophytes and Summer Deciduous Geophytes in winter covered but summer uncovered treatment, including 4 sample blocks (error bars indicate standard error).

4.3.4.3 The effect of collection locations on Summer Mortality of part one

(1) Geographical Region

In Figure 4.39, ROG, NAM, ESC, CAP, STH, WCT, SWT, SOU and CC represent Roggeveld (continental inland mountains), Namaqualand (coastal plain to inland mountains), Eastern Cape, Cape Peninsula, Stellenbosch to Hermanus (coastal mountain to coast), West coast (coastal plain), Swartland (lower altitude to inland mountains), Southern valleys & mountains and Cedarberg & Clanwilliam (inland mountains) respectively. The comparison of summer mortality in summer 2012 between summer uncovered and covered treatments was arranged from low to high based on the summer uncovered treatment. Contrary to expectation (Figure 4.29), in most mortality in summer covered treatments was generally higher than in treatments exposed to summer rainfall. This result may however be an artifact of the fact that seedlings covered in summer, had been uncovered in winter, and their higher mortality may be a reflected being damaged in the previous winter (2011/2012), rather than a response to summer conditions per se.

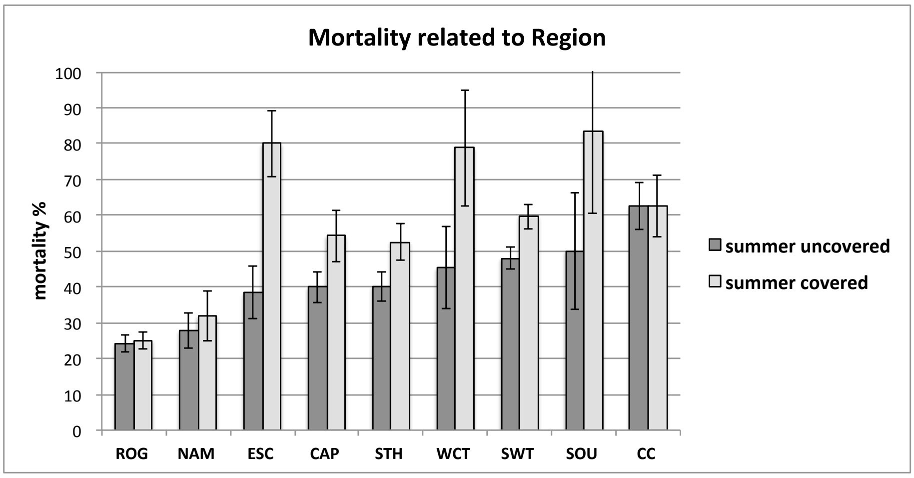


Fig. 4.29 Comparison of over summer mortality of species in both covered and uncovered treatments in different geographical regions in summer 2012 (error bars indicate standard error).

This source of uncertainty does not however affect the summer uncovered treated (covered in winter 2011-12) which shows (Figure 4.29) marked differences in tolerance of summer wet between the species-provences originating in different geographical regions. Table 4.16 highlights the regions which had significant different mortalities when uncovred in summer. The different responses to summer wettness may related to geophytes from higher altitude, or more moisture retentive soil types being more tolerant of sitting in moist soil over summer.

Table 4.16 Univariate ANOVA pairwise comparisons between different geographical regions. Only comparisons which were significantly different at P= 0.05 are shown.

Pairwise Comparisons

Dependent Variable: 2012 Summer mortality %

(I) Geographical Region	(J) Geographical Region	Mean Difference (I-J) %	Std. Error	Sig.b	South African "Bio-region type"	
					Region (I)	**Region (J)**
Stellenbosch to Hermanus (coastal mountain to coast)	Roggeveld (continental inland mountains)	15.971*	4.851	0.046	low altitude Fynbos/Renosterveld	high altitude Renosterveld
Swartland (lower altitude to inland mountains)	Namaqualand (coastal plain to inland mountains)	20.285*	5.513	0.011	low-high altitude Fynbos/Renosterveld	low-high altitude Renosterveld
	Roggeveld (continental inland mountains)	23.847*	3.978	0.000	low-high altitude Fynbos/Renosterveld	high altitude Renosterveld
Cedarberg & Clanwilliam (inland mountains)	Namaqualand (coastal plain to inland mountains)	34.678*	7.49	0.000	medium-high altitude Fynbos	low-high altitude Renosterveld
	Roggeveld (continental inland mountains)	38.239*	6.445	0.000	medium-high altitude Fynbos	high altitude Renosterveld
Namaqualand (coastal plain to inland mountains)	Swartland (lower altitude to inland mountains)	-20.285*	5.513	0.011	low-high altitude Renosterveld	low-high altitude Fynbos/Renosterveld
	Cedarberg & Clanwilliam (inland mountains)	-34.678*	7.49	0.000	low-high altitude Renosterveld	medium-high altitude Fynbos
Roggeveld (continental inland mountains)	Stellenbosch to Hermanus (coastal mountain to coast)	-15.971*	4.851	0.046	high altitude Renosterveld	low altitude Fynbos/Renosterveld
	Swartland (lower altitude to inland mountains)	-23.847*	3.978	0.000	high altitude Renosterveld	low-high altitude Fynbos/Renosterveld
	Cedarberg & Clanwilliam (inland mountains)	-38.239*	6.445	0.000	high altitude Renosterveld	medium-high altitude Fynbos

Based on estimated marginal means
* The mean difference is significant at the
b Adjustment for multiple comparisons: Sidak.

(2) Provenance

Table 4.17 shows summer mean mortality of each provenance group of species in the summer uncovered treatment. There were 13 provenances of involving 237 pots had mortality of less than 30. Nine of these 13 provenances were categorised as Renosterveld which are characterized by more water retentive clay based soil. There were 14 provenances involving 107 pots with mortality >50%, from which 9 provenances were categorised as Fynbos, with sandy soil. There was no clear relation with local mean average precipitation.

Table 4.17 2012 Summer mortality of uncovered treatment and related information of each provenances.

Provenance	Mean summer mortality %	Std. Error	South African "Bio-region type"		Altitude	Mean average precipitation (mm)
			Fynbos	Renosterveld		
Caledon (4)	0.000	16.512		✔	low	490
Garies (2)	0.000	23.352		✔	low-medium	145
McGregor (4)	0.000	16.512		✔	low	370
Komsberg (12)	4.833	9.533		✔	high	230
Groot Swartberg mountains (4)	5.000	16.512	✔		high	375-585
Sutherland (18)	6.389	7.784		✔	high	230
Bot River (4)	9.000	16.512	✔		low	1330
Kamiesberg (40)	15.825	5.222		✔	high	235
Noordaoek (12)	17.833	9.533	✔		low	780
Rooiwal (8)	20.250	11.676		✔	high	290
Napier (8)	23.125	11.676		✔	low	380
Nieuwoudtville (114)	26.851	3.093		✔	medium-high	290
Pakhuis Pass (7)	28.571	12.482	✔		medium-high	395
Roggeveld (25)	32.160	6.605		✔	high	290-305
Bainskloof (31)	33.323	5.931	✔		low-high	1200
Mossel Bay (4)	34.000	16.512	✔		low	605
Middelpos (10)	35.000	10.443		✔	high	230
Stellenbosch (42)	37.381	5.096	✔		low-medium	865-1330
Hantamsberg (4)	37.500	16.512		✔	high	250
Ceres (4)	39.250	16.512		✔	medium	430
Namaqualand (11)	39.364	9.957		✔	medium-high	160
Cape Peninsula(22)	41.818	7.041	✔		low-high	780
Malmesbury (34)	43.647	5.664		✔	low	520
Kovebekkeveld (7)	43.857	12.482		✔	high	430
Paarl moutain (12)	44.250	9.533	✔		low	985
Table Mountain (24)	44.708	6.741	✔		low-high	780
West coast (12)	45.333	9.533	✔		none	250-350
Hermanus (16)	47.063	8.256		✔	low	1070
Tulbagh (24)	53.125	6.741		✔	low	370
Piketberg (7)	53.714	12.482	✔		medium-high	510
Scarborough (8)	54.125	11.676	✔		low	960
Cedarberg (14)	54.714	8.826	✔		high	395
Spoegrivier Namaqualand (3)	66.667	19.067		✔	low	160
Somerset West (4)	69.250	16.512		✔	low	430
Arniston (4)	73.500	16.512	✔		none	400-600
Gouda (12)	77.000	9.533	✔	✔	low	430-655
Clanwilliam (11)	83.091	9.957	✔		low-medium	260-355
Villiersdorp (4)	84.250	16.512	✔		low	830
Citrusdal (4)	92.000	16.512	✔		medium	316-450
Wolseley (4)	100.000	16.512	✔	✔	low	370-480
Springbok (4)	100.000	16.512		✔	high	160
Montagu (4)	100.000	16.512		✔	low	230

4.3.4.4 Effect of geophyte age on summer mortality

In the 9 age groups as shown in Table 4.18 and Figure 4.30 below, there were only a few units of 0.5-1.5 mixed age group and 3.5 years old group in both summer covered and uncovered treatments. These two age groups have larger standard error bars (Fig. 4.30) are statistically unsound as comparisons. Table 4.18 shows that the main age related statitistically significant differences were restricted to two age groups; 1 year old and 2.5 years. It seems high likely that these results are just an artifact of the species present in these groups. Figure 4.30 present summer mortality of each age group in two treatments, but there were no relation with different ages.

Table 4.18 Univariate ANOVA pairwise comparisons between different age groups in summer mortality 2012.

Pairwise Comparisons

Dependent Variable: 2012 summer mortality

Age	(I) Summer.cover.condition	(J) Summer.cover.condition	Mean Difference (I-J)	Std. Error	Sig.a
0.5 yr seedling (newly sown seed)	summer uncovered blocks (258)	summer covered blocks (160)	-6.835	3.749	0.069
0.5 yr and 1 yr mixed seedlings (sown in autumn and spring 2011)	summer uncovered blocks (68)	summer covered blocks (55)	-7.025	6.191	0.259
0.5 yr and 1.5 yr mixed seedlings (sown in autumn 2011 and autumn 2010)	summer uncovered blocks (4)	summer covered blocks (7)	7.143	34.421	0.840
1 yr seedlings (sown in spring 2011)	summer uncovered blocks (124)	summer covered blocks (72)	-16.784*	5.764	**0.004**
1 yr and 1.5 yr mixed seedlings (sown in spring 2011 and autumn 2010)	summer uncovered blocks (20)	summer covered blocks (15)	-6.967	13.721	0.615
1.5 yr old plants (sown in autumn 2010)	summer uncovered blocks (68)	summer covered blocks (88)	2.051	6.429	0.750
2 yrs old plants (sown in spring 2010)	summer uncovered blocks (79)	summer covered blocks (67)	1.336	6.807	0.845
2.5 yrs old plants (sown in autumn 2009)	summer uncovered blocks (76)	summer covered blocks (60)	-17.096*	4.977	**0.001**
3.5 yrs old plants (sown in autumn 2008)	summer uncovered blocks (3)	summer covered blocks (4)	-50.000	34.157	0.203

Based on estimated marginal means

* The mean difference is significant at the

a Adjustment for multiple comparisons: Sidak.

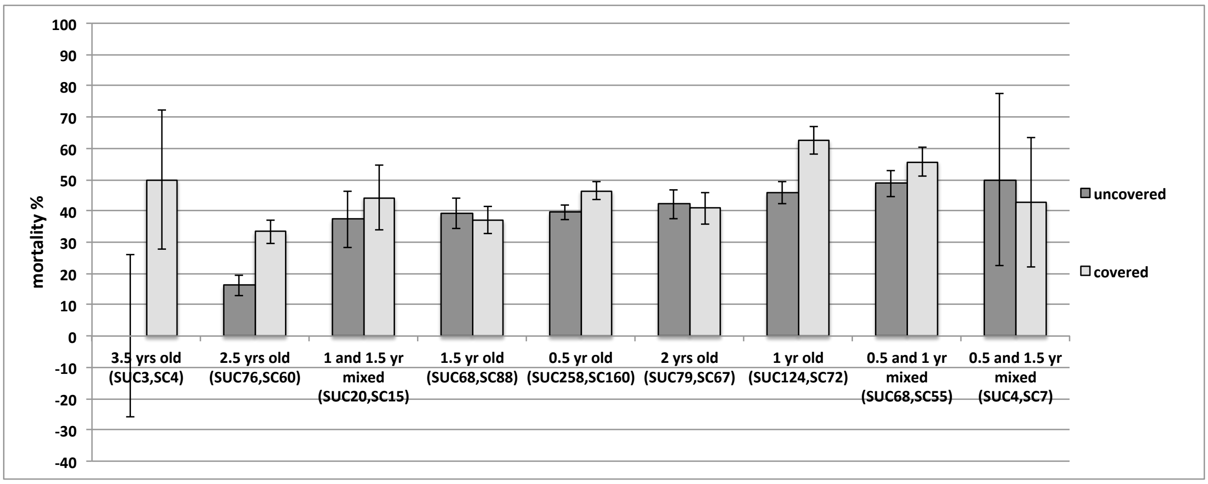


Fig. 4.30 Mortality as mean of all species within given age groups over summer 2012. Error bars indicate standard error.

4.3.4.5 Mean individual summer mortality of part one

There were 192 provenances comprised of more than 3 replicates tested over summer 2012. The overall mortality of these species in uncovered treatment in all replicates was 39%. 65 populations of 48 species (33.9%) tolerated summer wetness in Sheffield with less than 15% mortality in the wettest summer on record in the UK. 30 populations of 25 species (15.6%) had 0% summer mortality. These 25 species involved 11 (44%) shrub/forb/evergreen geophyte species and 14 (56%) deciduous geophyte species. Most of these zero mortality species are naturally distributed in Renosterveld (84%) in medium to high altitude mountains such as the Roggeveld continental inland mountains (Komsberg, Sutherland, Nieuwoudtville, Middelpos, Rooiwal), Namaqualand coastal plain to inland mountains (Namaqualand, Kamiesberg) and Swartland inland mountains (Bainskloof). Similar pattern can be found in populations with <10% mortality. Only *Bulbinella elata* (Bainskloof), *Scabiosa africana* (Cape Peninsula), *Watsonia fourceadei* (Stellenbosch), *Watsonia marginata* (Stellenbosch) and *Podalyria leipoldtii* (Clanwilliam) were from sandy soil Fynbos. The first 4 of these 5 species experienced mean average precipitation between 780-1200mm. In the 36 most sensitive to summer wetness populations (>75% mortality) half were collected from Fynbos and the other half were collected from Renosterveld. In the whole table, there was only few species showed significant difference in summer mortality comparison, as marked in bold in Table 4.19 below (sig.b (I-J)).

The most sensitive species to summer wet were: *Albuca clanwilliamgloria, Lachenalia aloides, Lachenalia pallida, Wachendorfia paniculata, Haemanthus saguineus, Moraea fugax, Moraea ramossisima, Tritonia pallida, Lachenalia carnosa, Spiloxene capensis, Lachenalia rubida, Lachenalia viridiflora* and *Ornithogalum thyrsoides,* which had summer mortality over 90% in both uncovered and covered treatments. By contrast, *Aloinopsis spathulata, Arctotis adpressa, Dimorphotheca cuneata (white/orange), Dimorphotheca tugax, Gazania heterochaeta, Gazania krebsiana, Podalyria leipoldtii, Scabiosa africana* were the most summer wet tolerant forb species. Amongst geophyte species *Bulbinella elata, Bulbinella elegans, Bulbinella nutans, Bulbinella latifolia var latifolia, Hesperantha humilis, Hesperantha cucullatus, Moraea tripetala, Ixia curvata, Ixia rapunculoides, Romulea atrandra, Romulea sabulosa, Romulea komsbergensis, Kniphofia uvaria, Spiloxene spp. (orange/yellow), Watsonia marlothii, Watsonia schlecterii* were extremely tolerant of summer wet soils with less than 10% mortality in both treatments over summer.

Some species showed similar mortality rate even from different provenances. The summer deciduous geophytes *Bulbinella elata* showed 0% mortality from both Bainskloof and Pakhuis Pass, likewise *B. elegans* from the Roggeveld and Nieuwoudtville. Evergreen geophytes *Aristea capitata (major)* from the Cedarberg and Table Mountain had simuilarly low mortality of less than 15%. Forb species *Gazania krebsiana* from Namaqualand and Rooiwal also had low mean mortality 7.5% and 0%. In contrast *Lachenalia aloides* had very high summer mortality over 90% in all three provenances.

Other species present quite different mortalilty figures in different provenances. *Babiana fragrans* from Stellenbosch had mortality of 17.5%, whilst those from Bainskloof, 56.5%. *Babiana cuneata* also showed divergent morality between populations experiencing similar high altitude and low annual rainfall conditions; Nieuwoudtville (30.36%) and Middelpos (50%).

Table 4.19 Mean mortality of individual species in summer uncovered and covered treatment over summer 2012.

Species Name	collection location	Summer.cover.condition				Sig.b (I-J)	Provenance		Altitude	Mean average precipitation (mm)
		summer uncovered blocks (I)		summer covered blocks (J)						
		2012 Mean summer mortality %	Std. Error	2012 Mean summer mortality %	Std. Error		Fynbos	Renosterveld		
Aloinopsis spathulata	Komsberg	0.000	0.000	.	.	.		✔	high	230
Arctotis adpressa	Komsberg	0.000	0.000	.	.	.		✔	high	230
Bulbinella elata	Bainskloof	0.000	0.000	0.000	0.000	.	✔		low-high	1200
Bulbinella elegans	Nieuwoudtville	0.000	0.000	0.000	0.000	.		✔	medium-high	290
Bulbinella nutans	Nieuwoudtville	0.000	5.834	8.250	5.834	0.356		✔	medium-high	290
Dimorphotheca cuneata (white)	Rooiwal	0.000	.	.	.	.		✔	high	290
Dimorphotheca tugax	Namaqualand	0.000	.	.	.	.		✔	medium-high	160
Gazania heterochaeta	Garies	0.000	0.000	.	.	.		✔	low-medium	290
Gazania krebsiana (orange)	Namaqualand	0.000	.	.	.	.		✔	medium-high	160
Gazania krebsiana (orange)	Rooiwal	0.000	0.000	.	.	.		✔	high	290
Geissorhiza aspera	Malmesbury	0.000	12.133	34.500	12.133	0.091		✔	low	520
Gladiolus carinatus	Unknown	0.000	.	67.000	.	.				
Gladiolus floribundus var rudis	McGregor	0.000	0.000	60.000	0.000	.		✔	low	370
Gladiolus splendens	Middelpos	0.000	25.820	50.000	22.361	0.203		✔	high	230
Hesperantha humilis	Sutherland	0.000	0.000	0.000	0.000	.		✔	high	230
Moraea tripetala	Nieuwoudtville	0.000	0.000	0.000	0.000	.		✔	medium-high	290
Moraea tripetala	Nieuwoudtville	0.000	1.414	2.000	1.414	0.356		✔	medium-high	290
Podalyria leipoldtii	Clanwilliam	0.000	.	.	.	.	✔		low-medium	260-355
Scabiosa africana	Cape Peninsula	0.000	0.000	.	.	.	✔		low-high	780
Watsonia aletroides	Caledon	0.000	18.597	45.000	18.597	0.138		✔	low	490
Watsonia foureadei	Stellenbosch	0.000	28.868	83.333	16.667	0.130	✔		low-medium	865-1330
Watsonia marginata	Stellenbosch	0.000	42.500	58.750	21.250	0.304	✔		low-medium	865-1330
Watsonia 'stanford scarlet'	Unknown	0.000	.	.	.	.				
Bulbinella elegans	Roggeveld	0.000	0.000	0.000	0.000	.		✔	high	290-305
Bulbinella elata	Pakhuis Pass	0.000	8.660	30.000	8.660	0.050				395
Romulea atrandra	Roggeveld	0.000	0.000	0.000	0.000	.		✔	high	290-305
Bulbinella nutans	Nieuwoudtville	0.000	0.000	0.000	0.000	.		✔	medium-high	290
Dimorphotheca tragus	Namaqualand	0.000	.	.	.	.		✔	medium-high	160
Romulea sabulosa	Nieuwoudtville	0.000	0.000	0.000	0.000	.		✔	medium-high	290
Moraea macronyx	Komsberg	0.000	22.502	25.333	12.991	0.432		✔	high	230
Kniphofia uvaria	Kovebekkeveld	1.750	1.750	.	.	.		✔	high	430
Dimorphotheca cuneata (orange)	Kamiesberg	2.000	2.000	.	.	.		✔	high	235
Spiloxene spp. (orange)	Kamiesberg	3.500	6.337	8.250	6.337	0.615		✔	high	235
Spiloxene spp. (yellow)	Kamiesberg	4.250	3.005	0.000	3.005	0.356		✔	high	235
Watsonia borbonica	Unknown	4.250	8.859	16.750	8.859	0.357				
Watsonia spectabilis	Paarl moutain	4.500	15.248	63.500	15.248	**0.034**	✔		low	985
Bulbinella latifolia var latifolia	Kamiesberg	4.750	3.276	3.250	3.276	0.757		✔	high	235
Watsonia marlothii	Groot Swartberg mountains	5.000	5.000	.	.	.	✔		high	375-585
Bulbinella latifolia var latifolia	Kamiesberg	5.000	9.171	18.750	9.171	0.330		✔	high	235
Gladiolus carneus var. macowan	Stellenbosch	6.250	18.888	33.333	21.810	0.391	✔		low-medium	865-1330
Gladiolus maculatus	Stellenbosch	6.250	9.270	25.000	10.704	0.243	✔		low-medium	865-1330
Ixia curvata	Sutherland	6.250	4.419	0.000	4.419	0.356		✔	high	230
Ixia rapunculoides	Nieuwoudtville	6.250	12.019	23.000	12.019	0.362		✔	medium-high	290
Hesperantha cucullatus	Nieuwoudtville	6.500	4.821	10.250	4.821	0.602		✔	medium-high	290
Ixia curvata	Sutherland	6.500	3.250	0.000	2.298	0.178		✔	high	230
Ixia thomasiae	Roggeveld	7.000	6.636	26.750	6.636	0.080		✔	high	290-305
Sparaxis tricolor	Nieuwoudtville	7.000	5.212	13.000	5.212	0.447		✔	medium-high	290
Geissorhiza aspera	Cape Peninsula	7.500	10.161	22.250	10.161	0.344	✔		low-high	780
Aristea capitata(major)	Cedarberg	8.000	4.690	.	.	.	✔		high	395
Gladiolus carneus	Noordaoek	8.250	17.054	50.000	19.692	0.170	✔		low	780
Ixia curvata	Sutherland	8.250	5.834	0.000	5.834	0.356		✔	high	230
Ixia rapunculoides	Nieuwoudtville	8.750	4.127	8.000	4.127	0.902		✔	medium-high	290
Gladiolus carneus	Bot River	9.000	9.545	30.000	11.021	0.209	✔		low	1330
Romulea komsbergensis	Roggeveld	10.250	4.586	0.000	4.586	0.165		✔	high	290-305
Watsonia schlecterii	Bainskloof	10.500	5.737	.	.	.	✔		low-high	1200
Gazania pectinata	Kamiesberg	11.000	11.000	.	.	.		✔	high	235
Gladiolus hirsutis	Bainskloof	11.000	11.000	0.000	19.053	0.667	✔		low-high	1200
Kniphofia sarmentosa	Sutherland	11.000	6.364	.	.	.		✔	high	230
Ixia rapunculoides	Nieuwoudtville	11.500	4.949	22.750	4.949	0.159		✔	medium-high	290
Aristea capitata(major)	Table Mountain	12.000	4.564	.	.	.		✔	low-high	780
Aristea confusa	Stellenbosch	12.000	4.320	.	.	.	✔		low-medium	865-1330
Gladiolus carneus	Noordaoek	12.500	11.011	27.750	11.011	0.365	✔		low	780
Aristea confusa	Stellenbosch	14.000	7.746	.	.	.	✔		low-medium	865-1330
Aloinopsis spathulata	Komsberg	14.500	8.529	.	.	.		✔	high	230

Species Name	collection location	Summer.cover.condition				Sig.b (I-J)	Provenance		Altitude	Mean average precipitation (mm)
		summer uncovered blocks (I)		summer covered blocks (J)						
		2012 Mean summer	Std. Error	2012 Mean summer	Std. Error		Fynbos	Renosterveld		
Gazania krebsiana (orange)	Namaqualand	15.000	15.000	.	.	.		✔	medium-high	160
Hesperantha vaginata	Nieuwoudtville	16.000	5.331	0.000	5.331	0.078		✔	medium-high	290
Spiloxene spp. (orange)	Kamiesberg	16.500	14.871	31.250	14.871	0.509		✔	high	235
Hesperantha luticola	Roggeveld	16.500	8.911	8.250	8.911	0.537		✔	high	290-305
Hesperantha pauciflora	Unknown	16.500	12.911	33.333	14.908	0.432				
Babiana thunbergii	West coast	16.750	16.750	0.000	33.500	0.685	✔		low	250-350
Babiana vanzyliae	Nieuwoudtville	16.750	12.974	0.000	14.982	0.437		✔	medium-high	290
sparaxis elegans	Nieuwoudtville	17.250	7.863	29.500	7.863	0.313		✔	medium-high	290
Babiana fragrans	Stellenbosch	17.500	10.819	29.000	12.493	0.518	✔		low-medium	865-1330
Geissorhiza tulbaghensis	Unknown	17.500	9.078	20.000	18.157	0.910				
Gladiolus cardinalis	Unknown	17.500	11.267	31.000	13.010	0.468				
Tritonia deusta	Unknown	18.250	11.557	43.250	11.557	0.177				
Ixia maculata	Malmesbury	18.500	11.608	25.750	11.608	0.674		✔	low	520
Ixia maculata	Malmesbury	19.750	10.258	79.250	10.258	**0.006**		✔	low	520
Crassula coccinea	Table Mountain	20.000	11.547	.	.	.		✔	low-high	780
Crassula dejecta	Bainskloof	20.750	12.472	.	.	.	✔		low-high	1200
Tritonia deusta	Unknown	20.750	20.656	66.667	23.852	0.205				
Watsonia aletroides	Napier	21.250	13.280	75.000	13.280	**0.029**		✔	low	380
Hesperantha pauciflora	Nieuwoudtville	22.750	9.020	34.000	9.020	0.412		✔	medium-high	290
Scabiosa africana	Cape Peninsula	23.000	16.503	.	.	.	✔		low-high	780
Bulbinella elegans	Nieuwoudtville	24.750	4.854	22.750	4.854	0.781		✔	medium-high	290
Babiana sambucifolia	Stellenbosch	25.000	10.206	0.000	10.206	0.134	✔		low-medium	865-1330
Hesperantha vaginata	Nieuwoudtville	25.000	19.365	100.000	22.361	0.052		✔	medium-high	290
Watsonia laccata	Napier	25.000	12.076	83.333	13.944	**0.025**		✔	low	380
Babiana vanzyliae	Nieuwoudtville	25.000	33.104	41.750	23.408	0.701		✔	medium-high	290
Bulbinella caudis-felis	Cedarberg	25.000	30.407	46.750	21.501	0.591	✔		high	395
Geissorhiza inflexa (red)	Tulbagh	25.250	10.103	72.667	11.666	**0.028**		✔	low	370
Romulea amoena	Unknown	25.500	10.663	35.000	10.663	0.552				
Babiana ambigua	Cape Peninsula	26.750	12.784	67.000	14.762	0.094	✔		low-high	780
Gladiolus tristis	Unknown	27.000	7.714	0.000	7.714	**0.048**				
Veltheimia capensis	Kamiesberg	27.000	10.400	.	.	.		✔	high	235
Watsonia tabularis	Table Mountain	27.250	21.116	.	.	.		✔	low-high	780
Dimorphotheca cuneata (orange)	Kamiesberg	28.000	16.274	.	.	.		✔	high	235
Babiana cuneata	Nieuwoudtville	29.000	16.707	60.750	16.707	0.228		✔	medium-high	290
Watsonia schlecterii	Bainskloof	29.500	10.658	.	.	.	✔		low-high	1200
Brunsvigia bosmaniae	Nieuwoudtville	30.000	20.833	8.500	29.463	0.583		✔	medium-high	290
Babiana thunbergii	West coast	30.250	13.829	100.000	27.657	0.109	✔		low	250-350
sparaxis elegans	Nieuwoudtville	31.250	13.063	47.250	13.063	0.420		✔	medium-high	290
Geissorhiza splendidissima	Unknown	32.250	7.825	30.750	7.825	0.897				
Gladiolus carneus	Noordaoek	32.750	12.392	40.000	24.784	0.811	✔		low	780
Gladiolus undulatus	Bainskloof	32.750	11.944	62.667	13.792	0.162	✔		low-high	1200
Sparaxis grandiflora ssp violaceae	Hermanus	33.250	9.818	91.250	9.818	**0.006**		✔	low	1070
Freesia corymbosa	Unknown	33.333	26.352	16.667	26.352	0.678				
Geissorhiza inflexa (red)	Tulbagh	33.750	16.915	27.000	16.915	0.787		✔	low	370
Geranium incanum	Mossel Bay	34.000	19.634	.	.	.	✔		low	605
Lapeirousia azurea	Malmesbury	35.000	10.702	31.250	10.702	0.813		✔	low	520
Gladiolus miniatus	Hermanus	36.750	14.769	75.000	14.769	0.117		✔	low	1070
Geissorhiza splendidissima	Nieuwoudtville	37.500	16.276	77.250	16.276	0.135		✔	medium-high	290
sparaxis elegans	Nieuwoudtville	37.500	13.685	27.667	15.802	0.658		✔	medium-high	290
Watsonia tabularis	Table Mountain	37.500	23.936	.	.	.		✔	low-high	780
Haemantitus cocccineus	Hantamsberg	37.500	13.975	25.000	19.764	0.633		✔	high	250
Amaryllis belladonna	Unknown	37.500	23.936	67.000	47.871	0.620				
Ixia latifolia	Ceres	39.250	8.321	36.500	8.321	0.823		✔	medium	430
Dimorphotheca cuneata (white)	Rooiwal	40.500	16.148	.	.	.		✔	high	290
Gladiolus floribundus var floribundus	Unknown	40.750	14.767	64.500	14.767	0.299				
Hesperantha vaginata	Nieuwoudtville	41.000	5.912	22.750	5.912	0.072		✔	medium-high	290
Babiana ambigua	Scarborough	41.750	17.250	33.500	24.396	0.796	✔		low	960
Babiana cuneata	Nieuwoudtville	41.750	24.355	31.250	24.355	0.771		✔	medium-high	290
Lapeirousia azurea	Malmesbury	43.500	8.018	21.333	9.258	0.130		✔	low	520
Gladiolus floribundus	Unknown	45.750	6.829	59.000	7.886	0.260				
Babiana angustifolia	Malmesbury	46.250	10.331	80.750	10.331	0.056		✔	low	520
Dimorphotheca nudicaulis	Nieuwoudtville	47.250	20.934	.	.	.		✔	medium-high	290
Babiana cuneata	Middelpos	50.000	15.426	44.750	15.426	0.818		✔	high	230
Gladiolus marlothii	Middelpos	50.000	28.137	37.500	24.367	0.751		✔	high	230
Ixia scilliaris	Paarl moutain	50.000	10.671	70.500	10.671	0.223	✔		low	985
Moraea gigandra	Piketberg	50.000	24.791	81.250	21.469	0.384	✔		medium-high	510
Geissorhiza tulbaghensis	Tulbagh	53.000	17.470	57.750	17.470	0.854		✔	low	370
Gladiolus miniatus	Hermanus	55.750	15.955	55.250	15.955	0.983		✔	low	1070

Species Name	collection location	Summer.cover.condition				Sig.b (I-J)	Provenance		Altitude	Mean average precipita-tion (mm)
		summer uncovered blocks (I)		summer covered blocks (J)						
		2012 Mean summer	Std. Error	2012 Mean summer	Std. Error		Fynbos	Renosterveld		
Moraea pritzeliana	Nieuwoudtville	56.000	12.376	73.000	12.376	0.369		✔	medium-high	290
Moraea pendula	Kamiesberg	56.250	7.454	62.250	7.454	0.590		✔	high	235
Babiana fragrans	Bainskloof	56.500	9.049	55.333	10.449	0.936	✔		low-high	1200
Tritoniopsis triticea	Piketberg	56.500	11.439	48.500	16.177	0.707	✔		medium-high	510
Babiana villosa	Tulbagh	56.750	13.068	62.333	15.090	0.791		✔	low	370
Geissorhiza tulbaghensis	Unknown	57.000	7.794	85.000	7.794	**0.044**				
Lachenalia mutabilis	Nieuwoudtville	57.250	19.756	30.000	27.939	0.470		✔	medium-high	290
Syncarpha vestita	Unknown	58.250	25.028	.	.	.				
Babiana villosa	Tulbagh	59.500	16.056	60.667	18.539	0.964		✔	low	370
Arctotis acaulos	Gouda	61.000	14.509	.	.	.	✔	✔	low	430-655
Moraea angusta	Hermanus	62.500	10.825	50.000	15.309	0.541		✔	low	1070
Babiana vanzyliae	Unknown	65.000	7.179	54.500	7.179	0.341				
Dimorphotheca nudicaulis	Scarborough	66.500	14.546	.	.	.	✔		low	960
Arctotis gumbletonii	Pakhuis Pass	66.667	9.528	.	.	.	✔		medium-high	395
Lapeirousia silenoides	Spoegrivier Namaqualand	66.667	23.570	100.000	23.570	0.374		✔	low	160
Freesia caryophyllacea	Stellenbosch	66.750	20.633	41.500	29.179	0.519	✔		low-medium	865-1330
Watsonia meriana	Somerset West	69.250	8.107	.	.	.		✔	low	430
Babiana angustifolia	Malmesbury	69.500	8.132	100.000	8.132	0.118		✔	low	520
Watsonia vanderspuyiae	Cedarberg	71.000	10.464	100.000	20.928	0.303	✔		high	395
Gladiolus caryophyllaceus	Nieuwoudtville	72.000	11.268	28.500	11.268	**0.034**		✔	medium-high	290
Moraea bipartita	Unknown	72.750	19.150	84.750	19.150	0.673				
Freesia fergusoniae	Stellenbosch	73.000	9.007	100.000	12.738	0.159	✔		low-medium	865-1330
Lachenalia contaminata	Malmesbury	73.250	9.768	100.000	13.815	0.189		✔	low	520
Gladiolus miniatus	Arniston	73.500	8.700	83.333	10.045	0.493	✔		low	400-600
Gladiolus caryophyllaceus	Nieuwoudtville	75.000	34.828	61.000	20.108	0.761		✔	medium-high	290
Babiana ringens	Stellenbosch	75.000	15.047	66.500	21.279	0.761	✔		low-medium	865-1330
Moraea villosa	Unknown	75.500	8.036	75.500	8.036	1.000				
Daubenya aurea	Roggeveld	76.250	6.711	89.000	6.711	0.228		✔	high	290-305
Ixia scilliaris	Paarl moutain	78.250	10.098	57.250	10.098	0.192	✔		low	985
Ornithogalum thyrsoides	Table Mountain	81.500	17.049	58.333	19.687	0.414		✔	low-high	780
Sparaxis meterlekampiae	Clanwilliam	82.000	11.008	44.000	22.015	0.220	✔		low-medium	260-355
Freesia furcata	Villiersdorp	84.250	7.041	83.667	8.130	0.959	✔		low	830
Moraea tulbagensis	Gouda	84.500	7.916	83.250	7.916	0.915	✔	✔	low	430-655
Moraea tulbagensis	Gouda	85.500	9.039	66.000	9.039	0.178	✔	✔	low	430-655
Lachenalia orchioides var. glaucina	Cape Peninsula	86.250	6.250	87.750	6.250	0.871	✔		low-high	780
Spiloxene capensis	Cape Peninsula	86.500	7.837	100.000	15.674	0.497	✔		low-high	780
Lachenalia bulbifera	West coast	89.000	3.790	93.250	3.790	0.458	✔		low	250-350
Ornithogalum thyrsoides	Table Mountain	90.000	9.354	90.000	13.229	1.000		✔	low-high	780
Lachenalia aloides	Tulbagh	90.500	4.229	94.333	4.883	0.579		✔	low	370
Aristea inequalis	Nieuwoudtville	91.000	9.000	.	.	.		✔	medium-high	290
Moraea bifida	Roggeveld	91.000	8.502	74.500	8.502	0.219		✔	high	290-305
Sparaxis grandiflora ssp acuticoba	Citrusdal	92.000	10.030	73.000	11.582	0.270	✔		medium	316-450
Gladiolus venustus	Clanwilliam	93.000	28.018	39.000	28.018	0.306	✔		low-medium	260-355
Lachenalia carnosa	Namaqualand	93.250	3.945	100.000	7.890	0.500		✔	medium-high	160
Moraea fugax	Unknown	93.750	4.419	100.000	4.419	0.356				
Lachenalia rubida	Unknown	95.750	3.380	93.000	4.780	0.663				
Lachenalia viridiflora	Unknown	95.750	3.863	91.000	5.463	0.517				
Lachenalia aloides	Stellenbosch	96.750	3.250	71.000	6.500	**0.038**	✔		low-medium	865-1330
Lachenalia purpureo-caerulea	Unknown	98.250	17.721	75.000	17.721	0.389				
Albuca clanwilliamgloria	Clanwilliam	100.000	0.000	100.000	0.000	.	✔		low-medium	260-355
Heterolepis aliena	Cedarberg	100.000	0.000	.	.	.	✔		high	395
Lachenalia aloides	Wolseley	100.000	0.000	100.000	0.000	.		✔	low	370-480
Lachenalia pallida	Malmesbury	100.000	0.000	100.000	0.000	.		✔	low	520
Moraea bipartita	Unknown	100.000	20.412	50.000	20.412	0.134				
Moraea fugax	Unknown	100.000	1.414	98.000	1.414	0.356				
Moraea ramossisima	Bainskloof	100.000	2.556	95.333	2.951	0.286	✔		low-high	1200
Tritonia pallida	Montagu	100.000	4.564	91.667	5.270	0.286		✔	low	230
Wachendorfia paniculata	Kovebekkeveld	100.000	0.000	100.000	0.000	.		✔	high	430
Tripteris oppositifolius	Springbok	100.000	0.000	.	.	.		✔	high	160
Heamanthus coccineus	Unknown	100.000	.	100.000	.	.				

4.3.4.6 Main summer mortality at the Generic level

There was a highly significant difference between genera in terms of 2012 summer mortality (P <0.001) (Table 4.20). The summer mortality response of major genera of summer deciduous geophytes and evergreen geophytes/ shrubs/forbs/ succulents are shown in Fig.4.32, with within genera comparisons in Fig.4.31. Bulbinella, Kniphofia, Gazania and Romulea were the most summer wet tolerant genera in summer 2012 with mortality <15%, followed by Hesperantha and deciduous Watsonia. The most summer wetness sensitive genera were Lachenalia, Moraea and Freesia in decreasing order of sensitivity.

Table. 4.20 Effect of genus on 2012 summer mortality.

Tests of Between-Subjects Effects

Dependent Variable: 2012 Summer mortality %

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	330603.737a	22	15027.443	15.925	0.000
Intercept	509059.052	1	509059.052	539.463	0.000
Genus	330603.737	22	15027.443	15.925	0.000
Error	638844.941	677	943.641		
Total	2038443	700			
Corrected Total	969448.679	699			

a R Squared = .341 (Adjusted R Squared = .320)

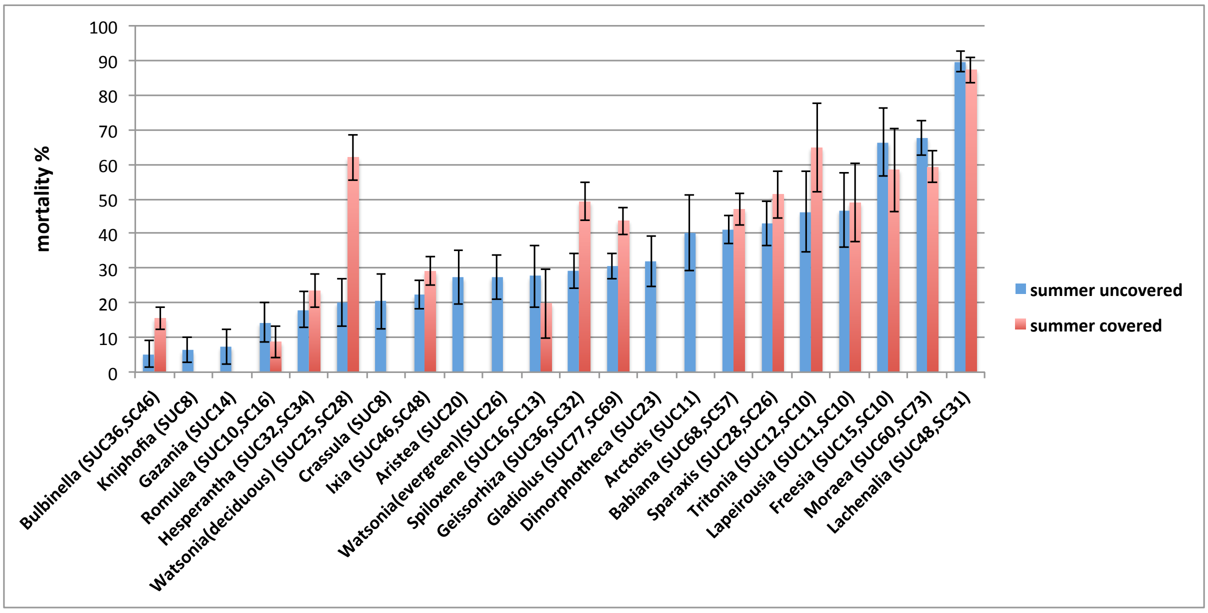
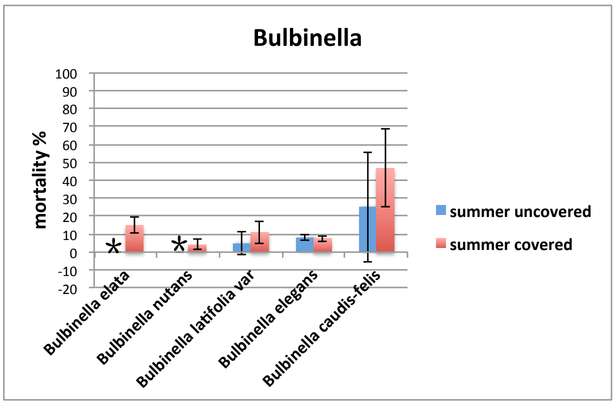


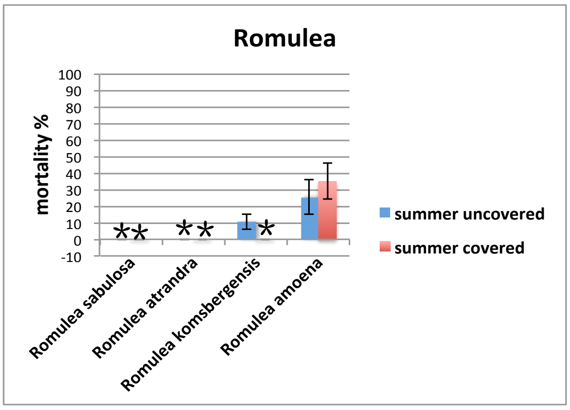
Fig.4.31 Mean mortality of genera in summer uncovered and covered treatments over summer 2012 (evergreen geophytes/ shrubs/forbs/ succulents were only tested in summer uncovered treatments) Error bars indicate standard error.

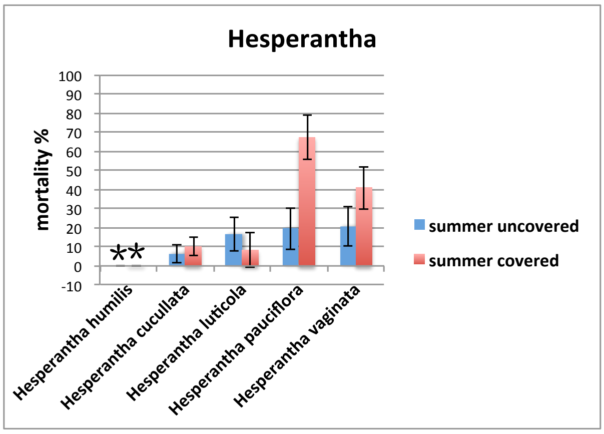
Figure 4.32 demonstrated more information on individual deciduous species of each main genus in uncovered and covered treatment, and individual frobs/shrubs/succulents and evergreen geophytes of each main genus in uncovered treatment. The bars in blue present mean mortality in uncovered treatment and red bars present mean mortality in covered treatment.

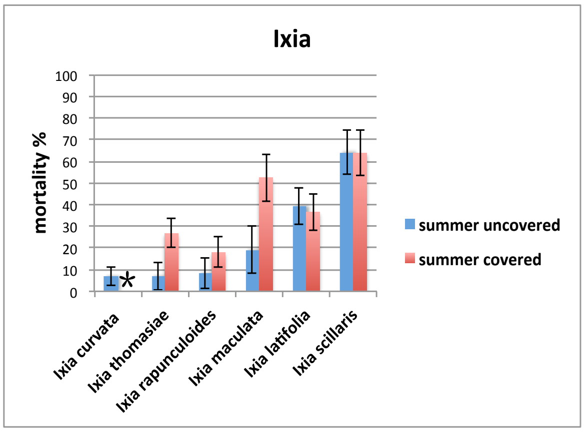
In the uncovered treatment, the four most summer wetness tolerate genus were Bulbinella, Kniphofia, Gazania and Romulea, among which 4 out of 5 Bulbinella species, 2 out of 2 Kniphofia species, 5 out of 5 Gazania species and 3 out of 4 Romulea species had mortality lower than 15%. In the following less sensitive genus, 5 Hesperantha species all had mortality less than 20%, 4 deciduous Watsonia species had less than 10% mortality, but *Watsonia vanderspuyiae* suffered 70% mortality. Both of the two Crassula species had 20% mortality. 4 out of 6 Ixia species present less than 20% mortality with *Ixia curvata, Ixia thomasiae* and *Ixia rapunculoides* all less than 10%. Compared to *Aristea inequalis*, *Aristea capitata (major)* and *Aristea confusa* could tolerate more wetness during summer. In evergreen Watsonia, only *Watsonia meriana* was much sensitive to wetness. Although Spiloxene spp. yellow and orange forms haven't been applied with confirmed names, both of them were pretty hardy in cold winters in UK and hardy in wet UK summer. *Geissorhiza aspera* was dorminatly less sensitive to wetness in its genus group. Gladiolus was a big group with 15 tested species. Gragh of gladiolus below showed an ascending curve with 3 species at 0% mortality and 1 species at over 90% mortality. Amongst 8 species with less than 20% mortality, *Gladiolus carinatus, Gladiolus floribundus var rudis* and *Gladiolus splendens* were with none loss over the historically wettest summer 2012, followed by *Gladiolus carneus var. macowan, Gladiolus maculatus, Gladiolus hirsutus, Gladiolus carneus* and *Gladiolus cardinalis. Dimorphotheca nudicaulis* was more sensitive to wetness than *Dimorphotheca cuneata.* Forb Arctotis was relatively less hardy in wet summers compared to other forbs. Mortality figures of Babiana distributed between 20-75%. In Sparaxis, *Sparaxis tricolor* was the best performer. *Tritonia deusta* had much less mortality than *Tritonia pallida*. *Lapeirousia azurea* had 26% less mortality than *Lapeirousia silenoides. Freesia corymbosa* suffered less loss than the other three species. Moraea was another big group under test, but most species performed much sensitive to summer wetness other than *Moraea tripetala* and *Moraea macronyx*. In the most sensitive genus group Lachenalia, there were 8 species had mortality more than 85%.

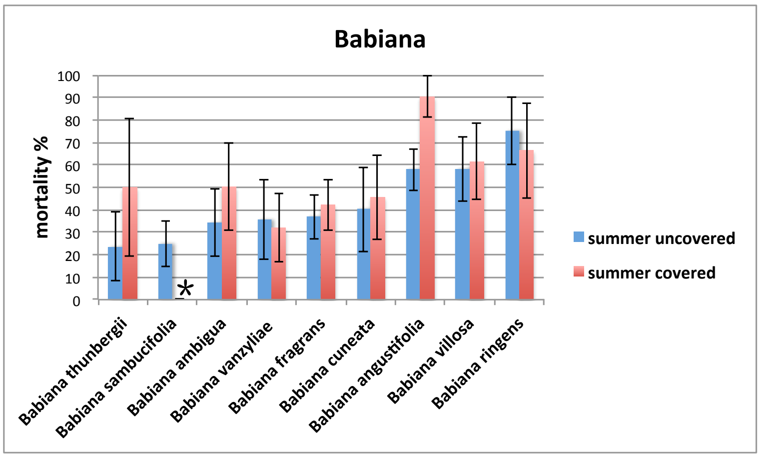
In comparison of covered and uncovered treatments, many deciduous species showed higher mortality in covered treatment in red bars. Some species present the similar figures in mortality, while others showed less mortality in covered treatment as they supposed to be.

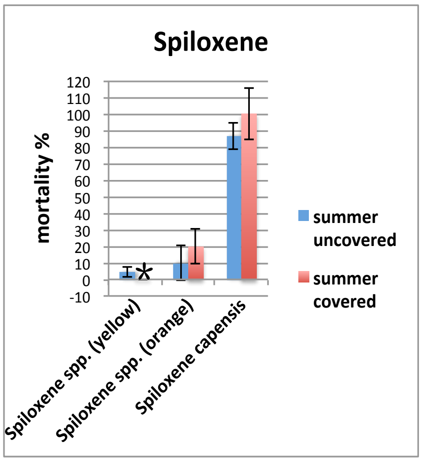


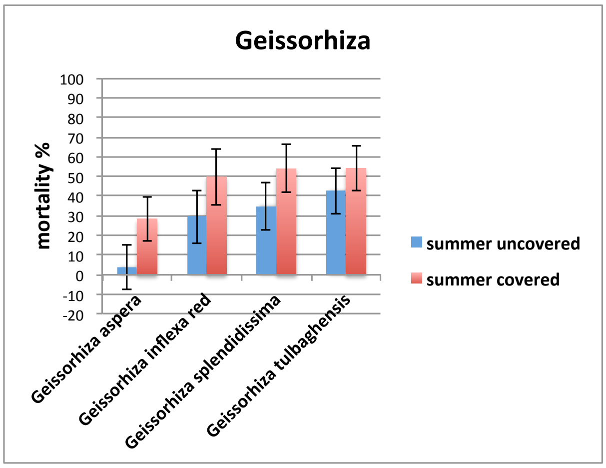


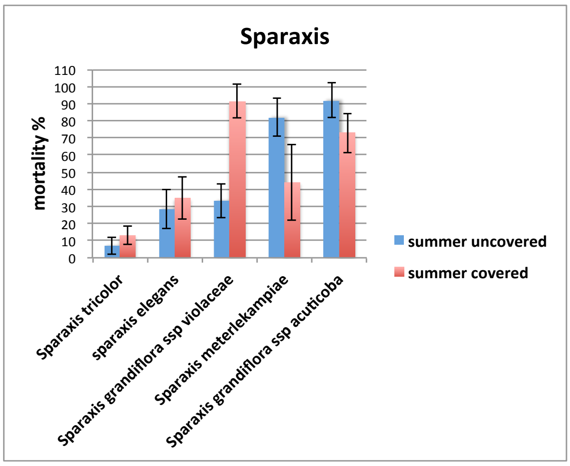


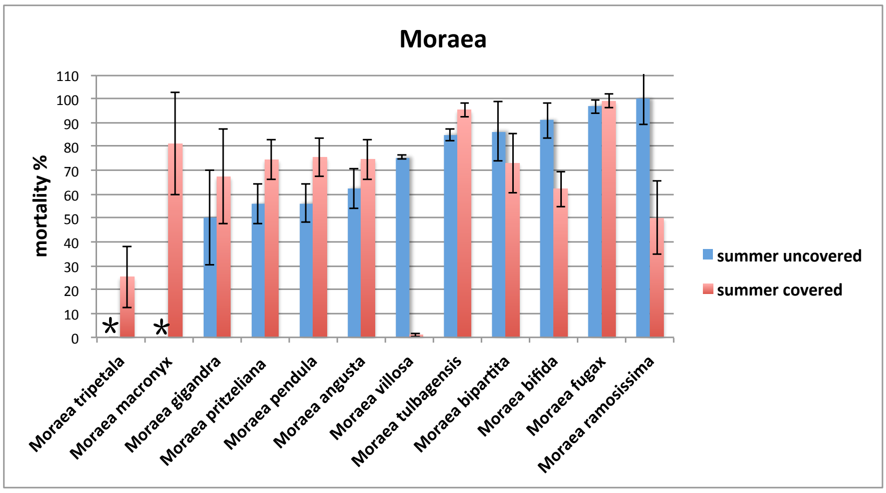


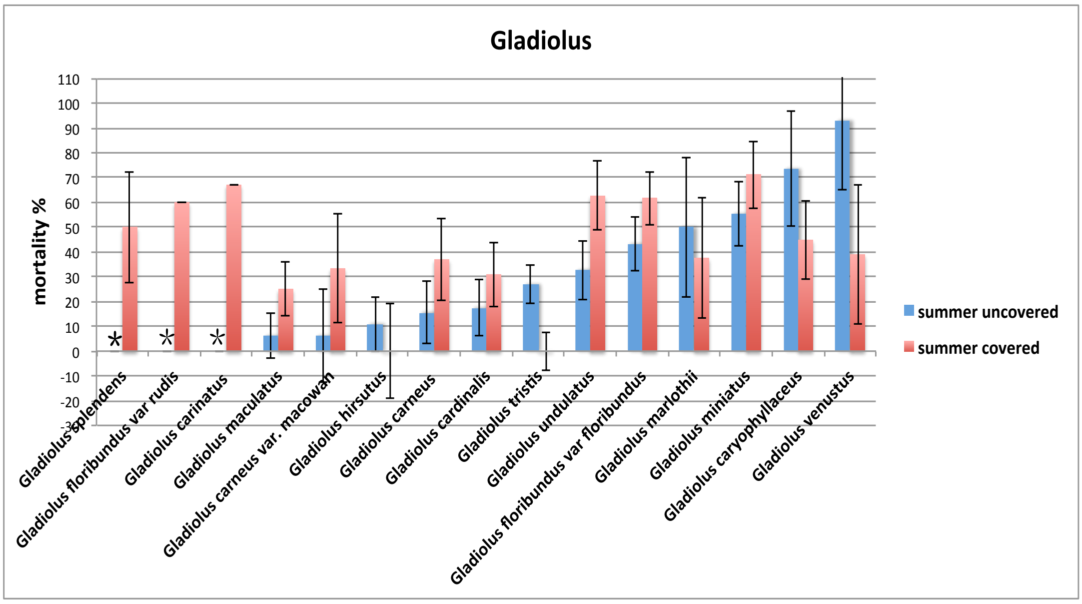


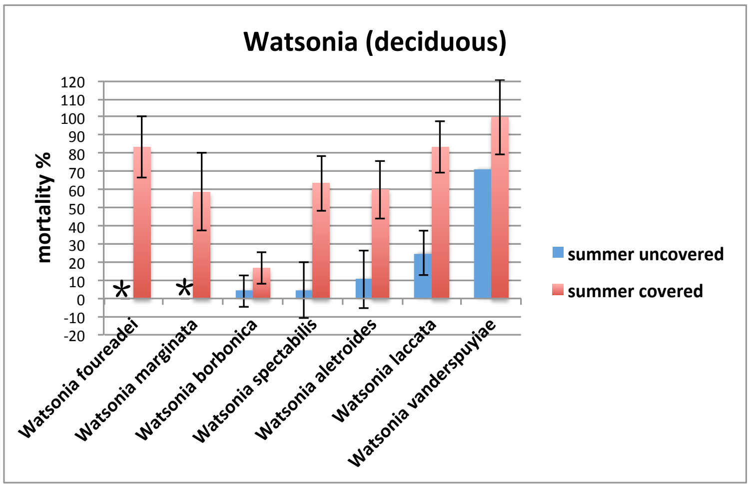


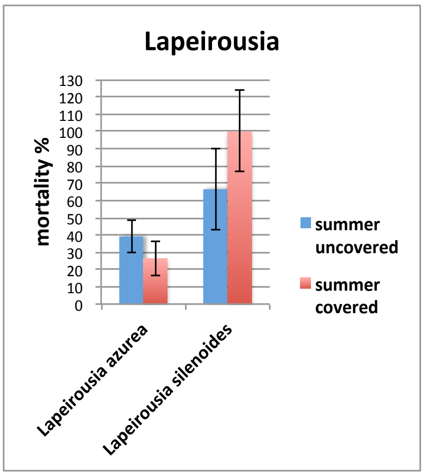

Geissorhiza
mortality %
100
90
80
70
60
50
40
30
20
10
0
-10
-20
Geissorhiza aspera
Geissorhiza inflexa red
Geissorhiza splendidissima
Geissorhiza tulbaghensis
summer uncovered
summer covered

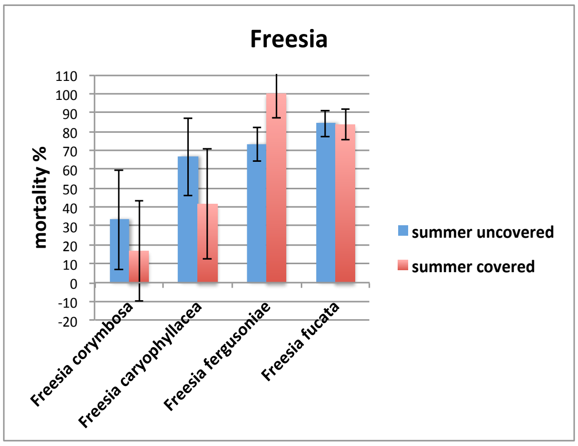

Sparaxis
mortality %
110
100
90
80
70
60
50
40
30
20
10
0
Sparaxis tricolor
sparaxis elegans
Sparaxis grandiflora ssp violaceae
Sparaxis meterlekampiae
Sparaxis grandiflora ssp acuticoba
summer uncovered
summer covered

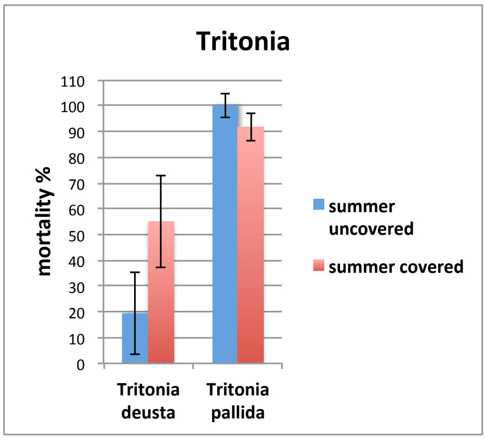

Moraea
mortality %
110
100
90
80
70
60
50
40
30
20
10
0
*
*
Moraea tripetala
Moraea macronyx
Moraea gigandra
Moraea pritzeliana
Moraea pendula
Moraea angusta
Moraea villosa
Moraea tulbagensis
Moraea bipartita
Moraea bifida
Moraea fugax
Moraea ramosissima
summer uncovered
summer covered

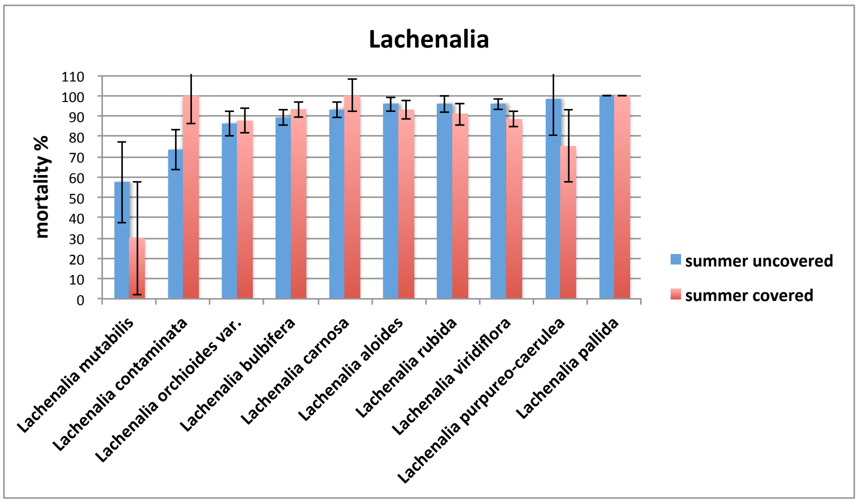

Gladiolus
mortality %
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
*
*
*
Gladiolus splendens
Gladiolus floribundus var rudis
Gladiolus carinatus
Gladiolus maculatus
Gladiolus carneus var. macowan
Gladiolus hirsutus
Gladiolus carneus
Gladiolus cardinalis
Gladiolus tristis
Gladiolus undulatus
Gladiolus floribundus var floribundus
Gladiolus marlothii
Gladiolus miniatus
Gladiolus caryophyllaceus
Gladiolus venustus
summer uncovered
summer covered


Watsonia (deciduous)
mortality %
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
*
*
Watsonia foureadei
Watsonia marginata
Watsonia borbonica
Watsonia spectabilis
Watsonia aletroides
Watsonia laccata
Watsonia vanderspuyiae
summer uncovered
summer covered


Lapeirousia
mortality %
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Lapeirousia azurea
Lapeirousia silenoides
summer uncovered
summer covered


Freesia
mortality %
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
Freesia corymbosa
Freesia caryophyllacea
Freesia fergusoniae
Freesia fucata
summer uncovered
summer covered


Tritonia
mortality %
110
100
90
80
70
60
50
40
30
20
10
0
Tritonia deusta
Tritonia pallida
summer uncovered
summer covered


Lachenalia
mortality %
110
100
90
80
70
60
50
40
30
20
10
0
Lachenalia mutabilis
Lachenalia contaminata
Lachenalia orchioides var.
Lachenalia bulbifera
Lachenalia carnosa
Lachenalia aloides
Lachenalia rubida
Lachenalia viridiflora
Lachenalia purpureo-caerulea
Lachenalia pallida
summer uncovered
summer covered

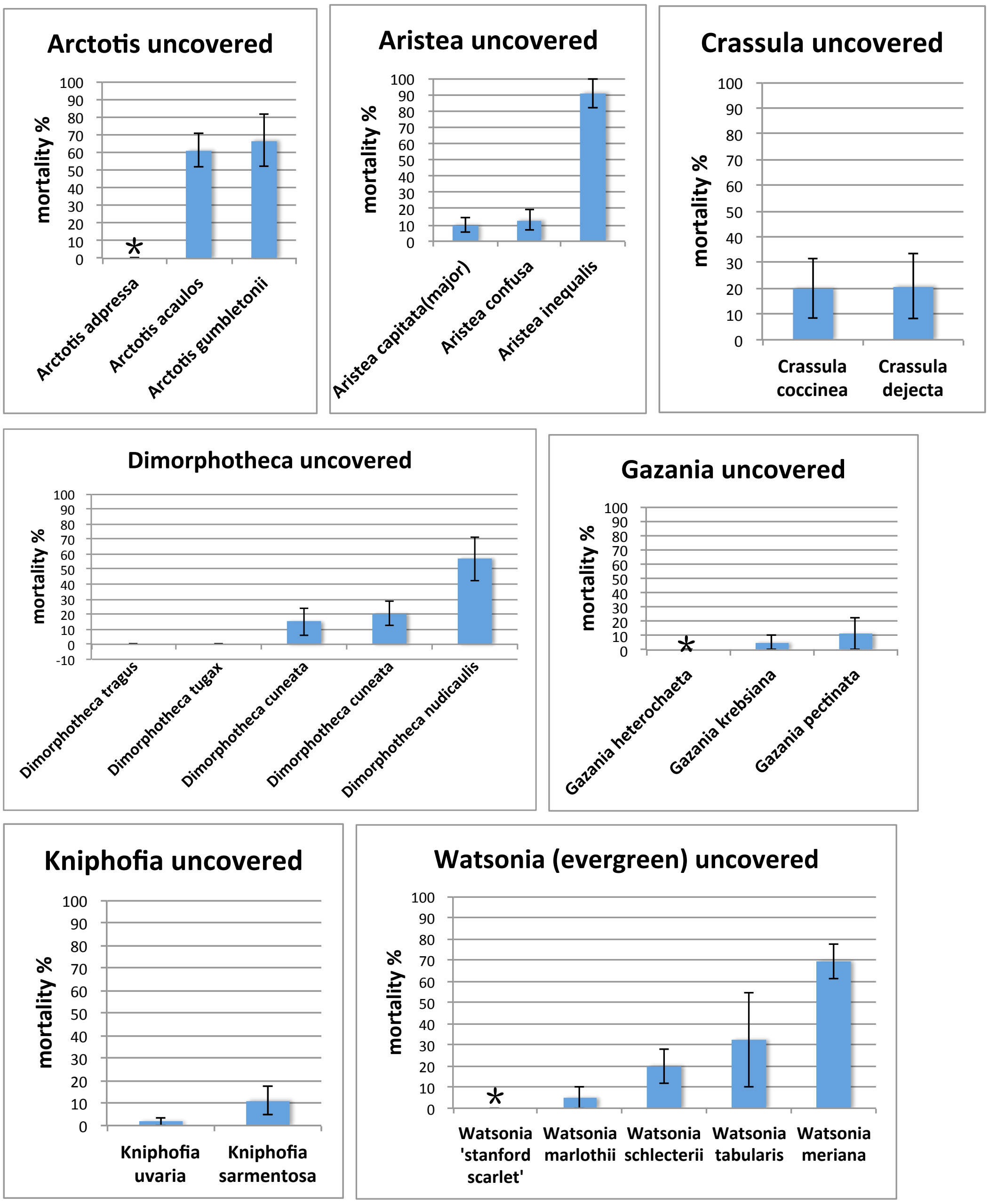


Fig.4.32 Mean mortality of individual species within main genus in summer uncovered and covered treatments over summer 2012 (*indicates 0% mortality, error bars indicate standard error).

4.3.5 Summer Wet Tolerance Experiment Phase 2 (summer 2013)

4.3.5.1 General summer mortality of part two

There were 167 pots tested in the summer uncovered treatment and 98 pots tested in the summer covered treatment. Mortality between the two (Figure 4.33) at 28% in uncovered treatment and 35%

in covered treatment were relatively similar.

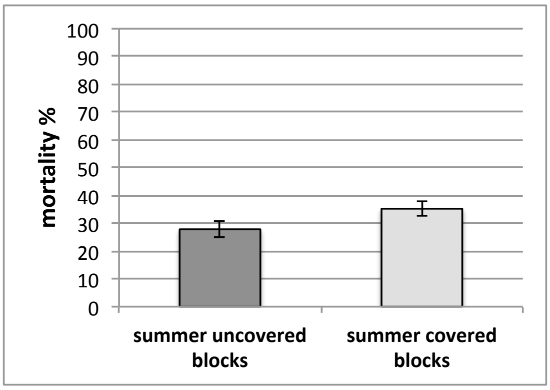


Fig. 4.33 General Mortality of all the species in covered and uncovered treatments over summer 2013 (error bars indicate standard error).

4.3.5.2 Summer mortality comparison between evegreen forbs/shrubs/geophytes and summer deciduous geophytes over summer 2013

There were 88 pot samples of summer deciduous geophytes tested in summer uncovered treatments, and 98 pot samples of summer deciduous geophytes in summer covered treatment; 79 pot samples of forbs, shrubs, evergreen geophytes tested in summer uncovered treatment, and no forbs, shrubs, evergreen geophytes in the summer covered treatment. Mortality was significantly different between life forms/growth phenologies (but only just) (P =0.048)

Table. 4.21 Effect of life form (summer deciduous geophytes v evergreen forbs/shrubs/geophytes) on 2013 summer mortality.

Tests of Between-Subjects Effects

Dependent Variable: 2013 summer mortality %

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5321.531a	1	5321.531	3.95	0.048
Intercept	323712.657	1	323712.657	240	0
Life.form	5321.531	1	5321.531	3.95	0.048
Error	451777.554	335	1348.59		
Total	793114.71	337			
Corrected Total	457099.085	336			

a R Squared = .012 (Adjusted R Squared = .009)

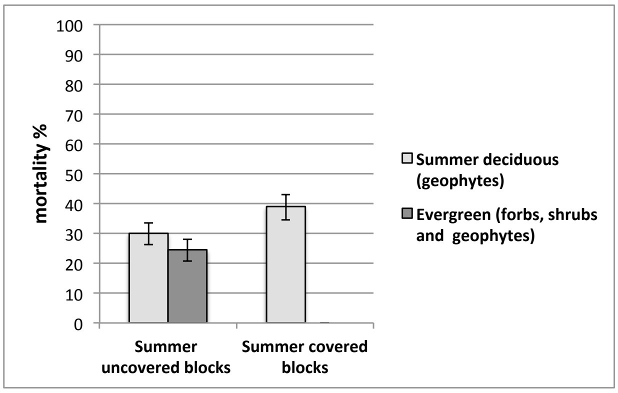


Fig. 4.34 Comparison of over summer mortality between Eevegreen Forbs/Shrubs/Geophytes and Summer Deciduous Geophytes in summer uncovered and covered treatment (error bars indicate standard error).

4.3.5.3 The effect of collection locations on Summer Mortality of part two

(1) Geographical Region

The trends apparent in 2012 studies are not fully reflected in Figure 4.35, suggesting that species being studies is probably more significant than regions per se.

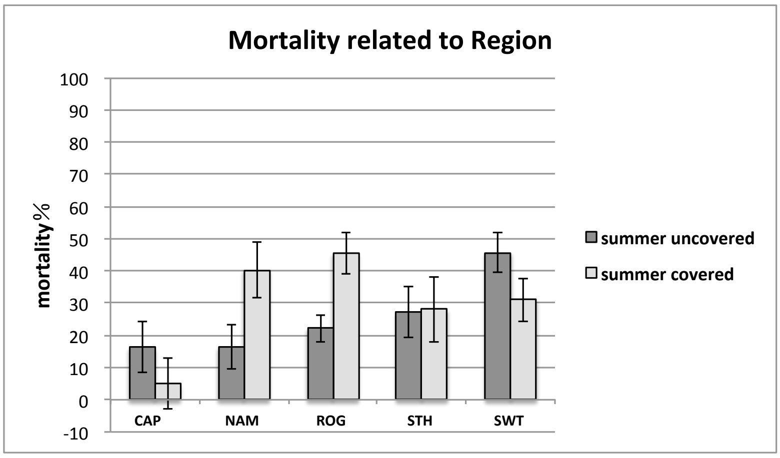


Fig. 4.35 Comparison of over summer mortality of species in both covered and uncovered treatments in different geographical regions in summer 2013 (error bars indicate standard error).

(2) Provenance

Table 4.22 summarises summer mean mortality of each provenance group of tested species in summer uncovered treatment. There were 8 provenances with mortality less than 30%, and 3 provenances with mortality over 50%. The summer mean mortality of each provenance was not clearly related to its habitat soil type, altitude and local mean average precipitation.

Table 4.22 2013 Summer mortality within the uncovered treatment .

Provenance	Mean summer mortality %	Std. Error	South African		Altitude	Mean average precipitation (mm)
			Fynbos	Renosterveld		
Calvinia (3)	0.000	0.000		✔	medium	250
near Middelpos (3)	0.000	0.000		✔	high	230
Franschhoek (3)	0.000	0.000	✔		medium	985
Table Mountain (8)	10.625	5.532	✔		low-high	780
Roggeveld (5)	17.117	18.694		✔	high	290-305
Kamiesberg (22)	19.679	3.838		✔	high	235
Perdaskop (20)	20.078	8.880	✔		high	1200
Groot Swartberg mountains (30)	22.204	5.134	✔		high	375-585
Piketberg (8)	32.075	10.285	✔		medium-high	510
Middelpos (16)	32.876	7.327		✔	high	230
Cold Bokkeveld (8)	34.338	11.140		✔	high	430
Matroosberg (20)	39.610	7.793		✔	high	430
Stellenbosch (9)	40.575	15.128	✔		low-medium	865-1330
Rooiwal (37)	40.865	7.544		✔	high	290
Komsberg (9)	43.825	14.917		✔	high	230
Tulbagh (8)	49.025	8.330		✔	low	370
Nieuwoudtville (7)	57.333	11.900		✔	medium-high	290
Leliefontein (4)	66.675	16.675		✔	high	235
Loeriesfontein (1)	100.000	0.000		✔	medium	190-2550

4.3.5.4 Mean individual summer mortality in phase 2

Comparison among species revealed that these had different response towards summer wetness. There were 64 populations tested in summer 2013. 23 populations of 22 species (36%) performed well in response to summer wetness with mortality less than 15%. 14 populations of 14 species (21.9%) had 0% over summer mortality. Amongst these 22 species (<15% mortality), there were 16 (72.7%) shrub/forb/evergreen geophyte species and 6 (27.3%) deciduous geophyte species. As listed in Table 4.23, most of these species naturally distributed in Renosterveld and high altitude coastal mountains of Fynbos with relatively medium to high precipitation.

The most sensitive species to summer wet were: *Crotalarca humclis, Lessertia rigida, Gladiolus* *saccatus, Stachys rugosa, Gladiolus equitans, Tritonia deusta,* which had summer mortality over 75% in uncovered treatments. By contrast, *Dimorphotheca cuneata (*white forms*), Dimporphotheca nudicaulis, Esterhuysenia alpina, Gazania rigida, G. krebsiana, G. leipoldtii, Lessertia frutescens, Leucadendron album, L. spissifolium spp. fragrans, Ruschia spp.* from Franschhoek and Groot Swartberg mountains, *Ursinia spp.* from Middelpos were the most summer wet tolerant forb species. Within geophyte species; *Bulbinella nutans, Gladiolus splendens, Romulea monadelpha, Watsonia borbonica, W. Tresco* Dwarf pink, *W. schlecteri* from Groot Swartberg mountains and Perdaskop, *W. marltothii* were extremely wet tolerant with less than 10% mortality in uncovered treatments over summer.

Table 4.23 Mean mortality of individual species in summer uncovered and covered treatment over summer 2013.

Species Name	collection location	Summer.cover.condition				Sig.b (I-J)	Provenance		Altitude	Mean average precipitation (mm)
		summer uncovered blocks (I)		summer covered blocks (J)						
		2013 Mean summer mortality %	Std. Error	2013 Mean summer mortality %	Std. Error		Fynbos	Renosterveld		
Ruschia spp.	Franschhoek	0.00	0.000	0.00	0.000	.	✔		medium	985
Ruschia spp.	Groot Swartberg mountains	0.00	0.000	0.00	0.000	.	✔		high	585
Watsonia borbonica	Perdaskop	0.00	8.839	12.50	8.839	0.356	✔		high	510
Watsonia Tresco Dwarf pink	Unknown	0.00	8.839	12.50	8.839	0.356				
Romulea monadelpha	Rooiwal	0.00	15.096	39.58	15.096	0.113		✔	high	290
Gazania rigida	Komsberg	0.00	0.000				✔		high	230
Lessertia frutescens	Kamiesberg	0.00	0.000					✔	high	235
Dimorphotheca cuneata (white)	Calvinia	0.00	0.000					✔	high	250
Gazania krebsiana	Rooiwal	0.00	0.000					✔	high	290
Dimporphotheca nudicaulis	near Middelpos	0.00	0.000					✔	high	230
Gazania leipoldtii	Kamiesberg	0.00	0.000					✔	high	235
Leucadendron album	Groot Swartberg mountains	0.00	0.000				✔		high	475
Leucadendron spissifolium spp. Fragrans	Groot Swartberg mountains	0.00	0.000				✔		high	475
Ursinia spp.	Middelpos	0.00	0.000					✔	high	230
Watsonia schlecteri	Groot Swartberg mountains 1730m	1.40	1.400				✔		high	475
Watsonia marlothii	Groot Swartberg mountains 1575m	1.68	1.675				✔		high	475
Bulbinella nutans	Unknown	6.08	3.973	7.30	3.973	0.835				
Watsonia schlecteri	Perdaskop	6.25	6.250				✔		high	510
Esterhuysenia alpina	Matroosberg	8.33	8.325					✔	high	1385
Gladiolus splendens	Middelpos	9.53	19.506	64.77	19.506	0.116		✔	high	230
Gladiolus splendens	Rooiwal	10.30	15.713	58.80	15.713	0.072		✔	high	290
Bulbinella elegans	Rooiwal	13.33	27.162	50.00	23.523	0.354		✔	high	290
Romulea komsbergensis	Roggeveld	15.00	7.342	0.00	7.342	0.146		✔	high	290-305
Watsonia marlothii	Groot Swartberg mountains 1900m	15.65	7.486				✔		high	585
Bulbinella nutans var. turfosicola	Table Mountain	16.25	7.823	5.00	7.823	0.348	✔		high	780
Watsonia schlecteri	Groot Swartberg mountains 1550m	17.20	11.177				✔		high	585
Romulea subtistulosa	Unknown	20.83	9.393	7.75	9.393	0.363				
Babiana dregei	Kamiesberg	21.60	7.335	23.70	7.335	0.846		✔	high	235
Babiana dregei	Kamiesberg	27.30	10.349	27.08	10.349	0.988		✔	high	235
Ixia thomasiae	Middelpos	32.60	13.065	35.58	13.065	0.877		✔	high	230
Gazania othonites	Rooiwal	33.33	33.333					✔	high	290
Gladiolus equitans	Leliefontein	33.35	23.582	100.00	23.582	0.184		✔	high	235
Watsonia borbonica	Stellenbosch	33.37	22.805	46.68	19.750	0.678	✔		low-medium	865-1330
Ornithogalum corticatum	Unknown	38.20	18.816	81.25	18.816	0.157				
Bulbinella eburnifolia	Nieuwoudtville	42.30	15.580	72.37	17.991	0.262		✔	medium-high	290
Tritoniopsis spp	Cold Bokkeveld	44.08	15.754	24.60	15.754	0.416		✔	high	430
Aristea spp.	Perdaskop	47.30	9.800				✔		high	510
Tritoniopsis triticea	Piketberg	47.48	14.546	16.68	14.546	185	✔		low	510
Aristea spp.	Perdaskop	47.63	2.367				✔		high	510
Gladiolus cardinalis	Matroosberg	48.68	14.125	45.03	14.125	0.861		✔	high	1385
Tritoniopsis spp	Groot Swartberg mountains	50.00	34.708	61.10	20.039	0.808	✔		high	475
Felicia filifolia	Rooiwal	50.00	50.000					✔	high	290
Aristea spp.	Perdaskop	60.00	30.551				✔		high	510
Babiana melaops	Tulbagh	62.20	11.780	35.85	11.780	0.165		✔	low	370
Tritoniopsis spp	Matroosberg	63.10	18.980	33.35	18.980	0.31		✔	high	1385
Tritonia deusta	Unknown	75.00	12.500	100.00	8.839	0.178				
Gladiolus equitans	Unknown	80.00	21.985	50.00	21.985	0.389				
Stachys rugosa	Komsberg	91.67	8.333				✔		high	230
Crotalarca humclis	Rooiwal	100.00	0.000	100.00	0.000	.		✔	high	290
Gladiolus saccatus	Loeriesfontein	100.00	0.000					✔	medium	190-2550
Lessertia rigida	Roggeveld	100.00	0.000					✔	high	290-305
Watsonia zeyheri	Stellenbosch			0.00	0.000		✔		low-medium	865-1330
Ixia curvata	Komsberg			32.65	16.696		✔		high	230
Lapeirousia oregena	Stellenbosch			100.00	0.000		✔		low-medium	865-1330

4.3.5.5 Main genus mean summer mortality of part two

There were 10 key genera of summer deciduous geophytes and evergreen geophytes/ shrubs/forbs/ succulents (Fig.4.36). The most summer wetness sensitive genus were *Tritonia* and *Aristea*. Even when represented by different species genera such as Bulbinella, Romulea, and Watsonia, continue to show high summer wetness tolerance.

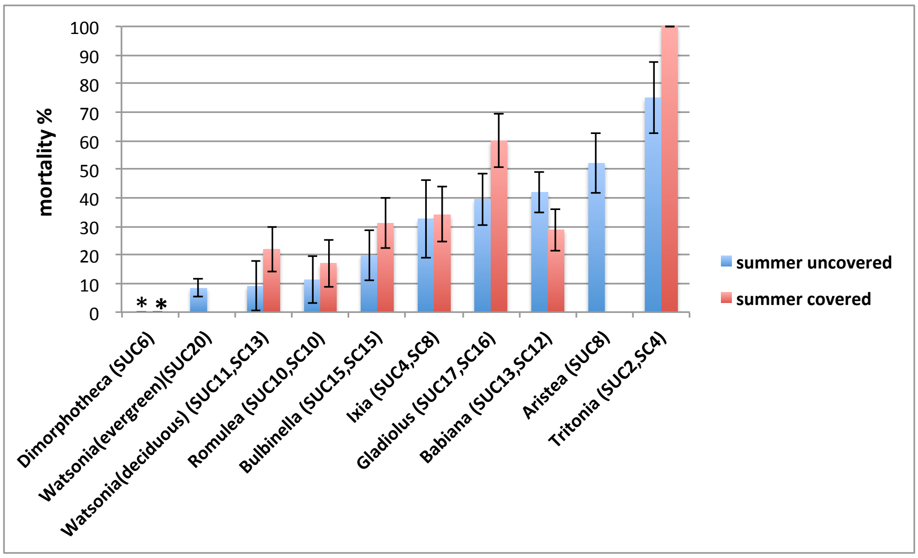
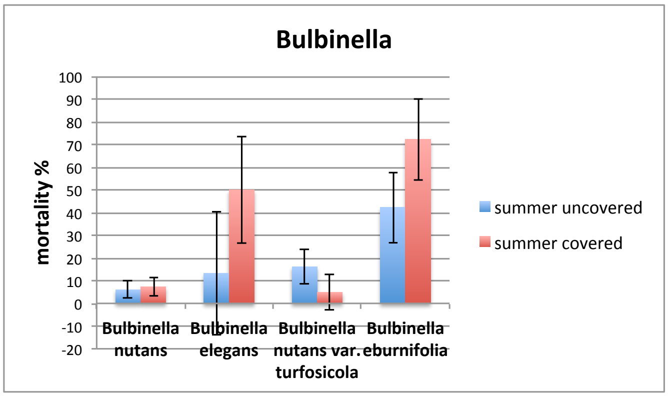
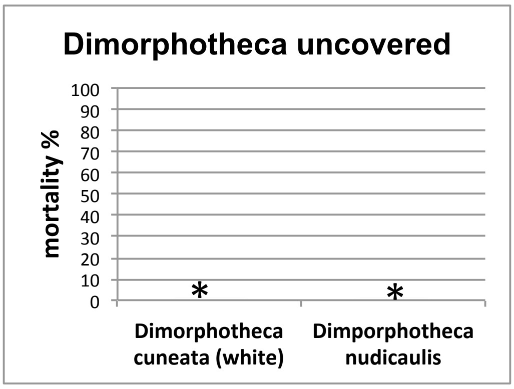


Fig.4.36 Mean mortality of genera in summer uncovered and covered treatments over summer 2013. Evergreen geophytes/ shrubs/forbs/ succulents were only tested in summer uncovered treatments) (* illustrates 0% mortality, error bars indicate standard error).

Figure 4.37 shows at the species level within a genus, there are often large differences in mortality in response to summer wetness. *Gladiolus splen*dens only had 10% mortality while the other three *Gladiolus* had mortality >45% in uncovered treatments.





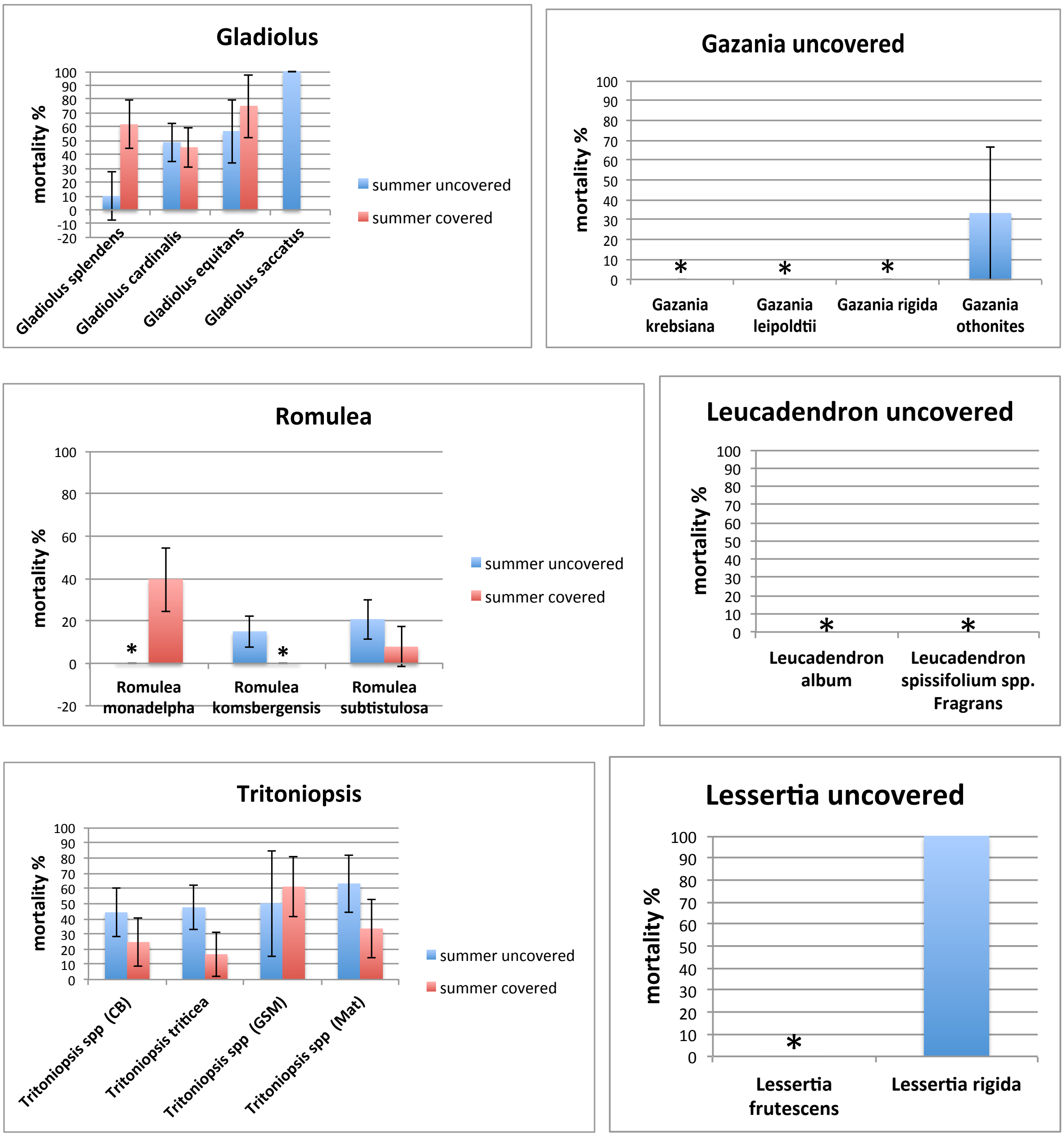


Fig.4.37 Mean mortality of individual species within main genus in summer uncovered and covered treatments over summer 2013 (＊indicates 0% mortality, error bars indicate standard error).

4. 4 Discussion

Winter 2011/12 was cold with 39 days of frost and more severe than most western SA species experience in their habitats. Winter 2012/13 was not cold but very wet with heavy snows. These two years were theoretically good for testing winter cold and wetness tolerance for these

Mediterranean species. Summer 2012, however, was historically the wettest summer in the UK since 1910, which was an extreme challenge summer for most of geophytes in the Phase 1 summer mortality test. Again these conditions were potentially valuable in exploring their ultimate tolerance of summer wetness, which has not been reviewed in the scientific literature.

4.4.1 Altitude and frost days

Species from the cold geographical regions particular those cold provenances tended to be the most cold tolerant species with lowest winter mortality. This suggests that the experimental hypothesis that the collection location strongly influences the winter cold tolerance of species can be accepted. The critical factor in the collection location in relation to cold tolerance appears to be altitude. Approximately 45 provenances in the phase 1 winter cold tolerance test were collected from high altitude (>1000m) and 43 populations were collected from medium height altitudes (400-1000m). The winter mean mortality of these were both around 40%, which is much lower than the groups of low altitude (75.3%), low-medium altitude (77%) and low-high altitude (72.2%). There were only 7 out of 45 and 2 out of 43 populations respectively that did not show some survival at -5 ^{o}C in these two altitude groups.

In this study, the lowest temperatures experienced at soil level was -5 ^{o}C, thus it is not known what the limits of cold tolerance are for the most cold tolerant genotypes. 21 winter-growing geophytes from the same region were tested in the author's preliminary experiment in outdoor conditions just adjacent to this winter cold experimental site in the extremely cold winter of 2010-11 tolerated -8°C at the soil surface. This study looked at the effect of different soil types in terms of their capacity to conduct and store heat on cold damage to corm and bulb structures, as well as the effect of cold damage to foliage. Sand based soils expose the basal plate of corms to lower temperatures than do clay based materials, the deeper the sand and the furthest the basal plate away from the underlying warmer soil, the more severe the temperatures, and the damage to the geophytes. Most species survived in clay based soil treatments (see Figure 6.1-6.5 in Chapter 6 Phenology), except *Aristea* and *Geissorhiza splendidissima.* Interestingly, there were also few

Wachendorfia paniculata, Watsonia alethroides, Gladiolus carneus, Gladiolus tristis, Watsonia borbonica survived in the coldest 150mm deep sand layers. *Gladiolus tristis*, had very high survival rate in all soil types. Although *Gladiolus carneus* from Bot River and Noordaoek both showed over 50% winter mortality in uncovered treatments in winter 2012 (-5 ^{o}C), one population of this species has showed no mortality in both 75mm deep soil and sand and only 7.1% mortality in 150mm sand in winter 2010 (-8 ^{o}C). This suggests that some seedlings could tolerate even lower temperatures. *Bulbinella nutans* was proved to be hardy in both winter and summer wet tolerance species as expected.

In most species, the calculated frost days metric derived from Mucina and Rutherford (2006) appears to correlate reasonably well with tolerance of winter cold. The Cedarberg (1000-1500m, is calculated to experience 20.1 days of frost) and Sutherland (1000-1600m, 56 days of frost). Forty populations in phase 1 from areas with >25 frost days showed 34% mean mortality in winter 2011/12. In contrast, amongst populations derived from locations experiencing less than 10 days of frost only 4.7% (4 populations) showed mortality of less than 80%. In many ways however the number of frost days is a poor surrogate for the actual temperatures experienced, as it is this that exceeds the genetically defined capacity of a species to prevent the formation of ice within cells leading to the rupture and death of those cells. It seems likely that there is some, but a far from perfect correlation between number of frost days and the minimum temperatures experienced (Lorenzetti et al. 1971; Warrington and Southward, 1995; Mayoral et al., 2015).

When their collection location frost days are subdivided into smaller sections, as shown in Figure 4.38 (a), the Univariate analysis displayed a clearer pattern between mortality and habitat frost days in winter 2011/12 in winter uncovered treatment (see Figure 4.38 (a) Tukey HSD). Mean mortality of genotypes from >40.1 frost days, 20.1-40 frost days and 10.1-20 frost days were 31.84%, 39.83% and 41.94% respectively, which were significantly different from species those which were collected from provenances with less than 10 days of frost. Length of frost days experienced in wild habitat significantly affected the winter mortality of different species under test (P=0.000, Figure 4.39).

2011-2012 Witer mortality %
Tukey HSD a,b,c

Frost days in habitat	N	Subset	
		1	2
≥40.1days	51	31.84	
20.1-40days	83	39.83	
10.1-20days	213	41.94	
5.1-10days	65		64.08
0.1-5days	289		74.92
0 day	16		79.5
Sig.		0.719	0.259

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square(Error) = 1301.439.
a Uses Harmonic Mean Sample Size = 50.979.
b The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.
c Alpha =

(a)

2011-2012 Witer mortality %
Tukey HSD a,b,c

Altitude	N	Subset	
		1	2
>1500m	30	34.43	
1001-1500m	155	38.39	
801-1000m	178	42.94	
≤200m	88		66.32
601-800m	33		72.61
401-600m	63		73.03
201-400m	170		79.36
Sig.		0.834	0.384

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square(Error) = 1301.439.
a Uses Harmonic Mean Sample Size = 64.323.
b The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.
c Alpha =

(b)

Fig.4.38 (a) Mean winter mortality of species groups based on frost days they experienced in the habitat. (b) Mean winter mortality of species groups based on their altitudes at collection locations. Mean mortality in subset 1 was significantly different from mortality in subset 2.

Tests of Between-Subjects Effects
Dependent Variable: 2011-2012 Witer mortality %

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	307208.913a	20	15360.446	11.803	0.000
Intercept	739085.246	1	739085.246	567.899	0.000
Altitude * Frost.days	67447.446	9	7494.161	5.758	0.000
Frost.days	41573.932	5	8314.786	6.389	0.000
Altitude	60263.507	6	10043.918	7.718	0.000
Error	905801.246	696	1301.439		
Total	3552129	717			
Corrected Total	1213010.16	716			

a R Squared = .253 (Adjusted R Squared = .232)

Fig.4.39 Effect of frost days, altitude of collection location and correlated effect of frost days and altitude on winter mortality of all the tested species in uncovered treatment over winter 2011/12.

Even species where there was very high mortality, there were often a few seedlings that survived relatively undamaged. This suggests that the genes that are present that confer cold tolerance are only found at a low percentage in a population, and that the more seed sown the greater the likelihood that these cold tolerant individuals even in species or populations that are not really very cold tolerant will be found. For instance, geophyte *Tritonia deusta* had mean mortality 87.5% in winter uncovered treatment, but some individuals had relatively little damaged foliage after winter 2011/12 (see Figure 4.40 below). This was observed in *Aristea confusa, Babiana villosa, Moraea tulbagensis, Geissorhiza tulbaghensis* and *Ixia scilliaris*. In more cold tolerant populations the percentage of individuals containing genes that confer hardiness increases.

Fig.4.40 Only one plant of *Tritonia deusta* (a high mortality species) survived from -5 °C in winter uncovered treatment over winter 2011/12. (photo taken in early April 2012)

In terms of the size of the seedlings, although in most cases the research does not present a compelling argument for older plants being more cold tolerant than others, many of the seedlings sown in autumn 2011 were extremely small when they experienced winter cold. In conventional horticultural terms the idea that seedlings as small and young as this could be as cold tolerant as much older larger plants is a really challenging one. What this finding that there is little difference in most species between the cold tolerance of very young seedlings and near adults of that species is that it validates the use of very young seedlings in screening experiments such as this. Using small seedlings allows large numbers of individuals to be exposed to the stress, in this case cold, and maximizes the chances of finding novel, more cold tolerant individuals.

There appears to be more capacity to find even more cold tolerant seedlings. The seed used in this study was in most part not collected specifically for the research, but was the standard "product" sold by Silverhill Seeds. What is clear from visiting South Africa is that given the complex topography over which species are distributed irrespective of altitude, seed collections which are targeted at the lowest lying areas in a landscape, which act as frost hollows would provide genotypes which in many cases would be even more cold tolerant. As air cools, increasing its density in the process, it then flows down slopes and collects in hollows. This process happens everywhere, but is most developed at high altitude. As a general principle mean temperature decreases by approximately 0.6^{o}C for every 100m increase in altitude, however under nocturnal conditions when radiation frosts typically form, this pattern of temperature decline is reversed, due to the process of increased air density as cooling takes place. Hence in a landscape such as the Cedarberg, which according to Mucina and Rutherford at 1000-1500m experiences approximately 21 frost days per year, there are many high altitude depressions known locally as “Fluctas” which will experience many more frost days and also much, much lower absolute minimum temperatures. Future research needs to focus on the promising species identified in the study and attempt to find genotypes of these species growing in hollows or high altitude plateau where these meteorological conditions prevail.

A large majority of plants that the literature suggests could only do well in special conditions such as glasshouses can tolerate outdoor settings without protection in winter as low as -5 ^{o}C， or even as low as -8 ^{o}C, such as *Sparaxis elegans, Babiana villosa, Gladiolus carneus* and *Gladiolus floribundus.* The overall results of individual species gained from the winter cold tolerance test are very different from the information provided in the standard South African horticultural literature, for example Duncan’s (2010) book *Grow Bulbs*.

4.4.2 Cover conditions

Cover screens with layers of fleece increased the soil surface temperature by 2-3 ^{o}C, which decreasd the mortality of most species. However, some species still suffered very high mortality. *Haemanthus sanguineus, Gladiolus caryophyllaceus, Gladiolus venustus, Podalyria leipoldtii* all had mortality over 80%, amongst which *Brunsvigia bosmaniae* suffered 100% mortality in covered treatment. It was collected from high altitude mountain area Kamiesberg with medium long frost days (12.85 days of frost). The sensitivity of these types of species is surprising and worthy of future research across populations of these types of species. Some genera studied show that cold tolerance varies substantially amongst the different genera present within a given geographical area. *Watsonia,* for example emerged as an unexpectedly cold intolerant genus, compared for example with genera such as *Hesperantha, Ixia, and Moraea.* Presumably this is a reflection on either their evolutionary history, of where the ancestral populations evolved and the cold tolerance that was required in these environments, or it is just part of the evolutionary game of chance. Many species such as *W. alethroides, W. borbonica, W. marginata, W. tabularis* from coastal mountain areas had mortality around 60%. Evergreen geophyte *W. marlothii* and widely spread *W. schlecterii* collected from colder inland regions were the most cold tolerant *Watsonia,* especially the highest altitude populations of *W. marlothii* that are found at up to 1800m.

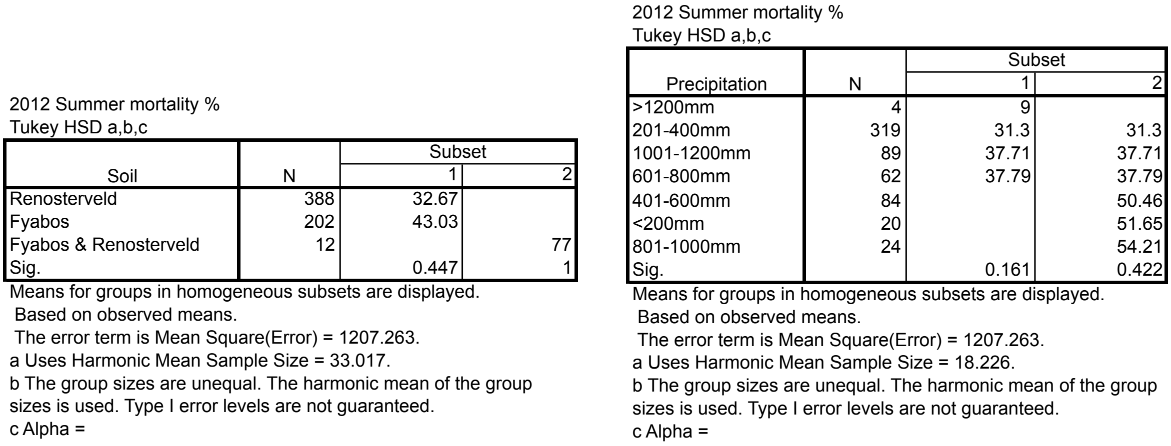
4.4.3 Soil wetness and mortality

4.4.3.1 Winter wetness in relation to habitat altitude and soil type

Most severe damage of geophytes during the winter was probably due to ice formation in the basal tissues at the corm-root interface. Winter wettness in the UK is often potentially problematic for most eastern South African species because winter is their dormant season. However, winter rainfall communities were expected to be better fitted in the wet winters in Sheffield because they grow through the wet Mediterranean winters in their habitats. The main issue was that most geophyte species were intolerant of winter cold below -3 to -4^{o}C, however some species looked unhealthy before being exposed to lethal temperatures, and this may be due to high levels of rain in combination with lower than normal temperatures for these species. This however remains speculation, however it would be interested to examine these interactions in future research.

4.4.3.2 Summer wetness in relation to habitat altitude and soil type

Species tolerance of summer wetness appeared to some degree to be related to soil types in the habitat with lower mortality commonly appeared on species from seasonally wet habitats. This was reflected in both geophyte and forb/shrub groups. Figure 4.41(a) below shows Tukey HSD analysis of summer mortality 2012 of tested species in relation to their habitat soil types. Renosterveld has clay-shale derived soil, and Fynbos typically has sandy soil. Species from Renosterveld had about 10% less in summer mortality in uncovered treatment than species from Fynbos, which was significantly different in comparison (P<0.05).



2012 Summer mortality %
Tukey HSD a,b,c

Soil	N	Subset 1	Subset 2
Renosterveld	388	32.67	
Fyabos	202	43.03	
Fyabos & Renosterveld	12		77
Sig.		0.447	1

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square(Error) = 1207.263.
a Uses Harmonic Mean Sample Size = 33.017.
b The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.
c Alpha =

2012 Summer mortality %
Tukey HSD a,b,c

Precipitation	N	Subset 1	Subset 2
>1200mm	4	9	
201-400mm	319	31.3	31.3
1001-1200mm	89	37.71	37.71
601-800mm	62	37.79	37.79
401-600mm	84		50.46
<200mm	20		51.65
801-1000mm	24		54.21
Sig.		0.161	0.422

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square(Error) = 1207.263.
a Uses Harmonic Mean Sample Size = 18.226.
b The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.
c Alpha =

(a) (b)

Fig.4.41 (a) Mean summer mortality in 2012 of species groups based on soil type in the habitat. (b) Mean summer mortality of species groups based on annual precipitation in the habitat. Mean mortality in subset 1 was significantly different from mortality in subset 2.

In summer 2012, most of species with 0% mortality were naturally distributed in Renosterveld mainly in medium to high altitude mountains such as Roggeveld continental inland mountains, Namaqualand coastal plain to inland mountains and Swartland inland mountains. Similar pattern can be found in those low mortality populations (<10%) as well. Coastal areas with higher annual rainfall provide wetter conditions for species during the summer periods. Inland continental mountains have very low annual rainfall levels, but also at altitude lower temperatures and evaporation than the coastal areas. A few geophyte species with low summer mortality were collected from sandy soil Fynbos, where experienced relatively high annual rainfall at low to medium altitude. The high permeable sandy soil allowed this group of geophyte species to survive from extreme wet periods at low soil oxygen levels. In summer 2013, because most species were from similar habitats, there were less clear patterns in response to summer wetness than in summer 2012.

Western Cape climatically has steep rainfall gradients, from less than 200mm up to 3000mm in the mountains above Stellenbosch. (Mucina and Rutherford, 2006) However, mean summer mortality in uncovered treatment in summer 2012 showed no significant difference in relation to habitat precipitation (see Figure 4.41(b) above). A group of genotypes from seasonally wet areas were proved to be better in tolerance of summer wetness. *Gladiolus tristis* and *Gladiolus carneus* naturally grow in seasonally poorly drained conditions (Goldblatt and Manning, 1998), and both has been propergated in Britain under summer moist soils, performed extremely hardy in tolerance of wettest summer 2012. Other species, which grow along streams or in seasonal damp areas, can tolerate heavy watering in cultivation in South Africa during summers (Manning et al., 2002), such as *Bulbinella latifolia var. latifolia, Gladiolus angustus. Gladiolus cardinalis* naturally restricted in permanetly wet conditions performed well in very wet summer 2012 as expected. *Gladiolus carinatus* prefers to well-drained sandy soils in the wild habitat (Goldblatt and Manning, 1998), however, showed 0% mortality in uncovered treatment in summer 2012. Not only species from coastal mountains that can tolerate summer wet in the UK, but also some species from the interior plateau and moutains. *Moraea tripetala* found on clay soil in Nieuwoudtville (Roggeveld region) was one of the most successful species in response to summer wetness with 0% mortality over wetest summer 2012. Area like Cold Bokkeveld with more than 1250mm annual rainfall in some mountain ravines (Manning et al., 2002) but highly permeable sandy soil. Even during the wet period, the soil dry out quickly and some geophytes exsited. There is much anecdotal evidence that when South African winter-growing geophytes are found in very sandy soils (Manning et al., 2002), they are relatively tolerant of summer irrigation or natural rainfall. Species like *Sparaxis elegans,* naturally grow in the very dry summer rainfall climate of the Roggeveld Plateau (Nieuwoudtville to Calvinia) is listed as highly sensitive to summer moisture in South African literature (Duncan, 2010). This species is however found on clay soils and tolerated summer rainfall in the author’s experiments (Hang, 2010).

Evergreen or semi-evergreen geophyte species from the winter-rainfall areas require some moisture throughout the year, which are correspondingly likely to be more tolerant of wetter summers. The effect of summer rainfall during the establishment was less and summer mortality of these geophytes as well as forbs, shrubs were generally lower as investigated in this research.

4. 5 Conclusion

The warming and shorten of winters may potentially provide even better emergency and growth conditions for species from lower altitude regions of Western Cape.

Although most data were obtained from only one field population per species, the number of species involved in the experiment was large. Variation in collection locations reflected various altitudes, including represetatives from the typically habitats in western Cape.

- Plants from the following natural habitats demonstrated best performance to the prevailing winter cold and wet conditions experienced in Sheffield:
  best performance concentrated in Roggeveld region;
  species from areas with long frost period, and best performance occurred in those provenace with extremely long mean frost days;
  marshland/ seasonal damp/stramside at high altitude of inland mountains;
  species from clay soil (Renosterveld) at high altitude of inland mountains;
  some species from hollows at the bottom of mountain slopes.

- Plants from the following natural habitats demonstrated best performance to the prevailing summer wetness experienced in Sheffield:
  species from wet or seasonal wet habitats;
  species from Renosterveld with heavy clay soil of inland high mountains;
  species from Renosterveld from caostal pain to high mountains;
  some species from Fynbos with sandy soil of inland high mountains in cold regions.

- Species tolerance of winter cold and summer wetness may relate to their evolution history.

- Plants survival abilities may relate to their age stages in certain species but there was no clear deduction in this test.

CHAPTER 5: EFFECT OF COMPETITION BETWEEN SPECIES OF DIFFERENT FOLIAGE CANOPY HEIGHT AND POTENTIAL PRODUCTIVITY ON COMMUNITY DYNAMICS AND APPEARANCE

5.1 Introduction

The prior field experiments provided the understanding of germination, winter cold and summer wetness tolerance of a large number of SA species from Western Cape, to create sown communities of Mediterranean South African plant communities based on multi-layered vegetation of Fynbos and Renosterveld species. These communities were designed to test naturalistic design principles as to achieve long flowering designed plantings in involving three canopy heights (tall, medium and low). Competition between shrubs/forbs/succulents and geophytes by using microcosm experiments mirrors the form of actual designed vegetation in practice. Theoretically, we assumed competitive ability of an individual species would differ within each plant combination, and this would provide key understanding of how these communities could be applied to practice. The communities were to run for a minimum of two years to provide data on community architecture productivity and appearance, and the mortality and productivity of individual species. This study is the first in the world to look at the development of synthetic, designed communities of Fynbos-renosterveld species. The provisional research hypothesis was that the addition of taller species would result in the elimination through light competition of lower canopy layers. The aim was to test critical thresholds for the elimination-persistence of key species.

5.1.1 Objectives

Specific research questions associated with this experiment were:

I. To document survival v decline of individual species within a community over two years effects of plant architecture and morphology, phenology and productivity on establishment and longer term survival.

II. To investigate the effect of foliage height on species survival in mixed communities.

III. To investigate the effect of life form in terms of species survival in mixed communities.

IV. To investigate the effect of different combinations of species with low, medium and tall foliage canopies on cover values (and hence potential invisibility) in the first 2 years.

V. To investigate the biomass production and phenology of species in different community types over a two year period.

5. 2 Methodology

5.2.1 Plant materials and experiment site

The target of the seedlings for each block was proposed to be the 72 seedlings/block (100 seedlings/m^2), however, the number of seeds sown to achieve these numbers varied. Because of complexities created by some species being able to germinate only in autumn, and others in spring, plus the limited seed supply of many species, the communities were established through a mix of sowing seed directly into the experiment supplemented by planting previously sown seedlings to achieve target numbers.

The technique for establishment in situ was to spot sow in July 2012 with 3 seeds per spot. Each species sowing point was labeled with colour coded labels. Seeds of *Bulbinella nutans, Bulbinella latifolia var. latifolia* and *Romulea komsbergensis* were sown in pots in autumn 2011 and had experienced one growing season before transplanting. All the pots with seedlings in were kept in the glasshouse in the Sheffield Botanical Gardens to maximize germination and minimise mortality due to the limited seed supply. All the seeds were purchased from Silverhill Seeds in Cape Town, except Jellito supplied *Goniolimon speciosum*, a non South African species used as a surrogate for a failed SA species (see Table 5.2).

5.2.2 Combined forbs/shrubs/succulents and geophytes in microcosm communities

This competition experiment microcosms contained both dwarf shrub/ forb/ succulent species and geophyte species, with 15 communities with the composition shown in Table 5.1 below. It was designed as a constant density experiment, with a total seedling target of 6 seedlings/species (100 seedlings/m^2). The exception to this are the nil forb and nil geophyte blocks in which the number of seedlings of each species is increased to 12 to compensate for the missing other life-form, but the principle of equal numbers is preserved. Competition experiments only allow for meaningful comparisons when constant total density is approximated to. This fully randomised block experiment involving 4 replicates of each treatment combination was established in late August 2012 in the Sheffield Botanical Garden. This experiment involved a total of 60, 800 × 900mm treatment blocks (see table 5.1 and Fig. 5.1). Each row of blocks was separated by 300mm wide cross paths from the adjacent row of blocks. Every 5 blocks were structured together with a 200mm gap from the neighboring 5 other blocks due to the site limitation. A blocked spatial distribution was used to account as best as possible (given the strictures of site choice) for the expected gradient due to the backing hedge. Each treatment block was surfaced with a standardised 100mm deep substrate of 20% composted green waste and 80% sand overlaid on the soil base to mirror the use of a sand sowing mulch in practice as well as provide a practical means of managing weeds in the first year. The initial design of the microcosm was 6 species of each life form group for each foliage canopy height and 12 species in each combination with a target seedling density of 100 seedlings/m^2. However due to seedlings or seeds not all being available in certain groups, the microcosm design was revised to 5 species of each life form group for each foliage canopy height and 10 species in each combination with a target seedling density of 83 seedlings/m^2.

The number of forbs/shrubs/ geophytes seedlings were counted in November 2012, the speed of species growth were observed in terms of above ground biomass, and cover values were estimated on a 0–100% scale for sown species and colonizing weeds through observation every 2-3 months. Simultaneously, incident and transmitted photo-synthetically active radiation (PAR) in plant canopies were measured by the Sunscan Canopy Analysis System (type SS1) (Delta-T Devices, Cambridge, UK) through a portable line quantum. This PAR measuring system involves 64 photodiodes embedded in a 1m long probe to present information about the penetration of

PAR penetration into a canopy. Incident PAR was measured prior to the measurement of communities on a clear sky day. Readings were all in units of PAR quantum flux (μ mol m^{-2}s^{-1}) to assess the degree of shade cast at soil surface level in the developing communities. In total, all the treatment blocks have been measured 9 times from August 2012 to September 2014, mainly between 12 and 2 o'clock.

The experiment was established during 2012, and was considered to have "started" at the beginning of 2013. All seedlings were harvested in autumn 2013 (before the new growing season for most geophytes) and individual dry weights were established. By this time the foliage of most geophytes was senescent, but readily identifiable. Shrubs were cut off above the first branch approximately 50mm leaving the woody base to allow resprouting, as an insurance policy for the second growing season. Geophytes and forbs were cut off at ground level, at approximately 0-10mm. The process was repeated in autumn 2014. All plants in every block were harvested, each plant was labeled and coded as previously discussed within an area of 800 x 100mm in the middle of each block, the reference frame to assess mortality and biomass. Plants rooted in an area 100mm wide within the wooden framework were left un-harvested. Any self-seeding seedlings or plants not included in the assessment are discussed in chapter 6 Phenology observation. Data was subjected to statistical analysis to establish how different combinations of species effect survival and community development.

Table 5.1: The composition of the fifteen communities used in the experiment in terms of combinations of forbs/shrubs/succulents and geophytes.

		Geophytes (G) (on basis of canopy height)			**nil geophytes**
		Tall (T)	**Medium (M)**	**Low (L)**	
Shrubs/Forbs /Succulents (on basis of Canopy height) (F)	**Tall (T)**	C1 (TF+TG) 10spp.(5f+5g)	C2 (TF+MG) 10spp.(5f+5g)	C3 (TF+LG) 10spp.(5f+5g)	C4 (TF) 5spp.(5f)
	Medium (M)	C5 (MF+TG) 10spp.(5f+5g)	C6 (MF+MG) 10spp.(5f+5g)	C7 (MF+LG) 10spp.(5f+5g)	C8 (MF) 5spp.(5f)
	Low (L)	C9 (LF+TG) 10spp.(5f+5g)	C10 (LF+MG) 10spp.(5f+5g)	C11 (LF+LG) 10spp.(5f+5g)	C12 (LF) 5spp.(5f)
nil Forbs		C13 (TG) 5spp.(5g)	C14 (MG) 5spp.(5g)	C15 (LG) 5spp.(5g)	

4 replicates
60 microcosms

in total

Proposed Density of each combination= **<u>6 plants of each species per unit X 12 spp./block</u> = 100/m2**

0.9 X 0.8 m2 (block size)

Final Density of each combination = **<u>6 plants of each species per unit X 10 spp./block</u> = 83/m2**

0.9 X 0.8 m2 (block size)

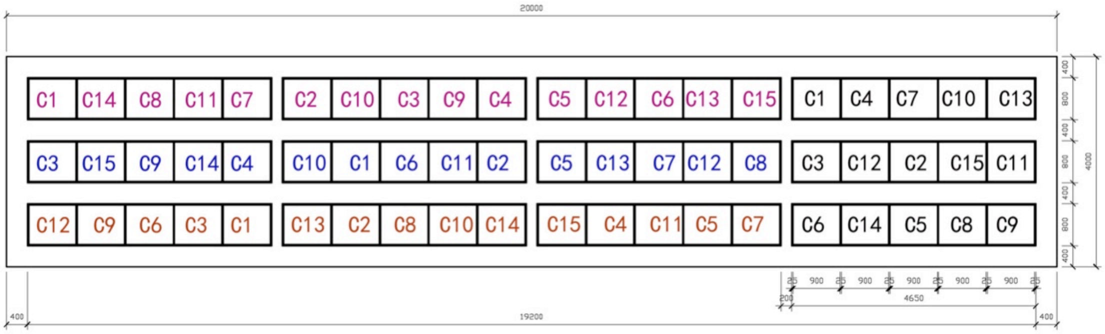


Fig. 5.1 Arrangement of the microcosm community replications (A-D) in the competition experiment. Numbers in the block present community types in relation to Table 5.1 from 1 to 15.

Fig. 5.2 The competition experiment with hedge on the northern side next to replicate A.

Table 5.2: Species used in the competition experiment, within the three canopy height groupings (family of species, habitat, root morphology, flowering height, flower colour, flowering season were described in table 3.5 in Chapter 3; mean seed weight, mean percentage of germination were summarised in table 3.7 in Chapter 3; relative coldness in relation to their collection location were described in table 4.1 in Chapter 4).

Species Name	Plant type	Collection Location	Sown/Trans-planted Divide Corms	Speed of Germination	Growth Rate
Tall (Shrub and Forb) (>600mm)					
Dimorphotheca cuneata white	shrub	Calvinia 900m	Trans Jun12	rapid(preT)	rapid
Felicia filifolia	shrub	Rooiwal 1100m	Trans Jun12	slow	slow
Lessertia frutescsens	shrub	Kamiesburg 1000+m	Trans Jun12	intermediate	rapid
Dimorphotheca cuneata orange	shrub	Kamiesburg 1000+m	Trans Jun12	Rapid (preT)	intermediate
Scabiosa africana	forb	Eastern Cape 500m	Trans Jun12	slow	slow
Medium (Shrub and Forb) (300-600mm)					
Dimorphotheca nudicaulis	forb	near Middelpos 1400m	Trans Jun12	rapid	intermediate
Geranium incanum	forb	Mossel bay 100-200m	SptS May12	intermediate	rapid
Ursinia sericea	forb	Little Karoo 200-500m	Trans Jun12	intermediate	intermediate
Goniolimon speciosum	forb	Jellito,unknown	Trans Jun12	intermediate	slow
Berkheya herbacea	forb	Somerset West 350m	Trans Jun12	intermediate	slow
Low (Forb/ Succulent) (<300mm)					
Gazania kresiana	forb	Rooiwal 1100m	Trans Jun12	rapid(preT)	rapid
Gazania othonites	forb	Rooiwal 1100m	Trans Jun12	rapid(preT)	rapid
Gazania leipoldtii	forb	Kamiesburg 1000+m	Trans Jun12	rapid(preT)	rapid
Esterhuysenia alpina	succulent	Matroosberg 1900m	Trans Jun12	slow	slow
Gazania rigida	forb	Komsberg 1600+m	Trans Jun12	intermediate (preT)	intermediate
Tall (Geophytes) (>600mm)					
Aristea major	Evergreen	Cedarberg 1000+m	Trans Jun12	rapid	intermediate
Watsonia marlothii	Deciduous	Swartberg 1800m	SptS May12	intermediate	intermediate
Kniphofia sarmentosa	Semi-ever green	Sutherland 1450m	SptS May12	rapid	rapid
Bulbinella latifolia var.*latifolia*	Deciduous	Nieuwoudtville 800-1000m	Trans Jun12	intermediate	rapid
Watsonia borbonica	Deciduous	Perdaskop 1500m	SptS May12	intermediate	rapid
Medium (Geophytes) (300-600mm)					
Gladiolus cardinalis	Deciduous	Matroosberg 1925m	SptS July12	intermediate	slow
Watsonia schlechteri	Deciduous	Bainskloof 1700m	SptS May12	intermediate	intermediate
Ixia rapunculoides	Deciduous	Nieuwoudtville 800-1000m	SptS July12	intermediate	rapid
Ixia thomasiae	Deciduous	Middelpos 1000m	SptS July12	intermediate	intermediate
Watsonia 'Tresco Dwarf Pink'	Evergreen		Corms Jul12	rapid	rapid
Low (Geophytes) (<300mm)					
Babiana cuneata	Deciduous	Nieuwoudtville 800-1000m	Trans Aug12	intermediate	slow
Romulea komsbergensis	Deciduous	Roggeveld 900-1300m	Trans Aug12	slow	rapid
Ixia curvata	Deciduous	Sutherland 1450m	SptS July12	rapid	rapid
Hesperantha pauciflora	Deciduous	Nieuwoudtville 800-1000m	SptS July12	slow	intermediate
Hesperantha vaginata	Deciduous	Nieuwoudtville 800-1000m	SptS July12	slow	slow

(*Note: SptS= Spot Sown, Trans=Transplanted, Corms= Corm Transplanted)

Fig. 5.3 (left) The C8 Medium Forb nil Geophyte community; (right) The C1 Tall Forbs + Tall Geophytes. (Photo taken on 1st Nov. 2012)

Winter protection using fleece and bubble wrap drapes was provided to avoid unwanted damage cause by unusual extreme low temperatures in the first two years, as the aim of the experiment was assessment of competition not cold tolerance. Protection was abandoned after the second year on. By using fleece-bubble wrap covers, as shown in Fig 5.4, temperature in the tunnel was generally 2-3^{o}C warmer than ambient temperature under nocturnal frost conditions. Snow was cleared frequently after heavy snowy days to protect the support structure. The covers were removed as soon as air temperature went above 0^{o}C to ensure the adequate ventilation.

Fig. 5.4: (left) Planting tunnel with bubble wrap protection during winter; (right) heavy snow occurred in Sheffield with 18cm deep on the experiment site. (photos taken on 21th January 2013)

5.2.3 Statistical analysis

Design and analysis of the experiment was undertaken in collaboration with University of Sheffield Statistical Services Unit. Repeated measures ANOVA was used for analyzing both mortality and biomass because these variables were assessed both during the first and second year for each plot.

5. 3 Results

5.3.1 Mortality

5.3.1.1 Year One (2012/13) vs Year Two (2013-14)

Figure 5.4 compares the overall mortality in year one and year two. The minimum soil surface temperatures recorded in winter 2012/2013 was -0.8°C, and in winter 2013/2014 was -1.1°C (see Figure 4.13 Tiny Tag recordings in Chapter 4). For most species, winter cold was only a contributory source of mortality. Geophytes had less mortality than shrub/forb/succulent species in the first two years. Life form showed significant difference in mortality (P<0.01), with no significant difference within geophyte group (P>0.05) but highly significantly different within shrub/forb/succulent group (P<0.01). Mortality in year two was highly significantly different from mortality in year one (P<0.01).

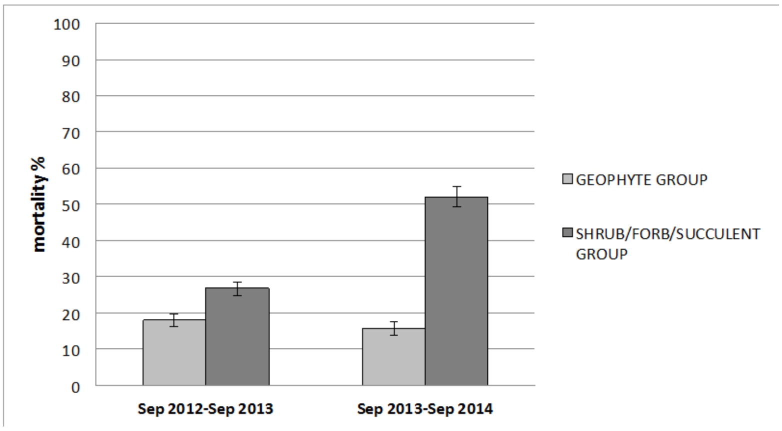
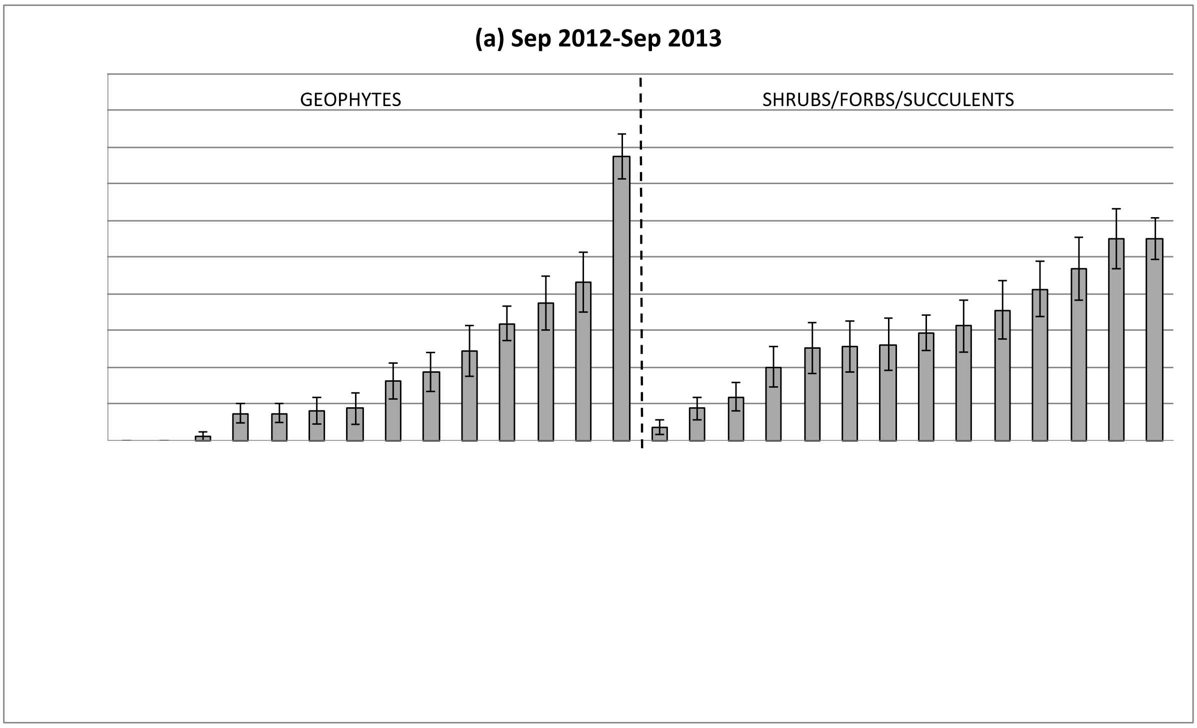


Fig. 5.5 Mortality of all the species in Year One 2012-2013 and Year Two 2013-2014. Error bars indicate standard error).

5.3.1.2 Shrubs/Forbs/Succulents vs Geophytes

Figure 5.6 compares the mortality of individual species in Year One and Year Two. The first graph illustrates the data at the first count in September 2013 and the second is based on the count recorded in September 2014. Percentage mortality was calculated in September 2013 by expressing the number of seedlings at this census as a percentage of those present at the beginning of the experiment in 2012. Mortality in September 2014 used the number of surviving plants present in September 2013 as the base line, with seedlings alive in 2014 expressed as a percentage of those survivors present in 2013. There were four species for which this was not the case, *Aristea capitata, Berkheya herbacea, Dimorphotheca cuneata* (white form) and *Gazania othonites* suffered close to 100% loss in winter 2012/13 so the decision was taken to replace these species with pot grown seedlings so as not to compromise the competition part of the study.

In the first testing period, small geophyte seedlings of *Hesperantha pauciflora* suffered the highest mortality, followed by succulent *Esterhuysenia alpina* and the forb *Gazania othonites* with more than 50% mortality. Due to an oversight about the possible adverse effects of being sealed in bubble wrap protection, the bubble wrap was left in situ for lengthy periods leading to very humid conditions, that resulted in a fungal pathogen mediated die back especially in *Gazania othonites* and white forms of *Dimorphotheca cuneata.* Neither of these latter two species showed any mortality on adjacent unprotected hardiness experiment*.* In year two, although the minimum temperature was -1.1°C (which was a bit lower than winter 2012/2013), it was obvious that most of geophytes had less mortality, except the highly cold sensitive form of *Aristea capitata* that we had inadvertently used. More shrubs/forbs/succulents had higher mortality in 2013-2014, especially after the very wet January and February 2014. It is however difficult to separate this mortality in the shrubby, species *Lessertia frutescens* (97.19%), *Dimorphotheca cuneata* (orange) (53.00%) and *Dimorphotheca cuneata* (white) (45.78%) from a failure to resprout after the first biomass harvest in September 2013.



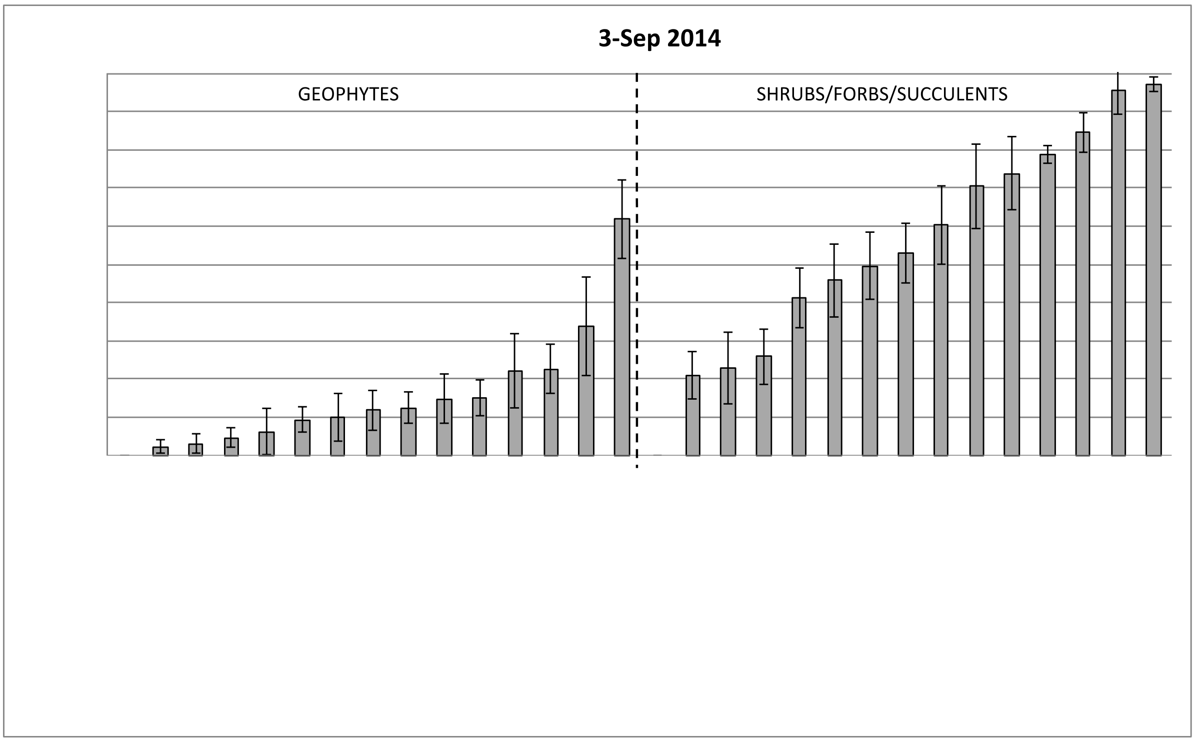


Fig. 5.6 Mortality of shrub/forb/succulent and geophyte species between late 2012 and September 2013 (a) and 2013-2014 (b), expressed as a % of the number of plants surviving in September 2014 as a percentage of those present in September 2013 (error bars indicate standard error).

5.3.1.3 Mortality of individual species across communities

As shown in Figure 5.7, mean plant mortality of individual species varied among species. Almost half of the species suffered more than 50% mortality (mostly in the shrub/forb/succulent group) whilst those in the geophyte group less than 50% mortality. The first five species with the lowest mortality (in descending order) were *Watsonia* 'Tresco Dwarf Pink'，*Watsonia marlothii*，*Romulea komsbergensis*，*Ixia curvata* and *Ixia thomasiae*. The species with the highest mortality (in descending order) were the steppe species *Goniolimon speciosum,* shrubby species *Lessertia frutescens,* forb species *Berkheya herbacea, Gazania othonites* and shrubby species *Felicia filifolia*. *Goniolimon speciosum* is a central Asia steppe species and was presumably damaged by wetness, whilst *Berkheya herbacea* is clearly sensitive to winter cold.

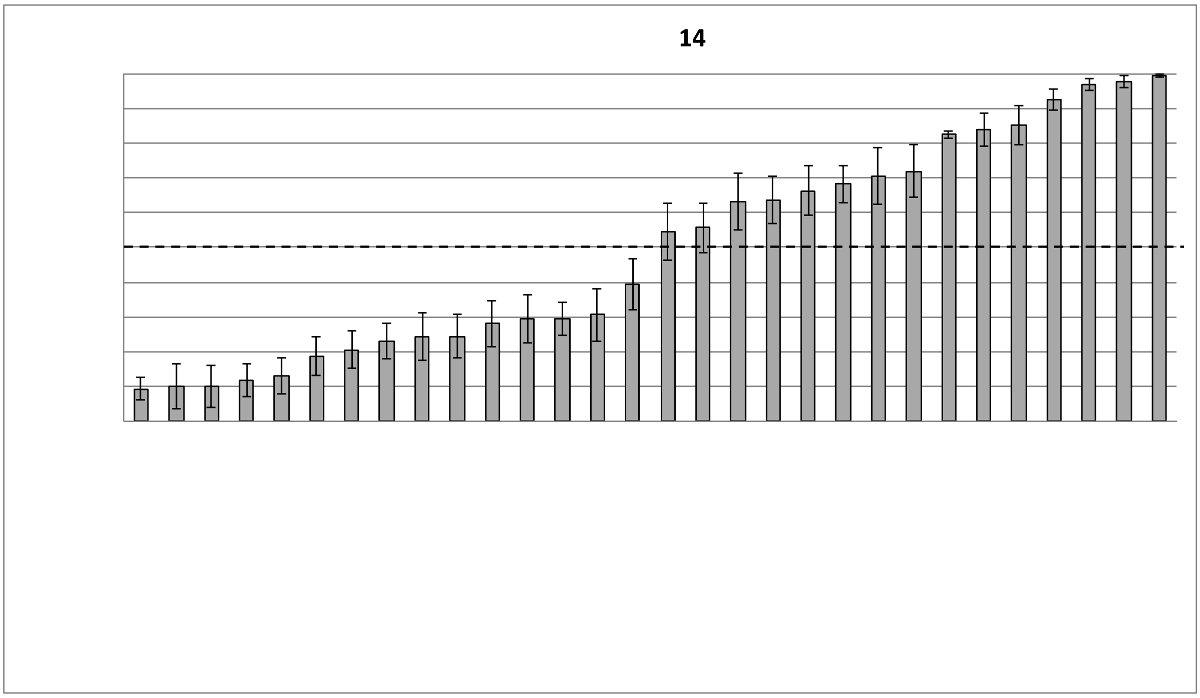
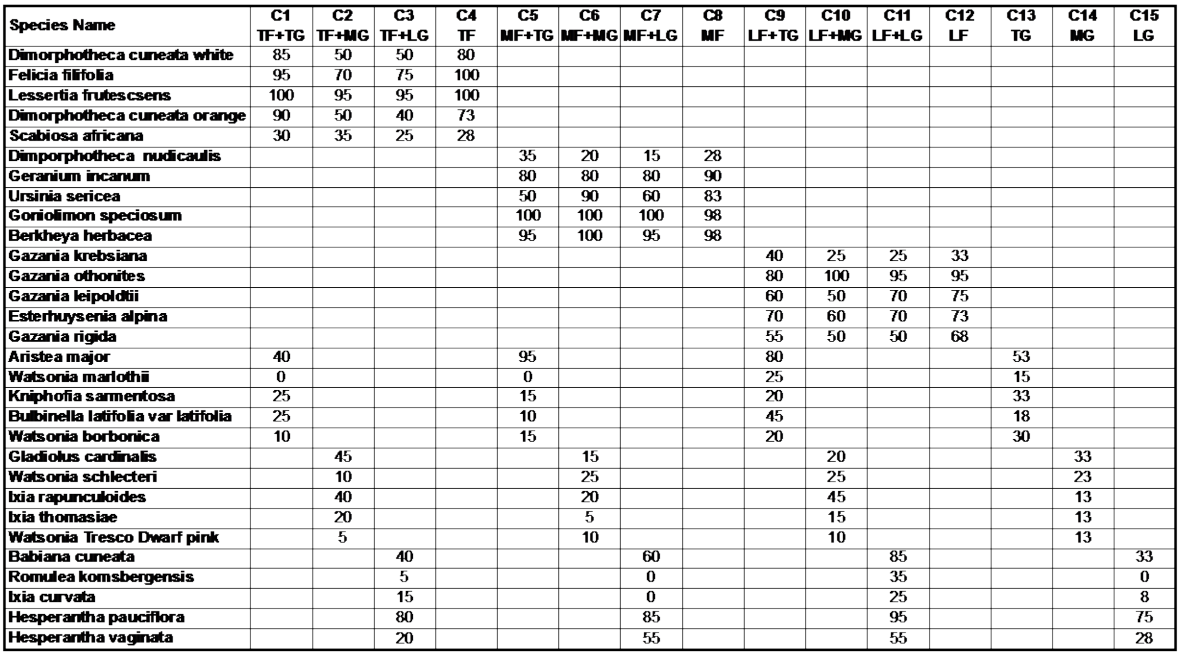


Fig. 5.7 Mortality of shrub/forb/succulent and geophyte species for the period 2012-2014, expressed as a % of the number of plants present between Sep. 2012 and Sep. 2014 (error bars indicate standard error).

In most individual species mortality showed no significant differences across the communities (Repeated Measures ANOVA). *Aristea capitata (major)* and *Felicia filifolia* (P<0.05) did however perform differently in different communities. *Aristea major* had 95% and 80% mean mortality in medium forb tall geophyte community C5 and low forb and tall geophyte community C9, while had only 40% and 53% mean mortality in tall forb tall geophyte community C1 and tall geophyte only C13. The slow growing shrubby species *Felicia filifolia* declined quickly when faster growing forb *Scabiosa africana* and the shrubby species *Dimorphotheca cuneata* in the same canopy group developed their shady canopies. It suffered higher mortality in tall forb only C4 (100%) and tall forb tall geophyte community C1 (95%), while less mortality in tall forb medium geophyte community C2 (70%) and tall forb low geophyte community C3 (75%). The low and medium canopy geophytes did not show any significant difference in mortality across communities even when they were combined with tall canopy shrub/forb group. Loss of *Gazania othonites* appears mainly due to a fungal pathogen, that was more damaging in some plots than others. Loss of *Lessertia frutescsens* was mainly due to cutting for biomass harvesting, it could not re-sprout from the woody base.

In the Table 5.3, although mean mortality of many other species didn't show significant difference across the communities, variations in different combinations existed. Both of *Dimorphotheca cuneata* white and orange forms showed higher mortality in tall forb/ tall geophyte community C1 and tall forb only C4 where competition for them was higher. The medium geophyte *Ixia rapunculoides* and *Ixia thomasiae* suffered higher mortality in tall forb/ medium geophyte community C2 and low forb medium geophyte community C10. *Babiana cuneata* had highest mortality in low forb/ low geophyte community C11 (85%) and lowest mortality in low geophyte only community C15 (33%).

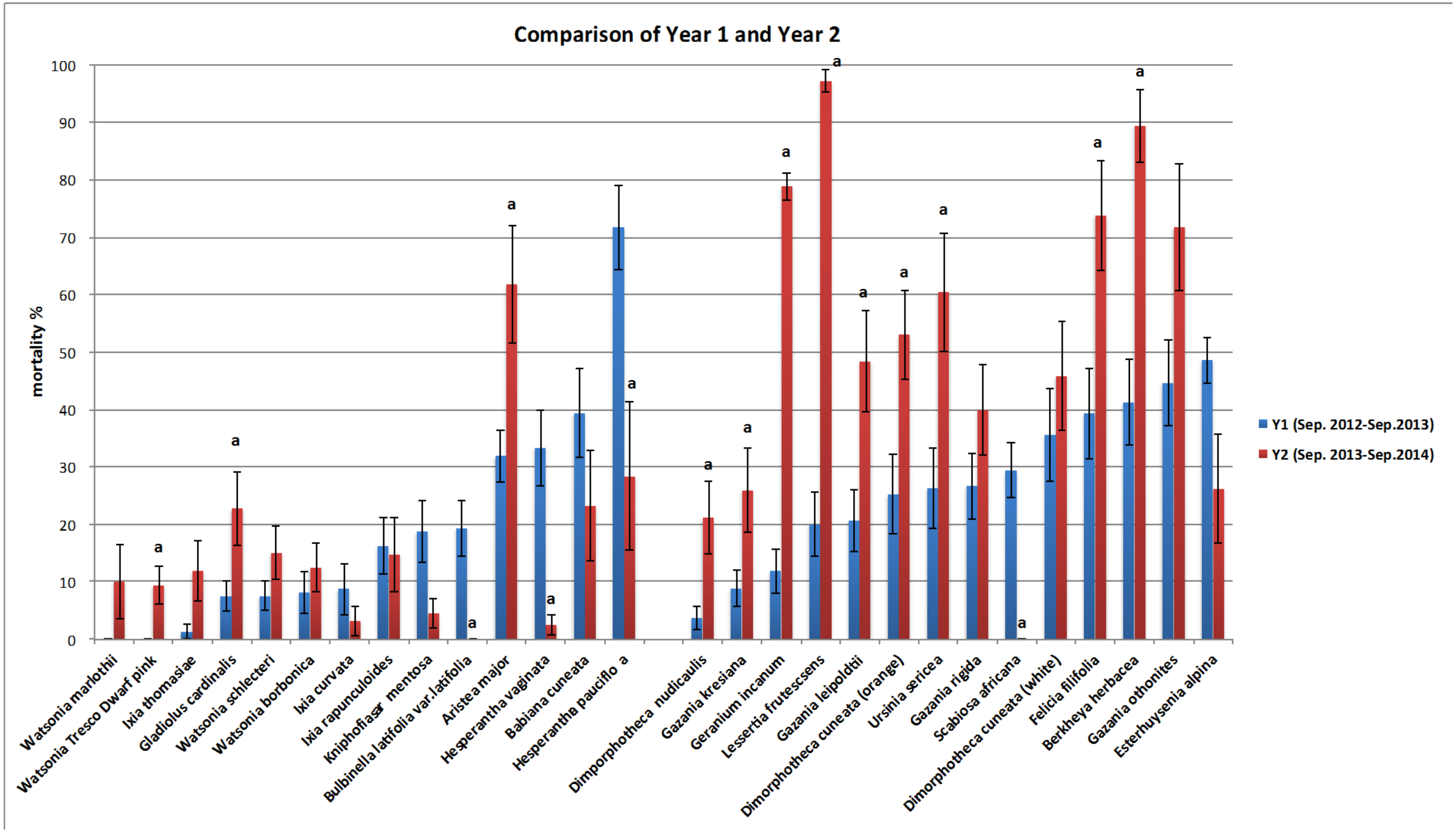
Table 5.3 Summary of mean mortality of individual species in communities where it represented for the period 2012-2014.



Species Name	C1 TF+TG	C2 TF+MG	C3 TF+LG	C4 TF	C5 MF+TG	C6 MF+MG	C7 MF+LG	C8 MF	C9 LF+TG	C10 LF+MG	C11 LF+LG	C12 LF	C13 TG	C14 MG	C15 LG
Dimorphotheca cuneata white	85	50	50	80											
Felicia filifolia	95	70	75	100											
Lessertia frutescsens	100	95	95	100											
Dimorphotheca cuneata orange	90	50	40	73											
Scabiosa africana	30	35	25	28											
Dimporphotheca nudicaulis					35	20	15	28							
Geranium incanum					80	80	80	90							
Ursinia sericea					50	90	60	83							
Goniolimon speciosum					100	100	100	98							
Berkheya herbacea					95	100	95	98							
Gazania krebsiana									40	25	25	33			
Gazania othonites									80	100	95	95			
Gazania leipoldtii									60	50	70	75			
Esterhuysenia alpina									70	60	70	73			
Gazania rigida									55	50	50	68			
Aristea major	40				95				80				53		
Watsonia marlothii	0				0				25				15		
Kniphofia sarmentosa	25				15				20				33		
Bulbinella latifolia var latifolia	25				10				45				18		
Watsonia borbonica	10				15				20				30		
Gladiolus cardinalis		45				15				20				33	
Watsonia schlecteri		10				25				25				23	
Ixia rapunculoides		40				20				45				13	
Ixia thomasiae		20				5				15				13	
Watsonia Tresco Dwarf pink		5				10				10				13	
Babiana cuneata			40				60				85				33
Romulea komsbergensis			5				0				35				0
Ixia curvata			15				0				25				8
Hesperantha pauciflora			80				85				95				75
Hesperantha vaginata			20				55				55				28

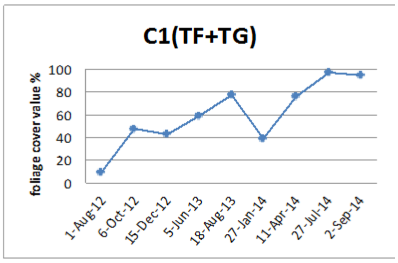
From the two year’s mean mortality comparison bar chart in Figure 5.8, generally, the forbs/ shrubs had much higher mortality in Year Two compared to Year One. There were various phenology observed in Year Two. *Geranium incanum*, *Gazania krebsiana* and *Gazania leipoldtii* have the capacity for self-seeding, however, adult plants seemed to be short-lived and some large clumps died out in the second year before the next growing season. *Lessertia frutescsens, Dimorphotheca cuneata orange* form and *Ursinia sericea* re-sprouted well post harvesting in August 2013 then quickly declined in September and October after a prolonged, particularly after wet periods. *Felicia filifolia* was intolerant of shade caused by other fast-growing tall forbs in its group which always presented in the same community with *Felicia filifolia.* The winter cold sensitive species *Berkheya herbacea* declined quickly during frost days and much quicker in more open positions. *Gazania othonites,* as previously mentioned, died because of fungal pathogen problem under humid tunnel during the protection rather than winter cold. Although winter 2013/14 had less frost than 2012/13, it was very wet in January and February 2014. Some individuals of forbs died out due to winter wet in these two months.

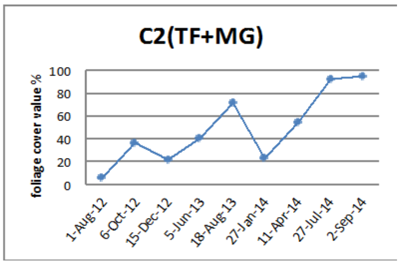
Fig. 5.8 Mortality comparison of shrub/forb/succulent and geophyte species in period of Year one 2012-2013 and Year Two 2013-2014, expressed as a % of the number of plants present between Sep. 2012 and Sep. 2013, Sep. 2013 and Sep. 2014. “a” indicates mortality of species in Year 2 was significant difference from mortality of the same species in Year 1 (error bars indicate standard error).

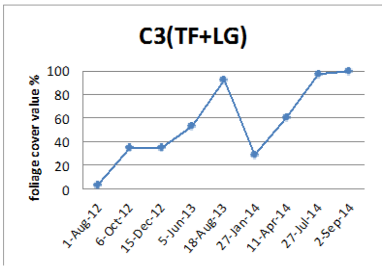


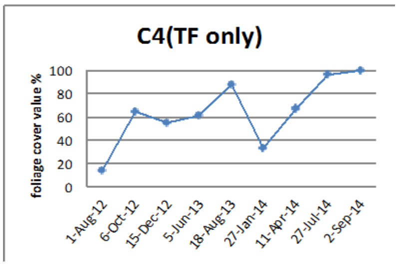
5.3.2 Cover value in 2012-2014

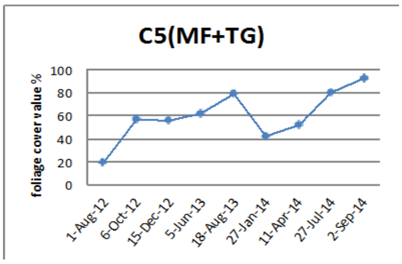
Foliage cover value (for all replicates of all communities) was estimated 9 times through observation between December 2012 and September 2014, using a modified Braun Blanquet scale. Figure 5.9 and Figure 5.10 shows estimated mean foliage cover values of individual communities from the commence of competition experiment on 1st August 2012 till September 2014. Community 12 (low forb only) initially had a higher canopy coverage because of the very rapid growth of *Gazania* in this community. The communities of low geophytes only and medium geophytes only were very slow to achieve coverage. All the cover value dropped down after late August 2013 due to the first harvesting carried out. The medium geophytes only combination shot up in from April to July 2014 because *Watsonia ‘Tresco Dwarf Pink’* is a vigorous species which produces most of its foliage in late spring to early summer.

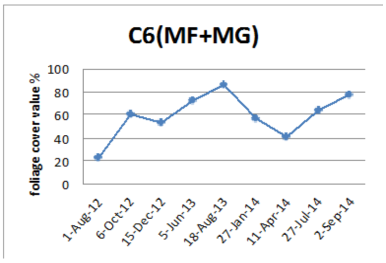


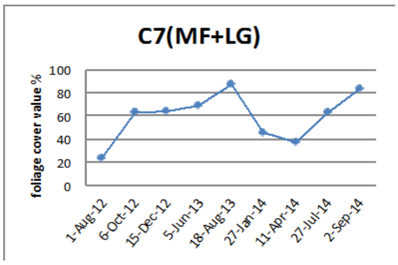


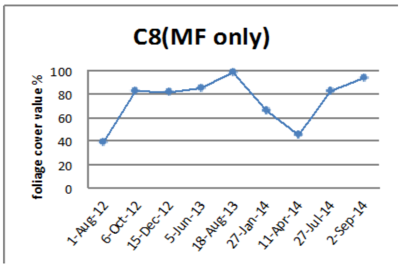


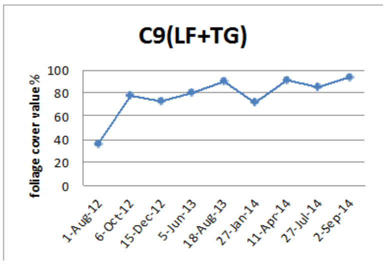












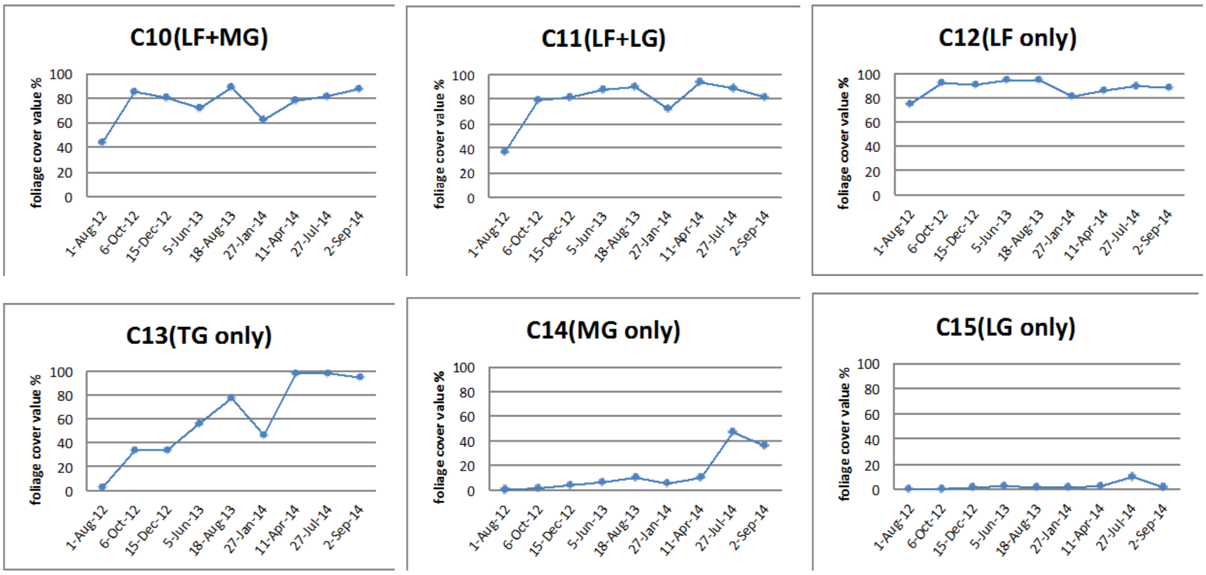

C10(LF+MG)
C11(LF+LG)
C12(LF only)
C13(TG only)
C14(MG only)
C15(LG only)

Fig. 5.9 Changes of percentage foliage cover value over time (2012-2014) with August 2012.

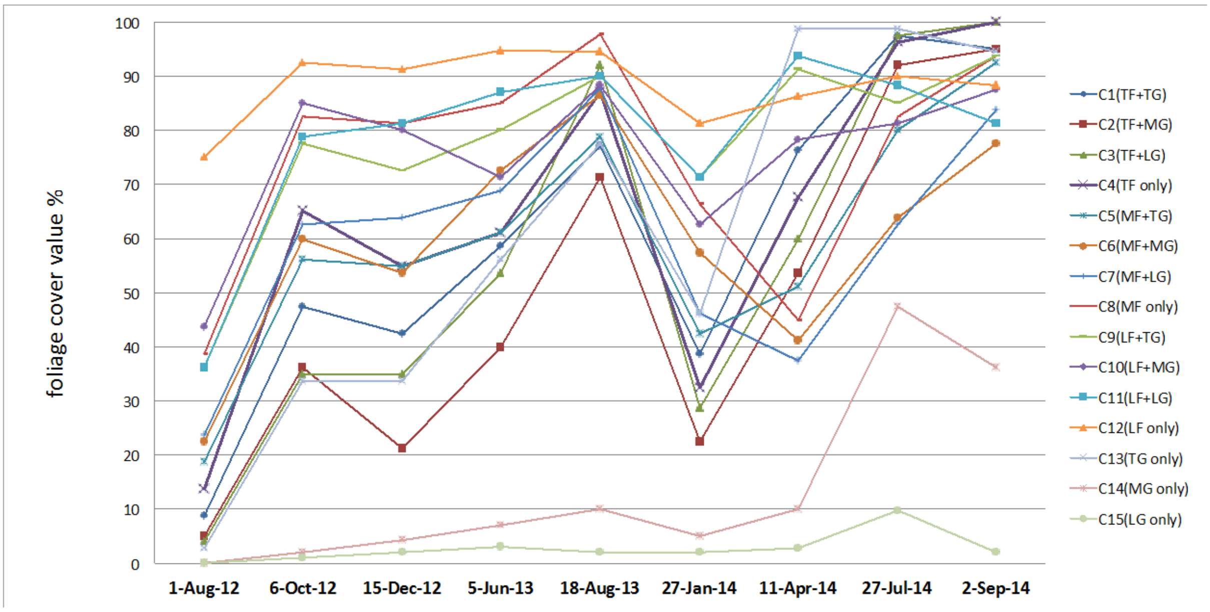


Fig. 5.10 Changes of foliage cover value over time (2012-2014). Rather unexpectedly for Mediterranean vegetation, differences in foliage canopy cover are maximal in winter, and least in summer. Nearly all communities have their highest cover in late summer early autumn, except the geophyte only C15 and C14.

By using Repeated Measures ANOVA as an exploratory technique, a Principle Component Analysis was carried out on the mean scores for coverage of each community at each measuring time point and the first two components extracted. This provided scores for overall coverage and increase in coverage. These components explained 92.7% of the overall variation. When plotted they produced the graph in Figure 5.11. C14 and C15 were the two lowest coverage communities, and C12 was the community with the highest coverage. C1, C2, C3, C4 and C13 were the five communities experienced biggest increase in coverage across the time. C12 and C15 had smallest change in coverage. C15 contained low canopy geophytes which were all small in size and mainly slow growing. The PCA analysis groupings matched the observations of what was happening in the experiment. Fast-growing and bigger canopy tall forbs presented in C1, C2, C3, C4 formed a group with the fastest growing tall geophytes *Kniphofia sarmentosa* which dominated in C13. Low forbs were mixed with tall to medium geophytes in C9, C10, C11, while medium forbs occurred in C9, C10, C11. The coverage of these communities is mainly contributed by only one species, and they formed another distinctive grouping.

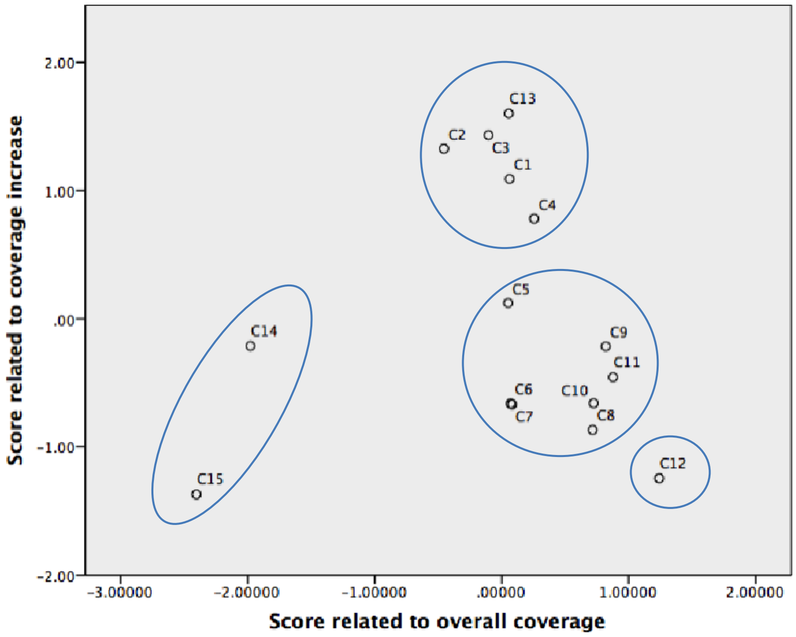


Fig. 5.11 Pattern showing mean scores for overall coverage of each community and increase in coverage, C15 had the lowest coverage and C12 had the in highest coverage, C15 and C12 had the smallest increase in coverage and C13 had the biggest increase in coverage.

Weed coverage was also observed, and was maximal in spring and than in early autumn after the annual canopy harvest-removal. On 11th April 2014, spring weeds started to compete with species in each community, with many more weeds in communities less occupied by South African species. Most communities with tall shrub/forb group or medium height shrub/forb group expanded quickly through summer and continuously out competed the mainly ruderal weeds. A large amount of weeds were restricted to a small percentage in observed areas or died out when shrub/forb species spread out. Community 15, containing low summer dormant geophytes only, was highly covered by weed in early autumn due to all the species within this community being dormant the whole summer. The species cover value of Community 14 (medium geophytes only) on 2nd September was only contributed by *Watsonia* 'Tresco Dwarf Pink', because other winter growing geophytes in this group were in dormancy during summer and re-shoot in September.

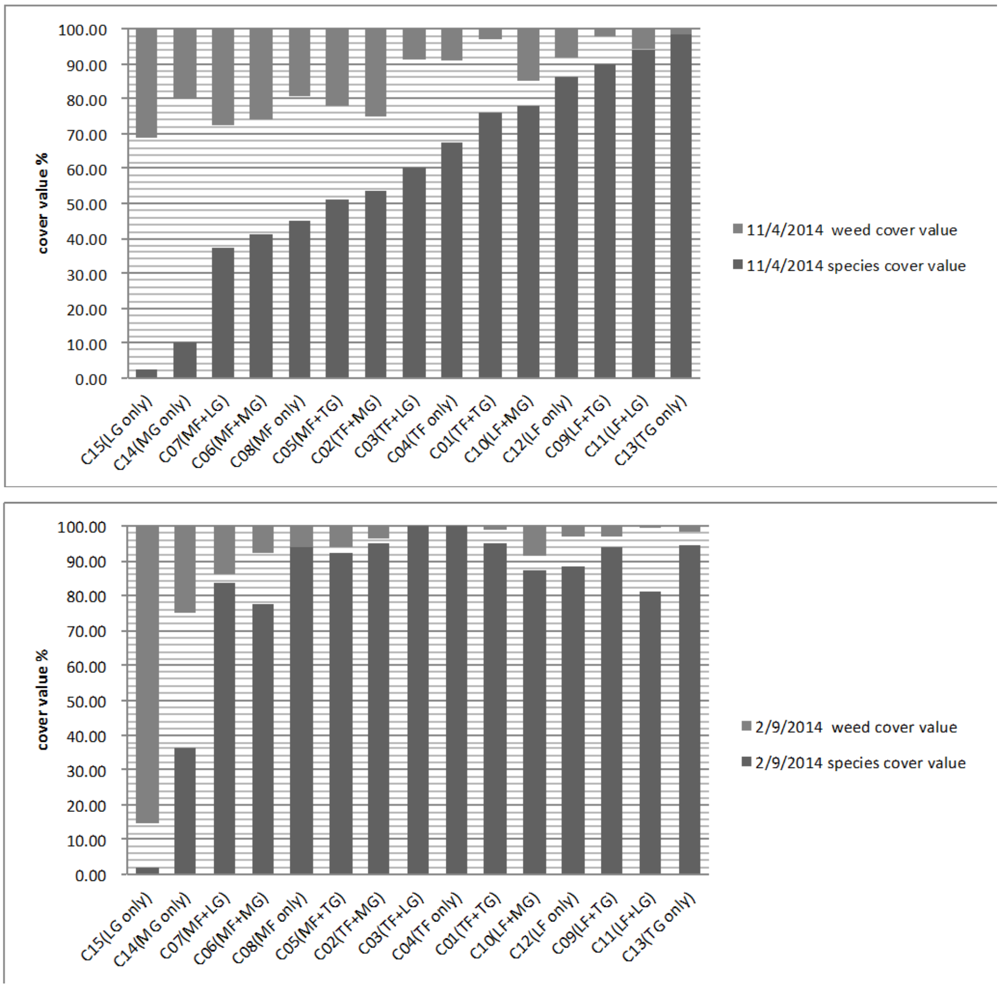
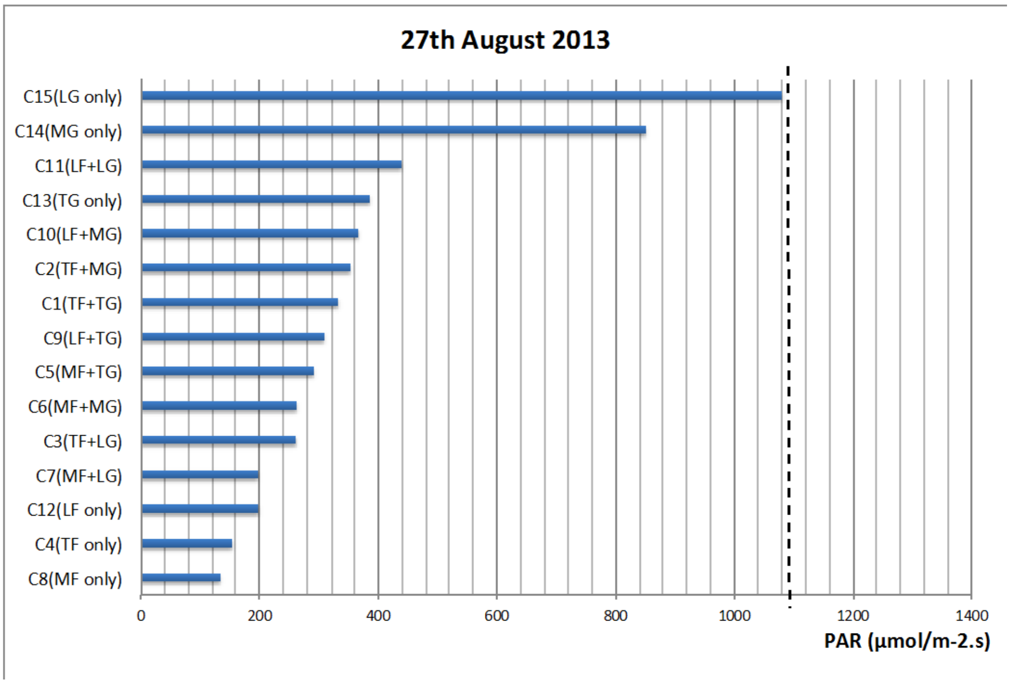
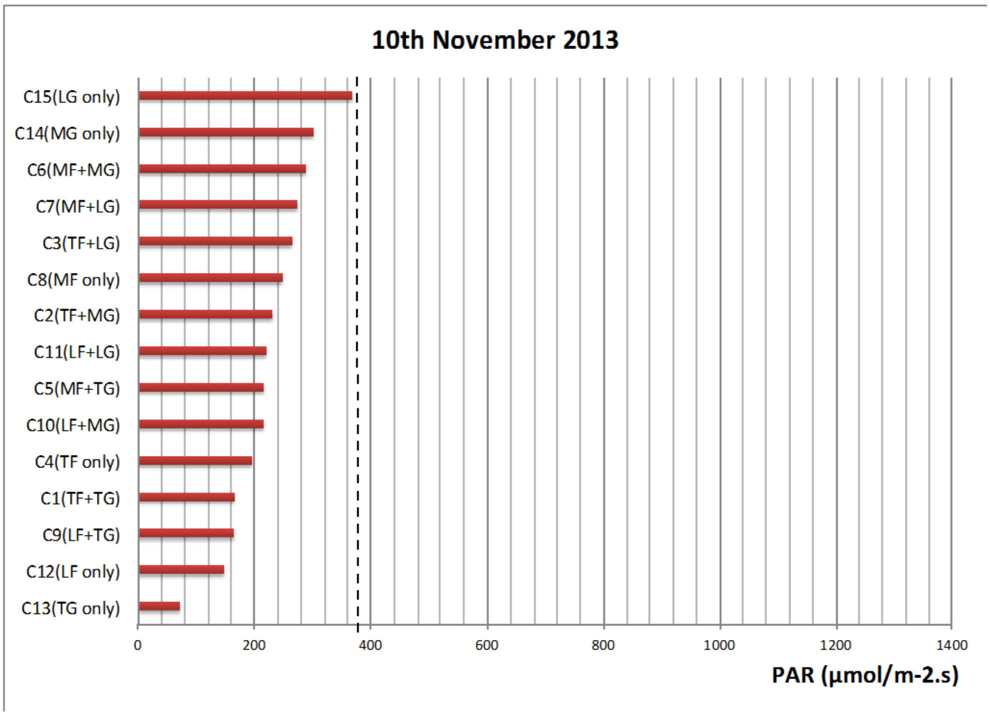


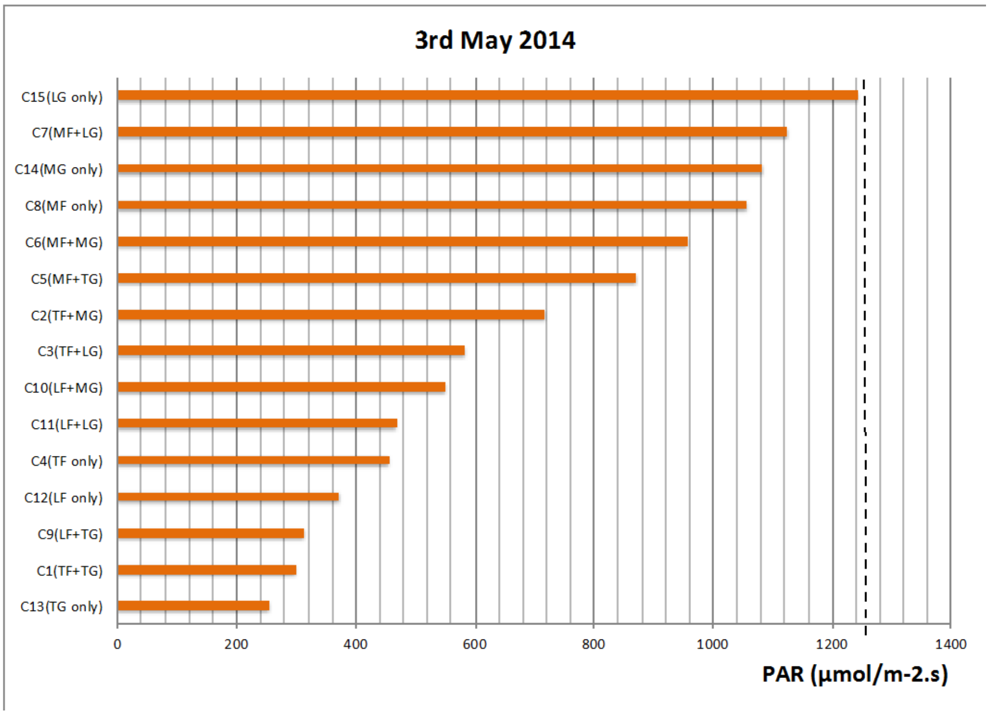
Fig. 5.12 Comparison of species foliage and weed cover value in spring and autumn 2014 (above: cover values in 11th April 2014, below: cover values in 2nd September 2014). The whole tested area within each block was regarded as 100%, the gaps between dark grey bars (species foliage cover value) and light grey bars (weed cover value) represent bare soil. The communities on 2nd September were listed in the same order as on 11th April to better assess the change in species cover values and compare the relations between species and weed cover values.

5.3.2.1 Sunscan cover value 2012-2014

The incident photo-synthetically active radiation (incident PAR) recorded before measuring the PAR in plant canopies were 1083.6 μ mol $m^{-2}s^{-1}$, 370.1 μ mol $m^{-2}s^{-1}$, 1245.2 μ mol $m^{-2}s^{-1}$ and 1303.4 μ mol $m^{-2}s^{-1}$ respectively in the following assessing time. High readings in PAR reflected less foliage development and low foliage coverage (measurements were carried out after weeding therefore weed coverage was not taken in account). Weed coverage was most composed of low ruderals such as hairy bitter cress and nursery Epilobium that would not in any case have had a significant affect on the readings. Low readings in PAR reflected more foliage development and high in foliage coverage. In Figure 5.13, measurement on 27th August 2013 was just before the first harvesting, C8 (medium forb only) was highest in foliage coverage, which was immediately replaced by C13 (tall geophytes only) after cutting till the following May. With the arrival of summer, C3 (tall shrub/forb low geophytes), C1 (tall shrub/forb tall geophytes), C4 (tall shrub/forb only) and C2 (tall shrub/forb medium geophytes) showed rapid foliage coverage, followed by C13 (tall geophytes only) and C9 (tall geophytes low forb).




10th November 2013
C15(LG only)
C14(MG only)
C6(MF+MG)
C7(MF+LG)
C3(TF+LG)
C8(MF only)
C2(TF+MG)
C11(LF+LG)
C5(MF+TG)
C10(LF+MG)
C4(TF only)
C1(TF+TG)
C9(LF+TG)
C12(LF only)
C13(TG only)
0
200
400
600
800
1000
1200
1400
PAR (μmol/m-2.s)


3rd May 2014
C15(LG only)
C7(MF+LG)
C14(MG only)
C8(MF only)
C6(MF+MG)
C5(MF+TG)
C2(TF+MG)
C3(TF+LG)
C10(LF+MG)
C11(LF+LG)
C4(TF only)
C12(LF only)
C9(LF+TG)
C1(TF+TG)
C13(TG only)
0
200
400
600
800
1000
1200
1400
PAR (μmol/m-2.s)

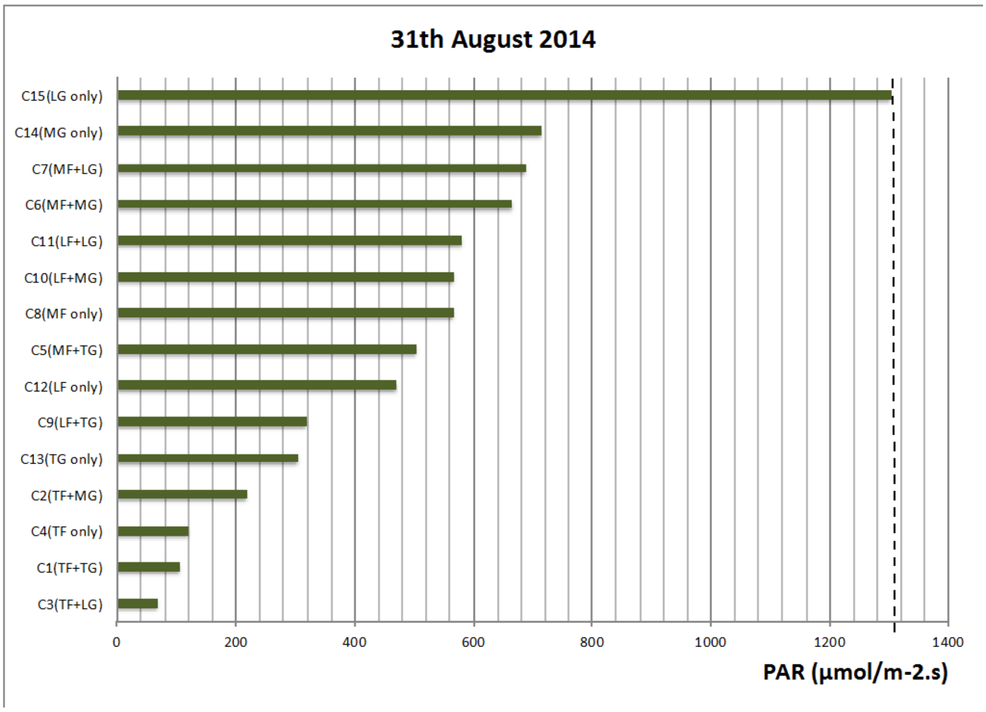


Fig.5.13 Mean PAR in communities was measured between August 2013 and August 2014 at 4 monitoring time points (27th Aug. 2013, 10th Nov. 2013, 3rd May 2014 and 31th Aug. 2014). Large value PAR indicates low community foliage cover value and small figure in PAR indicates high community foliage cover value. Dotted lines indicate incident PAR of each measurement.

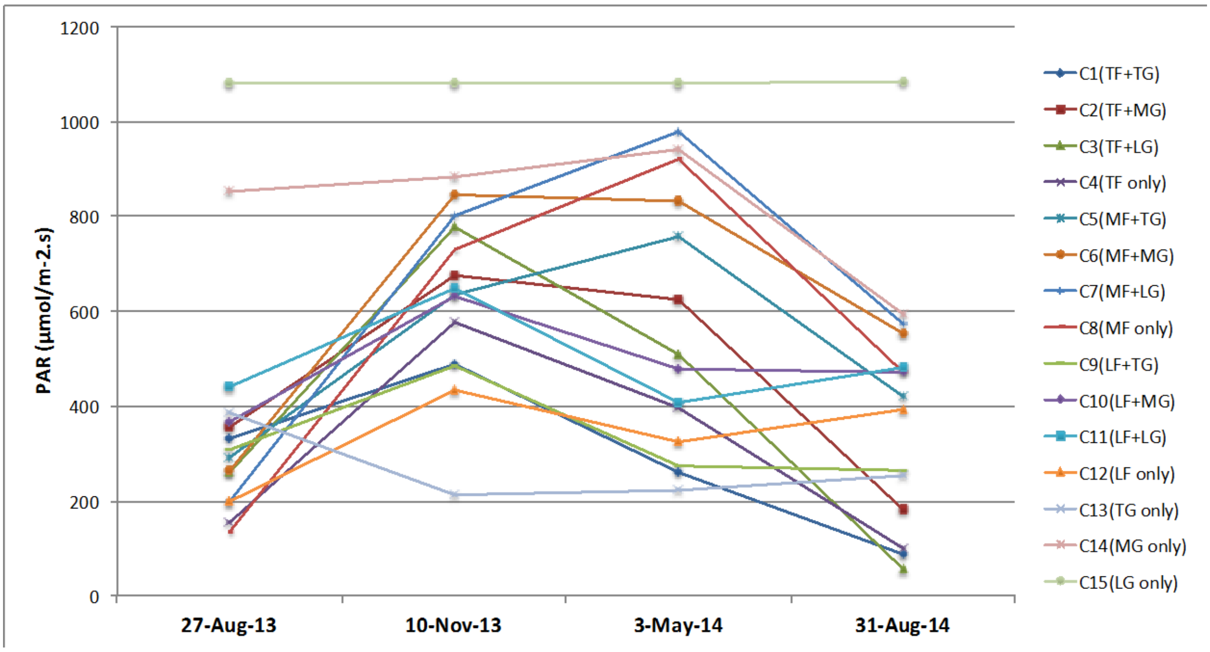


Fig. 5.14 Changes of PAR in Year Two (2013-2014) with August 2013 measurement as the baseline for each communities at 4 monitoring time points.

5.3.3 Biomass in Year One (September 2013 harvest)

5.3.3.1 Total biomass per community

A medium forb species was not available at the first harvest point due to the chosen species not being available in required number as seeds or seedlings, however the overall effect of this omission is relatively small. In addition, the transplanted corms of *Romulea komsbergensis* did not emerge in winter 2012/2013, therefore, data of one species is missing in the low geophyte group as well. There were 14 shrub/forb/succulent species and 14 geophyte species in the analysis. Total mean biomass of all geophytes and shrubs/forbs/succulents was highly significantly different (P<0.01) as shown in Figure 5.15.

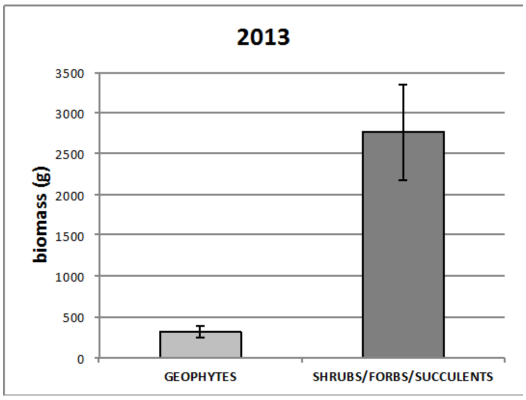
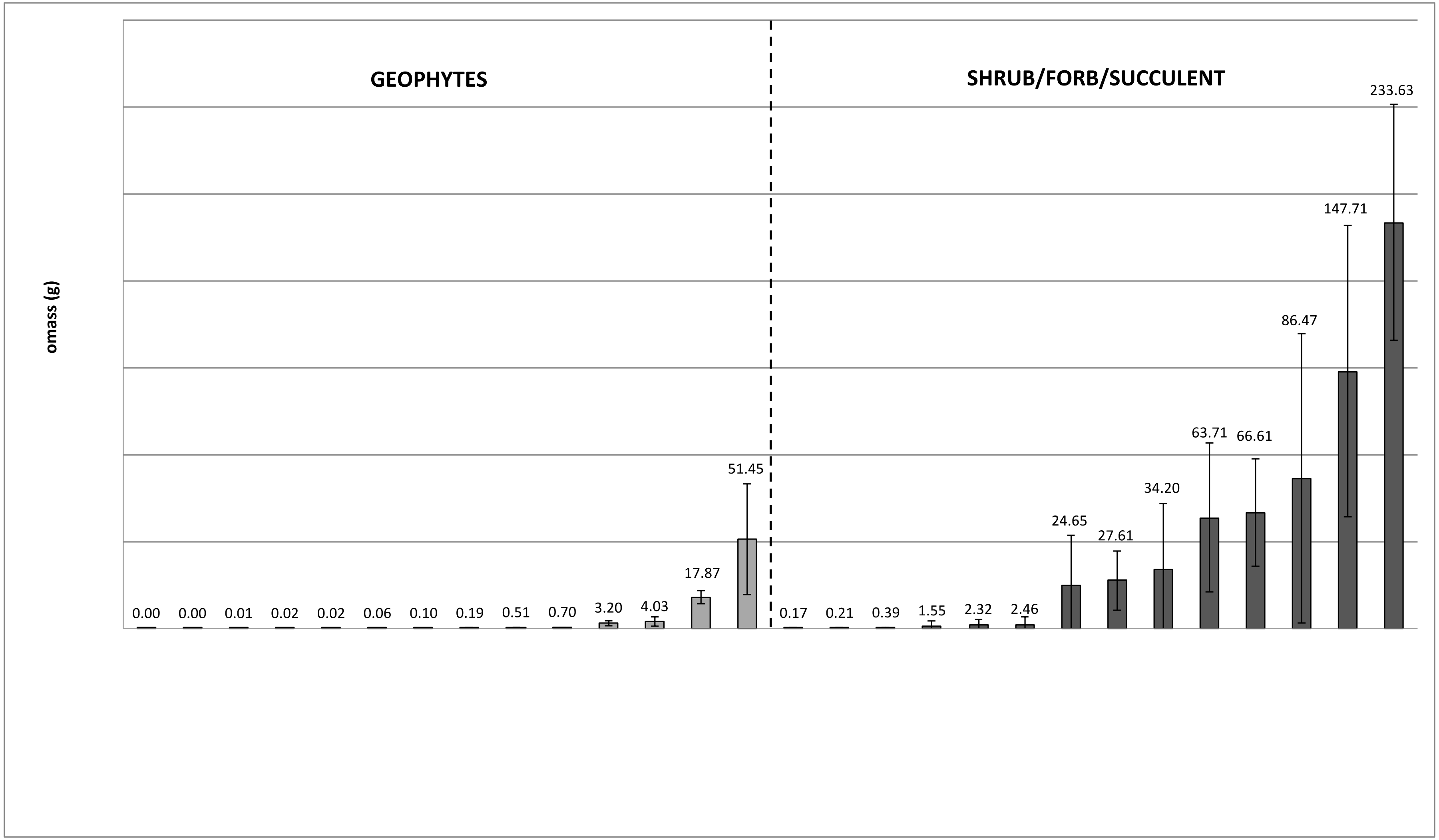


Fig. 5.15 Total Mean biomass of all geophytes and shrubs/forbs/succulents for all treatments and replicates in September 2013.

5.3.3.2 Total biomass of individual species

Figure 5.16 shows the mean total biomass of all the individual species across all the communities and replicates. The largest dry weight of geophytes at the summer maximum in 2013 was the spot sown evergreen geophyte *Kniphofia sarmentosa* (51.45g), whilst the maximum biomass recorded across the communities was the spot sown forb *Geranium incanum* (233.63g). G*azania kresiana, Scabiosa africana, Dimorphotheca cuneata* white and *Lessertia frutescenes* were the next four forb species in declining order. *Watsonia* ‘Tresco Dwarf Pink’ (17.87g) was the second in aboveground biomass production as geophytes, however, corms of this species were 1-2 years old when transplanted, giving this genotype and initial advantage. Generally, mean total biomass of geophytes were much less than forb and shrub species.

Fig. 5.16 Mean total biomass of individual species in all treatments all replicates in 2013.



5.3.3.3 Mean biomass of communities

Univariate ANOVA indicated biomass contributions of 15 communities were highly significantly different (P<0.01). C14 and C15 present significant differences from C4, C3, C8, C12 and C7. Communities with only low geophytes and only medium geophytes present lowest biomass in 2013 harvesting. Community of only tall forbs and community of tall forbs 50% mixed with low geophytes 50% achieved highest biomass in 2013.

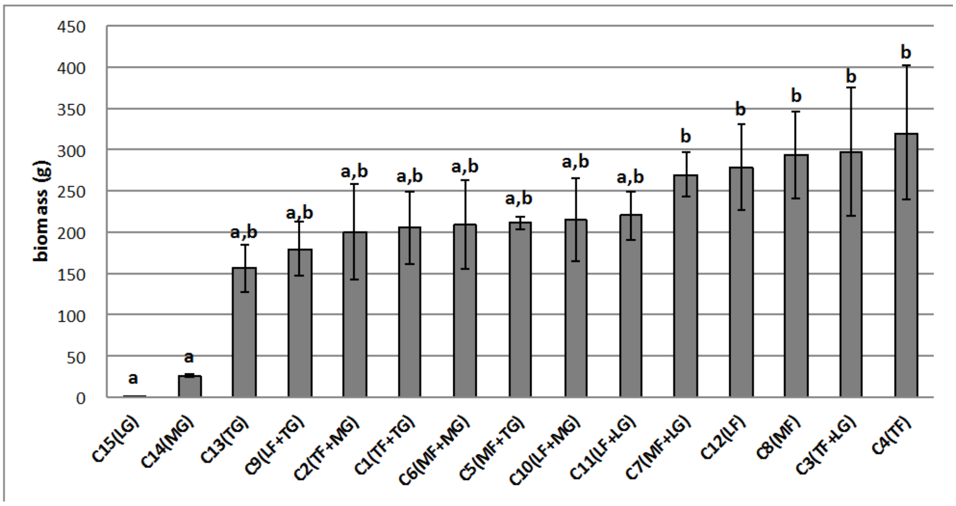


Fig. 5.17 Year one mean biomass of different communities in September 2013. Error bars indicate the standard error (biomass of species with “a” indicates it was significant difference from biomass of species with “b” in the same community (Tukey HSD^{ab})).

5.3.3.4 Effect of different communities on biomass of Individual species

In the tall shrub/forb/succulent group (Table 5.4), all of five species showed no significant differences in mean biomass across the communities. *Scabiosa africana* and *Lessertia frutescens* had the highest biomass in C4(TF) and C3(TF+LG). *Dimorphotheca cuneata* (white form) had similarly high biomass in most communities where it was present except in C1(TF+TG). In the tall forb only community, where the numbers of each species were doubled, the white form of *Dimorphotheca cuneata* produced more biomass than the orange form in the first year. *Felicia filifolia* was relatively slow-growing species and presented the lowest biomass in all the four communities where this species were present. All medium height forb species also showed no significant differences in mean biomass across communities (Table 5.4). *Geranium incanum* produced over 180g mean biomass in all medium forb communities, which was much higher than the other three species in the medium forb group. In the low canopy forb group, still no significant differences occurred in any species in four communities where they present. *Gazania krebsiana* produced 203.02g biomass in the C12(LF only) community , followed by C11(LF+LG) 142.65g, C10(LF+MG)128.07g then C9(LF+TG)117.11g. *Esterhuysenia alpina* had the least in biomass production.

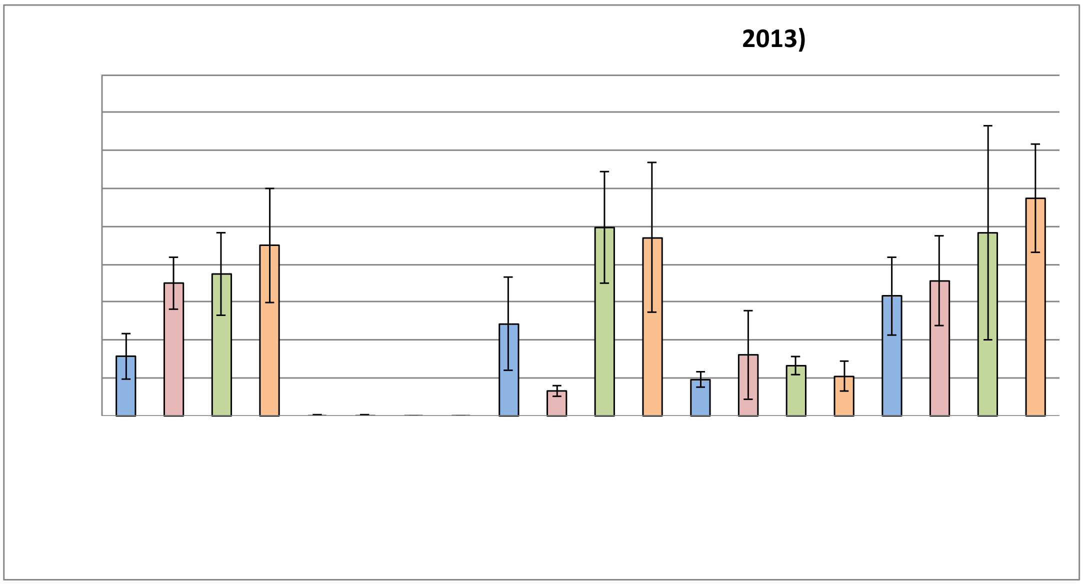
In the geophyte groups, most species showed highly significant differences (P<0.01) in biomass between communities, one species showed significant differences (P<0.05). *Watsonia schlecteri, Ixia rapunculoides, Hesperantha pauciflora* and *Hesperantha vaginata* showed no significant differences. *Kniphofia sarmentosa* had highest biomass (137.35g) in C13(TG only), which was much higher than its mean total biomass across the communities (51.45g). *Aristea capitata (major)* had its highest biomass in C13(TG) 10.87g, followed by C5(MF+TG) 3.82g. In medium and low canopy geophytes, all the species had their highest biomass in the nil forb communities C13(TG) and C15(LG). Most medium and low geophyte species grew slowly in the first year, *Hesperantha pauciflora* and *Hesperantha vaginata* had particularly low biomass production (Figure 5.18).

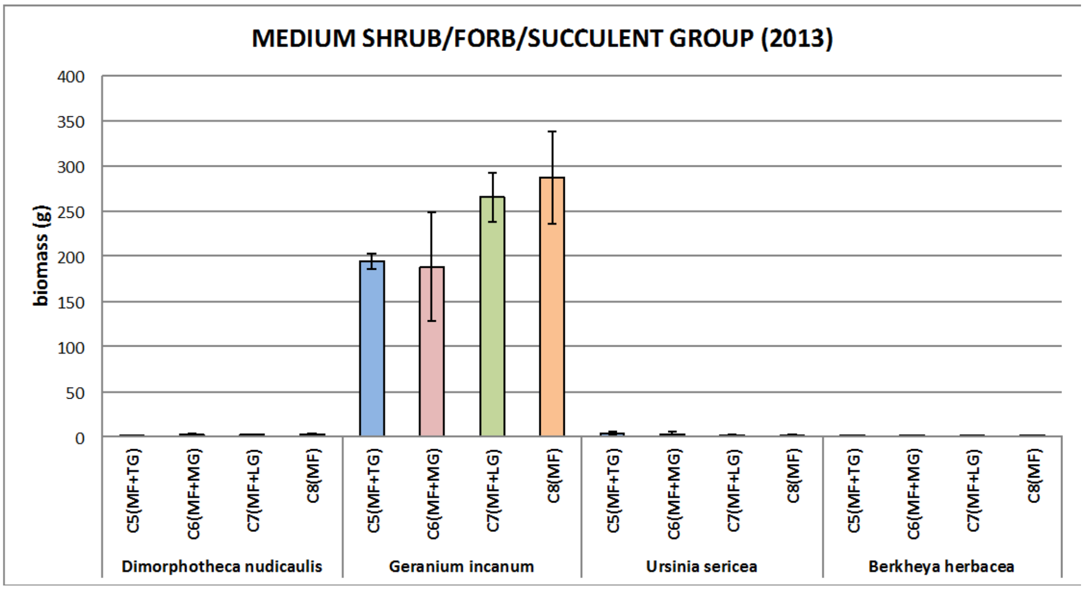
Figure 5.18 compares mean biomass based on life form and canopy height of individual species across the communities in all replicates. Shrub *Felicia filifolia* has been greatly restricted by the other four shrub and forb species in tall canopy group. Medium canopy forb/shrub group present in community 05,06,07 and 08. The mean total biomass of all the medium height forb/shrub species were in an increasing order in C5(MF+GT) 207g, C6(MF+MG) 224g, C7(MF+LG) 245g and C8(MF only) 277g. The figures showed medium height forb/shrub group had lowest total biomass in community mixed with tall geophytes and highest total biomass in community of medium forb/shrub only. Total biomass of all tall geophytes in C1(TF+TG), C5(MF+TG), C9(LF+TG) and C13(TG only) were 42.5g, 43.3g, 60g and 93.6g respectively. Tall geophytes produced lower biomass when competed with tall and medium height shrub/forb groups, and higher biomass when mixed with low canopy geophytes.

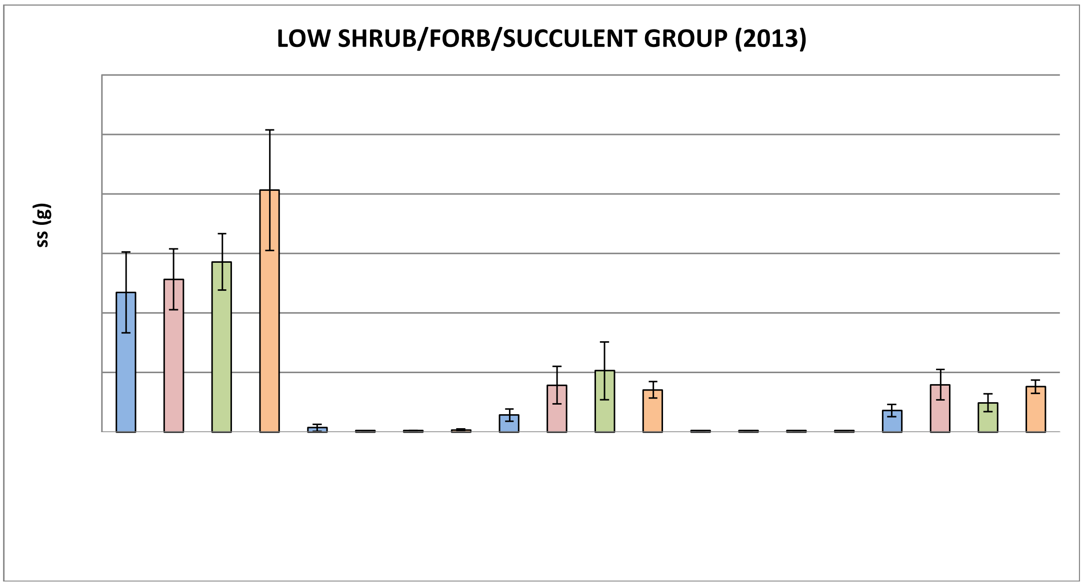
Table 5.4 Biomass of individual species across the experimental communities (biomass of species with “a” indicates it was significant difference from biomass of species with “b” in the same community. P-value with “ns” indicates there was no significant difference between individual biomass of the same species in different communities; “*” indicates significant difference and “**” indicates highly significant difference).

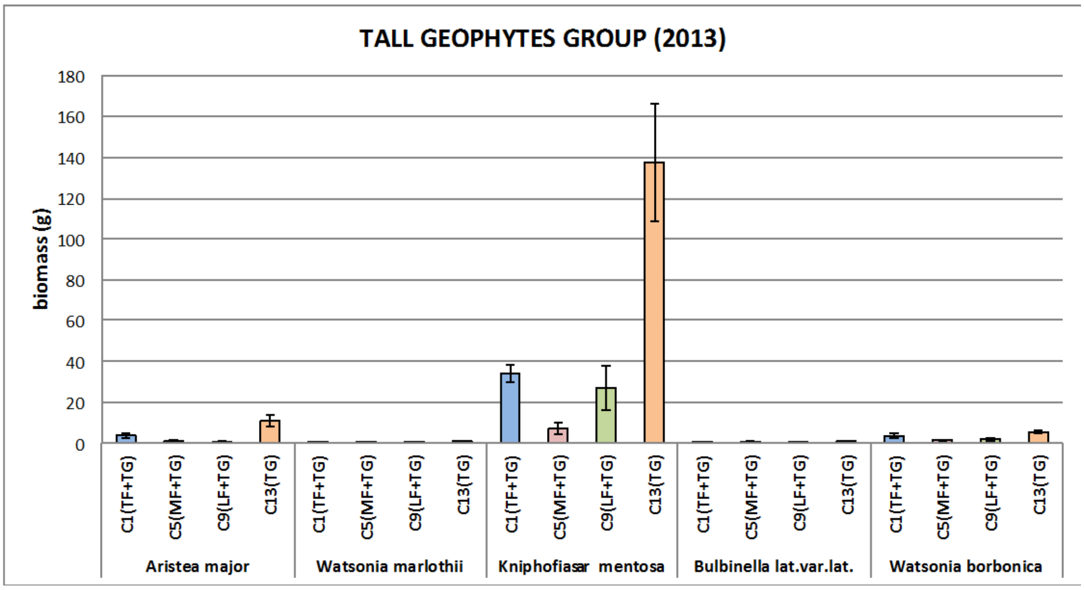
Total mean biomass for each species in communities in 2013 (g)

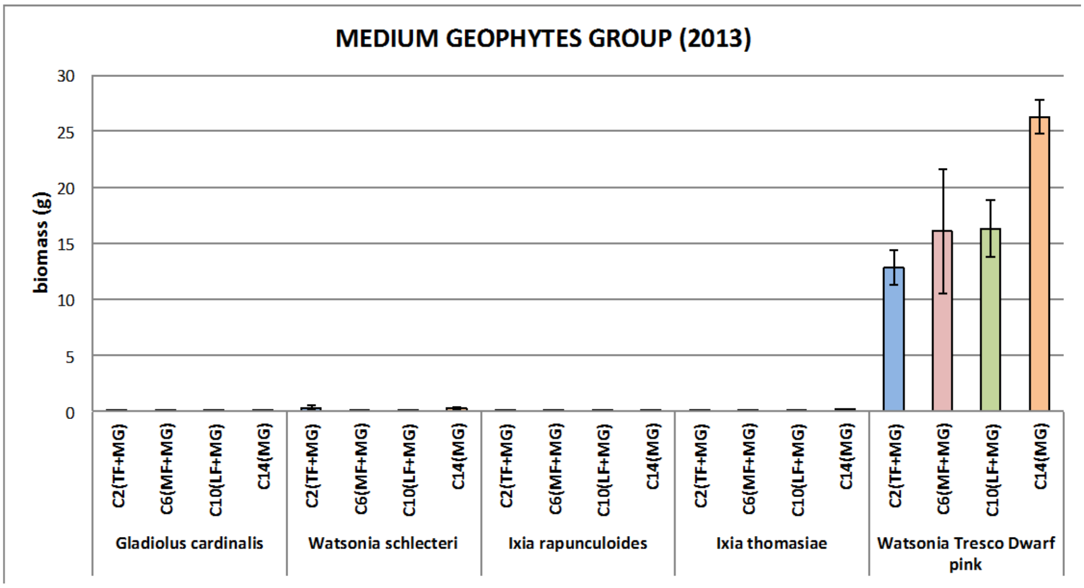
Species Name	Community															Mean	P-value
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
	TF+TG	TF+MG	TF+LG	TF	MF+TG	MF+MG	MF+LG	MF	LF+TG	LF+MG	LF+LG	LF	TG	MG	LG		
Tall forbs/shrubs																	
Dimorphotheca cuneata (white)	31.48a	70.09a	74.86a	90.02a												66.61	0.282ns
Felicia filifolia	0.27a	0.24a	0.17a	0.14a												0.20	0.904ns
Lessertia frutescsens	48.46a	13.18a	99.34a	93.88a												63.71	0.143ns
Dimorphotheca cuneata (orange)	19.10a	32.21a	26.49a	20.82a												24.65	0.885ns
Scabiosa africana	63.35a	71.17a	96.58a	114.78a												86.47	0.725ns
Medium forbs/shrubs																	
Dimorphotheca nudicaulis					1.59a	2.34a	2.15a	3.19a								2.32	0.608ns
Geranium incanum					194.24a	188.07a	265.09a	287.12a								233.63	0.291ns
Ursinia sericea					3.68a	3.03a	1.82a	2.06a								2.46	0.775ns
Berkheya herbacea					0.33a	0.39a	0.67a	0.19a								0.40	0.133ns
Low forb/shrub																	
Gazania krebsiana									117.11a	128.07a	142.65a	203.02a				147.71	0.356ns
Gazania othonites									3.80a	0.48a	1.27a	1.73a				1.82	0.473ns
Gazania leipoldtii									14.34a	39.21a	51.56a	35.28a				35.01	0.326ns
Esterhuysenia alpina									0.15a	0.19a	0.17a	0.47a				0.24	0.149ns
Gazania rigida									18.12a	39.65a	24.46a	38.13a				30.09	0.481ns
Tall geophytes																	
Aristea major	3.82ab				0.89a				0.75a				10.87b			4.08	0.002**
Watsonia marlothii	0.41a				0.27a				0.28a				1.07b			0.51	0.000**
Kniphofia sarmentosa	34.21a				7.26a				26.99a				137.35b			51.45	0.000**
Bulbinella latifolia var. latifolia	0.50a				0.71a				0.50a				1.19b			0.73	0.000**
Watsonia borbonica	3.59ab				1.63a				2.03a				5.54b			3.20	0.014*
Medium geophytes																	
Gladiolus cardinalis		0.01a				0.02a				0.01a				0.03a		0.02	0.217ns
Watsonia schlecteri		0.30a				0.08a				0.05a				0.32a		0.19	0.199ns
Ixia rapunculoides		0.01a				0.01a				0.00a				0.03b		0.01	0.002**
Ixia thomasiae		0.09ab				0.05a				0.10b				0.17c		0.10	0.000**
Watsonia Tresco Dwarf pink		12.84a				16.07a				16.30a				26.27a		17.87	0.062ns
Low geophytes																	
Babiana cuneata			0.05a				0.03a				0.02a				0.14b	0.06	0.000**
Ixia curvata			0.02a				0.02a				0.01a				0.05b	0.02	0.000**
Hesperantha pauciflora			0.00a				0.00a				0.00a				0.00a	0.00	0.108ns
Hesperantha vaginata			0.00a				0.01a				0.00a				0.01a	0.00	0.108ns


2013)


MEDIUM SHRUB/FORB/SUCCULENT GROUP (2013)
biomass (g)
400
350
300
250
200
150
100
50
0
C5(MF+TG)
C6(MF+MG)
C7(MF+LG)
C8(MF)
Dimorphotheca nudicaulis
Geranium incanum
Ursinia sericea
Berkheya herbacea


LOW SHRUB/FORB/SUCCULENT GROUP (2013)
ss (g)


TALL GEOPHYTES GROUP (2013)
biomass (g)
180
160
140
120
100
80
60
40
20
0
C1(TF+TG)
C5(MF+TG)
C9(LF+TG)
C13(TG)
Aristea major
Watsonia marlothii
Kniphofia sarmentosa
Bulbinella lat.var.lat.
Watsonia borbonica


MEDIUM GEOPHYTES GROUP (2013)
biomass (g)
30
25
20
15
10
5
0
C2(TF+MG)
C6(MF+MG)
C10(LF+MG)
C14(MG)
Gladiolus cardinalis
Watsonia schlecteri
Ixia rapunculoides
Ixia thomasiae
Watsonia Tresco Dwarf pink

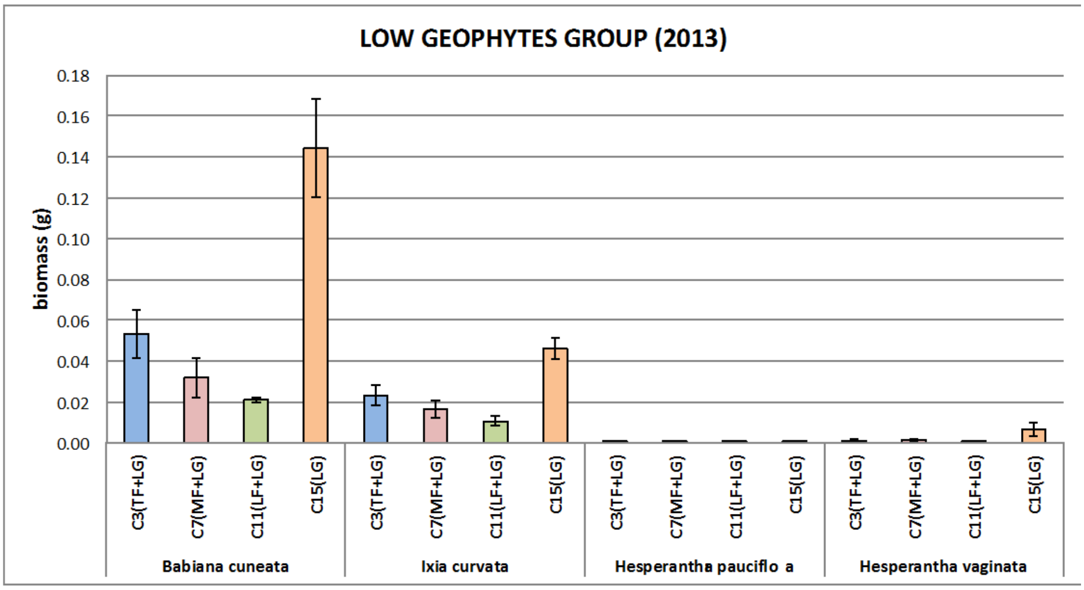

LOW GEOPHYTES GROUP (2013)
biomass (g)
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
C3(TF+LG)
C7(MF+LG)
C11(LF+LG)
C15(LG)
Babiana cuneata
Ixia curvata
Hesperantha pauciflora
Hesperantha vaginata

Fig. 5.18 Total mean biomass of individual species in different treatments in all replicates in September 2013. Species was compared within their life form groups and based on height division. These reflect how different communities affected individual species (error bars indicate standard error).

5.3.3.5 Biomass of Individual plants of each species within communities

This data was derived by taking the total biomass of a species across each of the four replicates and dividing it by the number of individuals of the species present. Data is shown in Table 5.5. Bar charts in Figure 5.19 present biomass variations within communities and pie charts clearly show the dominant species in each community in biomass production.

(1) One canopy layer only communities (C01, C04, C06, C08, C11, C12, C13, C14, C15)

This group can be divided into two sub-groups: communities with one life form only and communities with two life forms.

C4 (tall forb only mix), C8 (medium forb only mix), C12 (low forb only mix), C13 (tall geophyte only mix), C14 (medium geophyte only mix) and C15 (low geophyte only mix) represented communities with just one type of life form in each. The shrub *Dimorphotheca cuneata* white (29.66g), *Lessertia frutescsens* (12.17g) and the forb *Scabiosa africana* (16.71g) were obviously the three most dominant species in tall forb only community C4 and occupied 93.64% of total mean biomass of species within the community, which was significantly different from *Felicia filifolia* (0.16g, 0.06%) (C4 in Figure 5.19). *Geranium incanum* (273.08g) was another first year dominant occupying 97.29% of the medium forb only community biomass, and was highly significantly different from the other three species (P<0.01) (see C8 in Figure 5.19). *Gazania krebsiana* (22.333g) had 65.8% of total mean biomass of all the species in low forb only communities, followed by *Gazania rigida* (6.133g) 18.1% and *Gazania leipoldtii* (5.101g) 15% (see C12 in Figure 5.19). The fast growing evergreen tall geophyte, *Kniphofia sarmentosa*

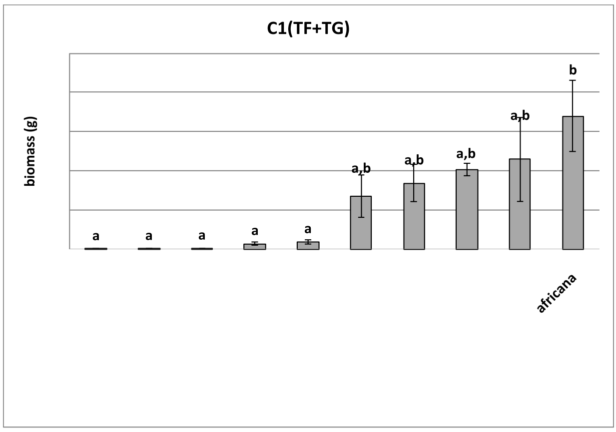
(18.726g, 89.61%) was clearly dominant in tall geophyte only community (see C13 in Figure 5.19). As might be expected the evergreen geophyte *Watsonia* 'Tresco Dwarf Pink' produced much more biomass than the other newly sown species in medium geophyte only community (see C14 in Figure 5.19). Biomass of low deciduous geophytes *Babiana cuneata* and *Ixia curvata* were significantly greater than the two *Hesperantha* species (see C15 in Figure 5.19).

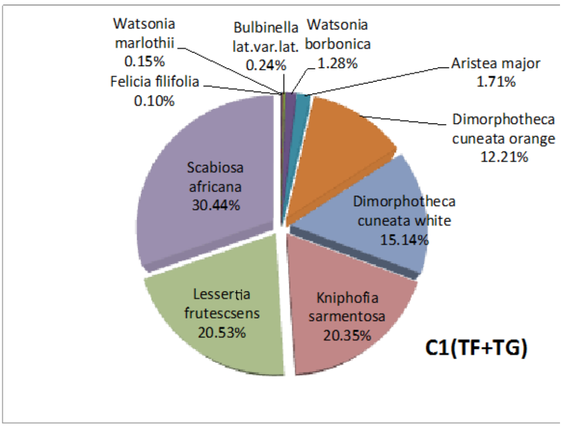
C1 (tall forb and tall geophyte mix), C6 (medium forb and medium geophyte mix) and C11 (low forb and low geophyte mix) showed comparisons between forbs/shrubs and geophytes within the same canopy level. In C1, 4 out of 5 forb/shrub species and only one geophyte species achieved the top five positions of biomass within the community (see C1 in Figure 5.19). Forbs were more competitive in tall forb and tall geophyte mix. In medium forb and medium geophyte mix, a very different pattern could be seen in C6 (Figure 5.19). *Geranium incanum* dominated the other species in biomass ($P<0.01$) Tukey HSD. The growth rate of medium forbs was slower than tall forbs and *Berkheya herbacea, Ursinia sericea* suffered severe frost damage in winter 2012/2013. Therefore, only a few plants of these two species were available for harvest. In low forb and low geophyte mix, bar chat shows similar pattern as C6 (see C11 in Figure 5.19). The evergreen forb *Gazania krebsiana* was much hardier than the other *Gazania*. Forbs overall were more dominant compared to geophytes.

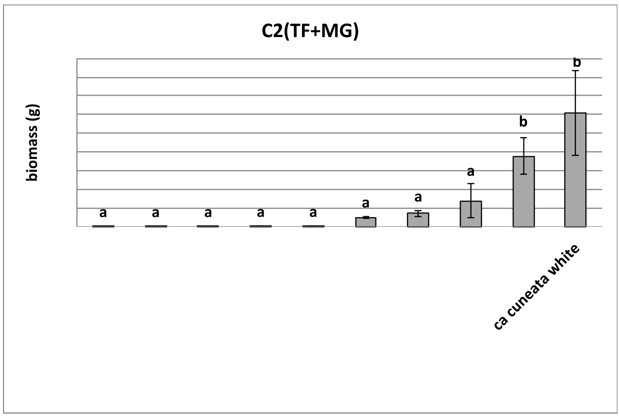
(2) Two canopy layer communities (C02, C03, C05, C07, C09, C10)

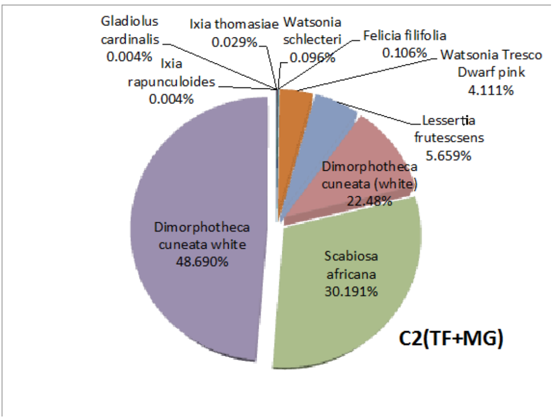
These six communities demonstrate more influence of competition between individual species within the communities, i.e there was more evidence of emerging winners and losers. Tall forb and medium geophyte mix (C2) and tall forb and low geophyte mix (C3) had similar results with *Lessertia frutescsens*, *Scabiosa africana* and *Dimorphotheca cuneata* white showing the highest biomass. Although the deciduous geophytes *Ixia, Gladiolus, Babiana* and *Hesperatha* had very low figures in biomass, they appeared to more or less tolerate the shade canopies of tall forbs. In the medium forb and tall geophyte mix (C5) and medium forb and low geophyte mix (C7), the, fast-growing forb *Geranium incanum* was the clear competitive dominant. Compared to low geophytes, tall geophytes in C7, tall geophytes in C5 produced more biomass in the first year.

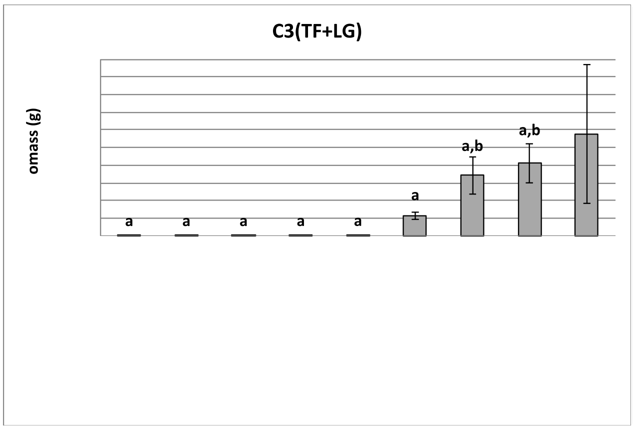
In the low forb and tall geophyte mix (C9 the most dominant species were the evergreen forbs *Gazania krebsiana, Gazania leipoldtii, Gazania rigida* and evergreen the emergent tall geophyte *Kniphofia sarmentosa,* followed by *Watsonia borbonica* and *Aristea major*. The very slow-growing succulent *Esterhuysenia alpina* was eliminated where shaded by other species, and thus produced the least biomass. In the low forb and medium geophyte mix (C10), three *Gazania* species were the dominants in C9, followed by *Watsonia* 'Tresco Dwarf Pink'. Although *Ixia* and *Hesperatha* were small and thin, they appeared to tolerate the shade of the *Gazania* canopies. *Babiana,* however, seemed to be less shade tolerate and declined when *Gazanias* covered up the experimental blocks.

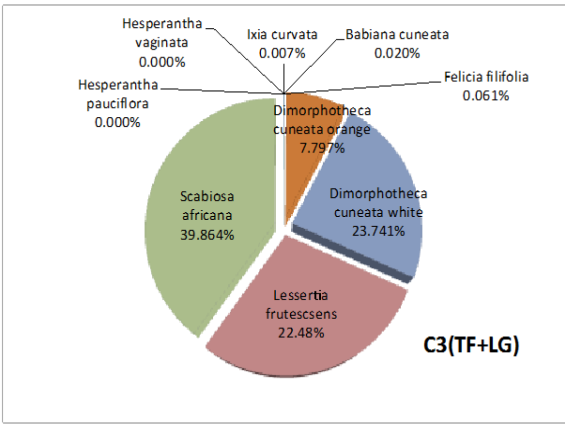


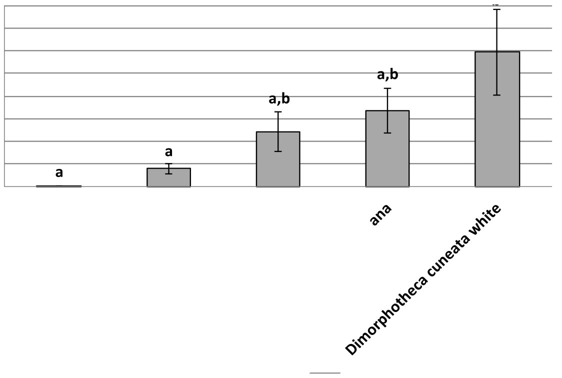


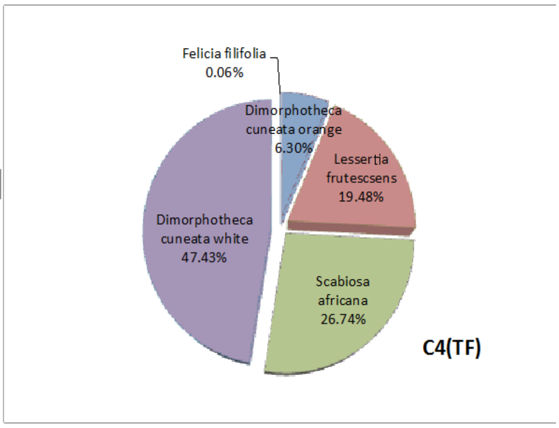


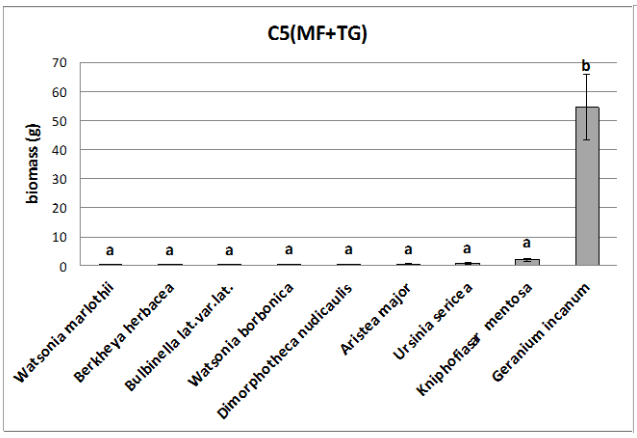


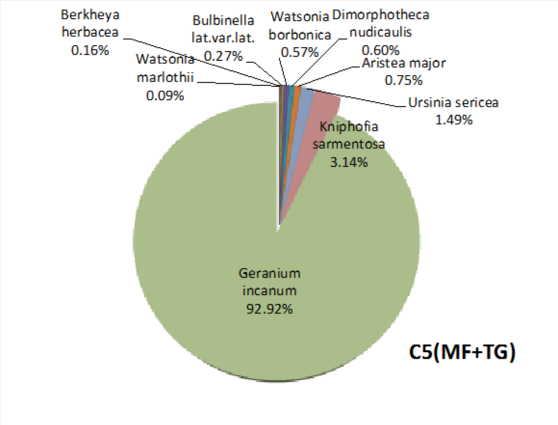

C3(TF+LG)
omass (g)
a
a
a
a
a
a
a,b
a,b

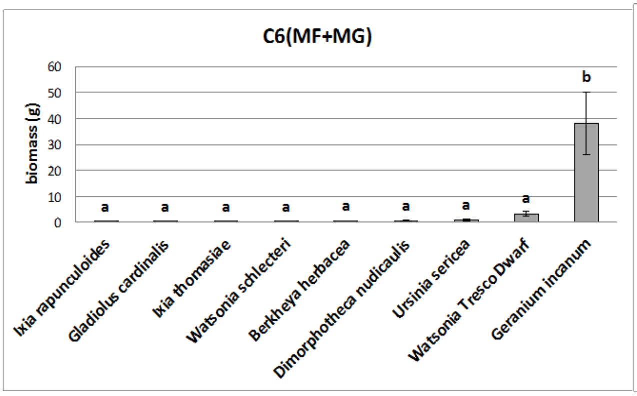

Hesperantha vaginata 0.000%
Ixia curvata 0.007%
Babiana cuneata 0.020%
Felicia filifolia 0.061%
Hesperantha pauciflora 0.000%
Dimorphotheca cuneata orange 7.797%
Dimorphotheca cuneata white 23.741%
Scabiosa africana 39.864%
Lessertia frutescsens 22.48%
C3(TF+LG)

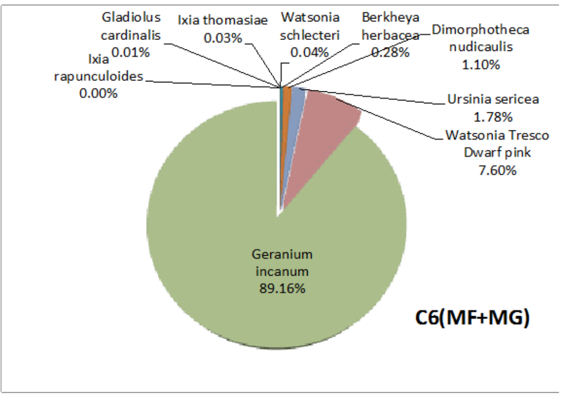

a
a
a,b
a,b
ana
Dimorphotheca cuneata white

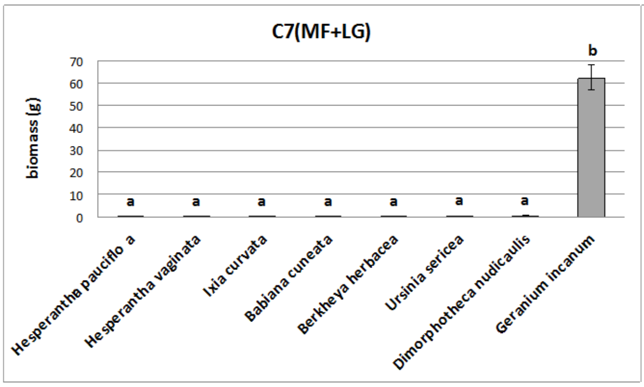

Felicia filifolia 0.06%
Dimorphotheca cuneata orange 6.30%
Lessertia frutescsens 19.48%
Dimorphotheca cuneata white 47.43%
Scabiosa africana 26.74%
C4(TF)

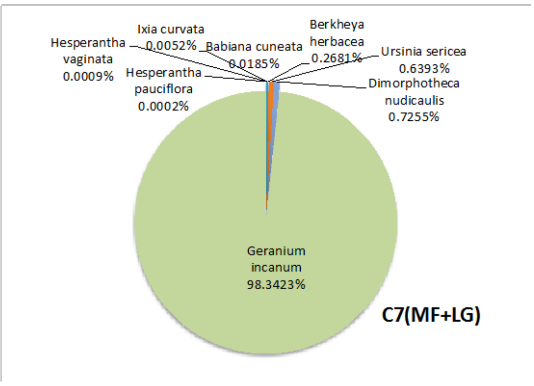

C5(MF+TG)
biomass (g)
70
60
50
40
30
20
10
0
a
a
a
a
a
a
a
a
b
Watsonia marlothii
Berkheya herbacea
Bulbinella lat.var.lat.
Watsonia borbonica
Dimorphotheca nudicaulis
Aristea major
Ursinia sericea
Kniphofiasar mentosa
Geranium incanum

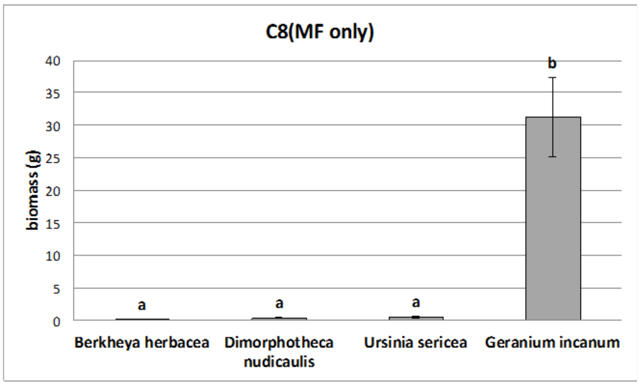

Berkheya herbacea 0.16%
Bulbinella lat.var.lat. 0.27%
Watsonia borbonica 0.57%
Dimorphotheca nudicaulis 0.60%
Aristea major 0.75%
Watsonia marlothii 0.09%
Ursinia sericea 1.49%
Kniphofia sarmentosa 3.14%
Geranium incanum 92.92%
C5(MF+TG)

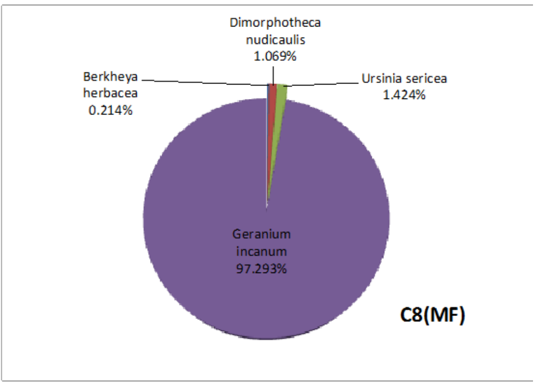

C6(MF+MG)
biomass (g)
60
50
40
30
20
10
0
a
a
a
a
a
a
a
a
b
Ixia rapunculoides
Gladiolus cardinalis
Ixia thomasiae
Watsonia schlecteri
Berkheya herbacea
Dimorphotheca nudicaulis
Ursinia sericea
Watsonia Tresco Dwarf
Geranium incanum

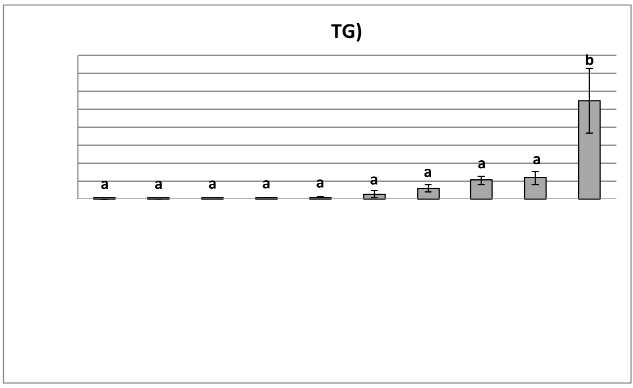

Gladiolus cardinalis 0.01%
Ixia thomasiae 0.03%
Watsonia schlecteri 0.04%
Berkheya herbacea 0.28%
Dimorphotheca nudicaulis 1.10%
Ixia rapunculoides 0.00%
Ursinia sericea 1.78%
Watsonia Tresco Dwarf pink 7.60%
Geranium incanum 89.16%
C6(MF+MG)

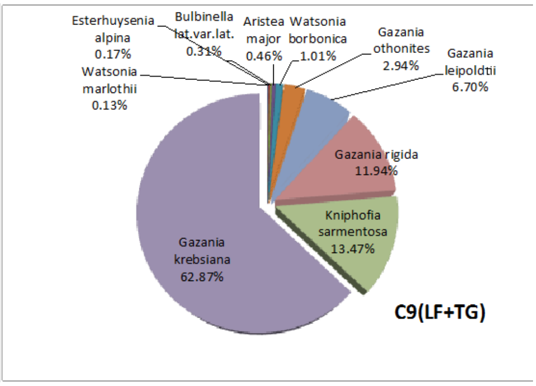

C7(MF+LG)
biomass (g)
70
60
50
40
30
20
10
0
a
a
a
a
a
a
a
b
Hesperanthe pauciflo a
Hesperantha vaginata
Ixia curvata
Babiana cuneata
Berkheya herbacea
Ursinia sericea
Dimorphotheca nudicaulis
Geranium incanum

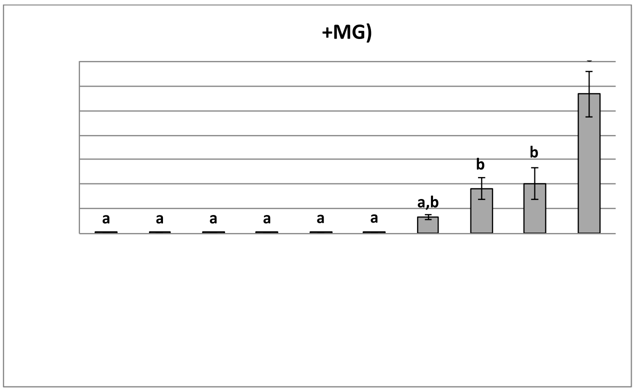

Hesperantha vaginata 0.0009%
Ixia curvata 0.0052%
Babiana cuneata 0.0185%
Berkheya herbacea 0.2681%
Ursinia sericea 0.6393%
Dimorphotheca nudicaulis 0.7255%
Hesperantha pauciflora 0.0002%
Geranium incanum 98.3423%
C7(MF+LG)

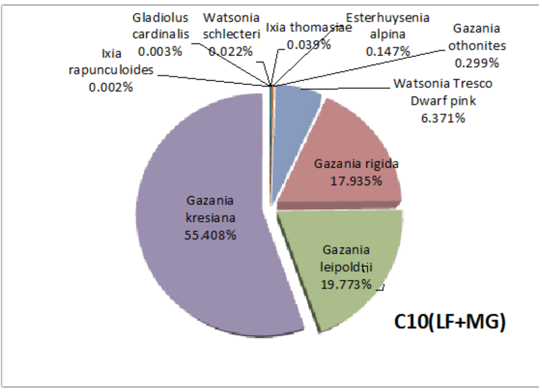

C8(MF only)
biomass (g)
40
35
30
25
20
15
10
5
0
a
a
a
b
Berkheya herbacea
Dimorphotheca nudicaulis
Ursinia sericea
Geranium incanum

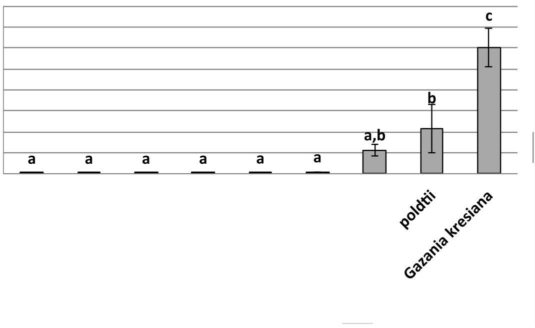

Dimorphotheca nudicaulis 1.069%
Berkheya herbacea 0.214%
Ursinia sericea 1.424%
Geranium incanum 97.293%
C8(MF)

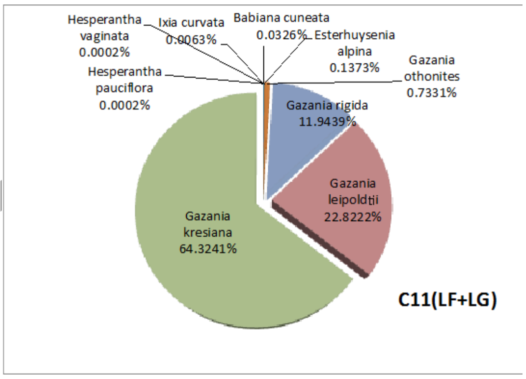

TG)
a
a
a
a
a
a
a
a
a
b

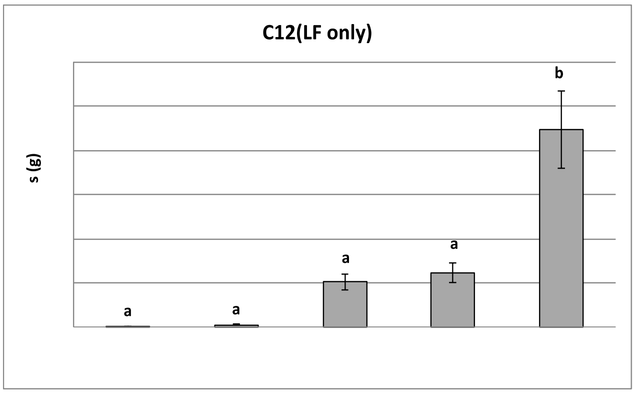

Esterhuysenia alpina 0.17%
Bulbinella lat.var.lat. 0.31%
Aristea major 0.46%
Watsonia borbonica 1.01%
Gazania othonites 2.94%
Gazania leipoldtii 6.70%
Watsonia marlothii 0.13%
Gazania rigida 11.94%
Kniphofia sarmentosa 13.47%
Gazania krebsiana 62.87%
C9(LF+TG)

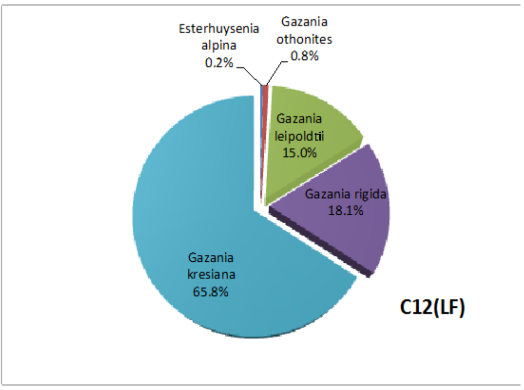

+MG)
a
a
a
a
a
a
a,b
b
b

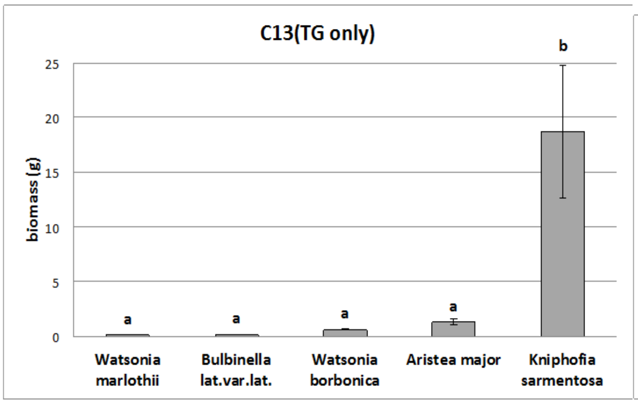

Gladiolus cardinalis 0.003%
Watsonia schlecteri 0.022%
Ixia thomasiae 0.039%
Esterhuysenia alpina 0.147%
Gazania othonites 0.299%
Ixia rapunculoides 0.002%
Watsonia Tresco Dwarf pink 6.371%
Gazania rigida 17.935%
Gazania kresiana 55.408%
Gazania leipoldtii 19.773%
C10(LF+MG)

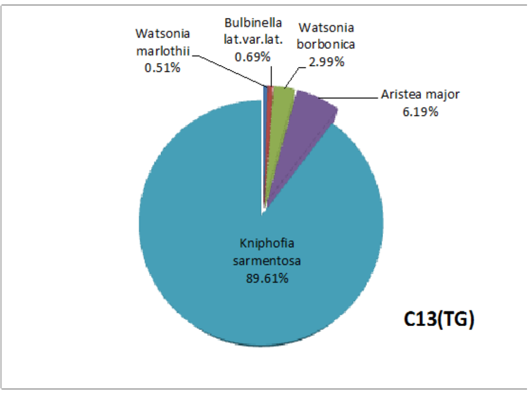

a
a
a
a
a
a
a,b
b
c
poldtii
Gazania kresiana

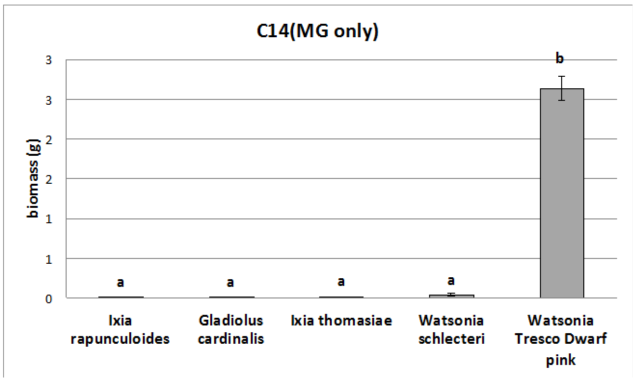

Hesperantha vaginata 0.0002%
Ixia curvata 0.0063%
Babiana cuneata 0.0326%
Esterhuysenia alpina 0.1373%
Gazania othonites 0.7331%
Hesperantha pauciflora 0.0002%
Gazania rigida 11.9439%
Gazania leipoldtii 22.8222%
Gazania kresiana 64.3241%
C11(LF+LG)

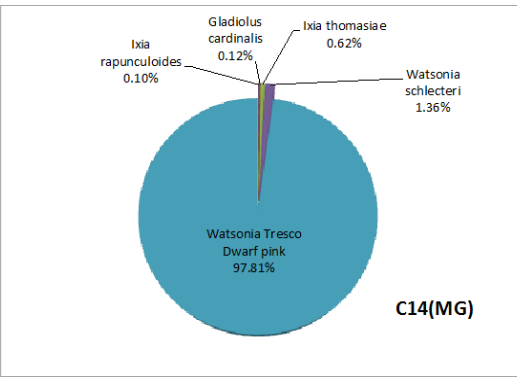

C12(LF only)
s (g)
a
a
a
a
b


Esterhuysenia alpina 0.2%
Gazania othonites 0.8%
Gazania leipoldtii 15.0%
Gazania rigida 18.1%
Gazania kresiana 65.8%
C12(LF)


C13(TG only)
biomass (g)
25
20
15
10
5
0
a
a
a
a
b
Watsonia marlothii
Bulbinella lat.var.lat.
Watsonia borbonica
Aristea major
Kniphofia sarmentosa


Watsonia marlothii 0.51%
Bulbinella lat.var.lat. 0.69%
Watsonia borbonica 2.99%
Aristea major 6.19%
Kniphofia sarmentosa 89.61%
C13(TG)


C14(MG only)
biomass (g)
3
3
2
2
1
1
0
a
a
a
a
b
Ixia rapunculoides
Gladiolus cardinalis
Ixia thomasiae
Watsonia schlecteri
Watsonia Tresco Dwarf pink


Ixia rapunculoides 0.10%
Gladiolus cardinalis 0.12%
Ixia thomasiae 0.62%
Watsonia schlecteri 1.36%
Watsonia Tresco Dwarf pink 97.81%
C14(MG)

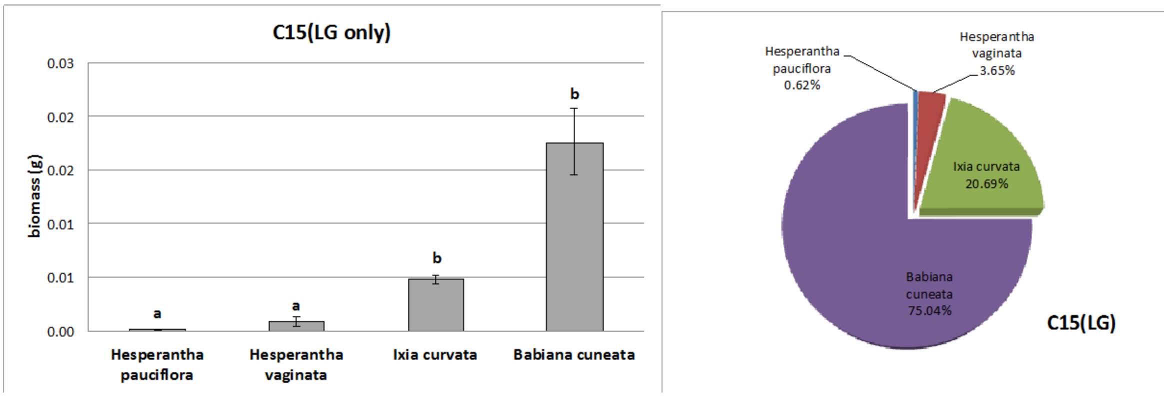


Fig. 5.19 Mean biomass of individual species within different treatments in all replicates in September 2013. Bar chats describe mean biomass of individual species in grams; Pie charts describe the proportion of biomass of individual species within each community.

Table 5.5 Individual species mean biomass <u>within</u> the experimental communities (biomass of species with “a” indicates it was significant difference from biomass of species with “b” in the same community. P-value with “ns” indicates there was no significant difference between individual biomass of the same species in different communities; “*” indicates significant difference and “**” indicates highly significant difference).

Mean biomass of individual species within community in 2013 (g)

	Community														
Species Name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
	TF+TG	**TF+MG**	**TF+LG**	**TF**	**MF+TG**	**MF+MG**	**MF+LG**	**MF**	**LF+TG**	**LF+MG**	**LF+LG**	**LF**	**TG**	**MG**	**LG**
Tall forbs/shrubs															
Dimorphotheca cuneata (white)	8.455ab	30.410b	17.175ab	29.662b											
Felicia filifolia	0.055a	0.066a	0.044a	0.035a											
Lessertia frutescsens	11.464ab	3.534a	20.625ab	12.179ab											
Dimorphotheca cuneata (orange)	6.821ab	6.940a	5.640a	3.938a											
Scabiosa africana	16.998b	18.856ab	28.839b	16.719ab											
Medium forbs/shrubs															
Dimorphotheca nudicaulis					0.355a	0.467a	0.460a	0.344a							
Geranium incanum					54.495b	37.717b	62.326b	31.259b							
Ursinia sericea					0.875a	0.752a	0.405a	0.458a							
Berkheya herbacea					0.093a	0.117a	0.170a	0.069a							
Low forb/shrub															
Gazania krebsiana									27.282b	28.351c	30.084c	22.333b			
Gazania othonites									1.275a	0.153a	0.343a	0.274a			
Gazania leipoldtii									2.906a	10.117b	10.674b	5.101a			
Esterhuysenia alpina									0.075a	0.075a	0.064a	0.078a			
Gazania rigida									5.182a	9.177b	5.586ab	6.133a			
Tall geophytes															
Aristea major	0.956a				0.441a				0.199a				1.294a		
Watsonia marlothii	0.083a				0.055a				0.057a				0.107a		
Kniphofia sarmentosa	10.165ab				1.844a				5.846a				18.726b		
Bulbinella latifolia var. latifolia	0.133a				0.159a				0.135a				0.145a		
Watsonia borbonica	0.717a				0.333a				0.437a				0.625a		
Medium geophytes															
Gladiolus cardinalis		0.002a				0.004a				0.002a				0.003a	
Watsonia schlecteri		0.060a				0.017a				0.012a				0.037a	
Ixia rapunculoides		0.002a				0.002a				0.001a				0.003a	
Ixia thomasiae		0.018a				0.012a				0.020a				0.017a	
Watsonia Tresco Dwarf pink		2.568a				3.214a				3.26ab				2.627b	
Low geophytes															
Babiana cuneata			0.014a				0.012a				0.015a				0.018b
Ixia curvata			0.005a				0.003a				0.003a				0.005a
Hesperantha pauciflora			0.0001a				0.0001a				0.0001a				0.0001a
Hesperantha vaginata			0.0003a				0.0004a				0.0001a				0.001a
Mean	5.585	6.246	8.038	12.507	6.517	4.700	7.922	8.032	4.339	5.117	5.197	6.784	4.179	0.537	0.006
P-value	0.000**	0.000**	0.034*	0.009**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.001**	0.000**	0.000**

5.3.4 Biomass in Year Two (Sep. 2013- Sep. 2014)

5.3.4.1 Total biomass of different life forms

The missing medium forb species in the first competition test period was supplemented by an Eurasian species. One-year old corms of *Romulea komsbergensis* were transplanted from the hardiness test experiment to replaced the ones didn't reshoot in 2012-2013. Eventually, 15 shrub/forb/succulent species and 15 geophyte species were available for the test period 2013-2014. Total mean biomass of all geophytes had increased substantially in 2014, relative to the first year (Figure 5.20). The shrub/forb biomass was however still dominant.

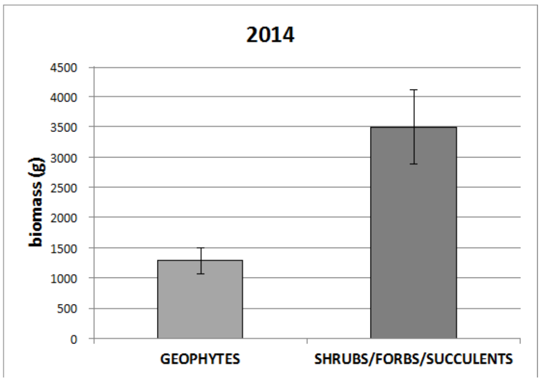
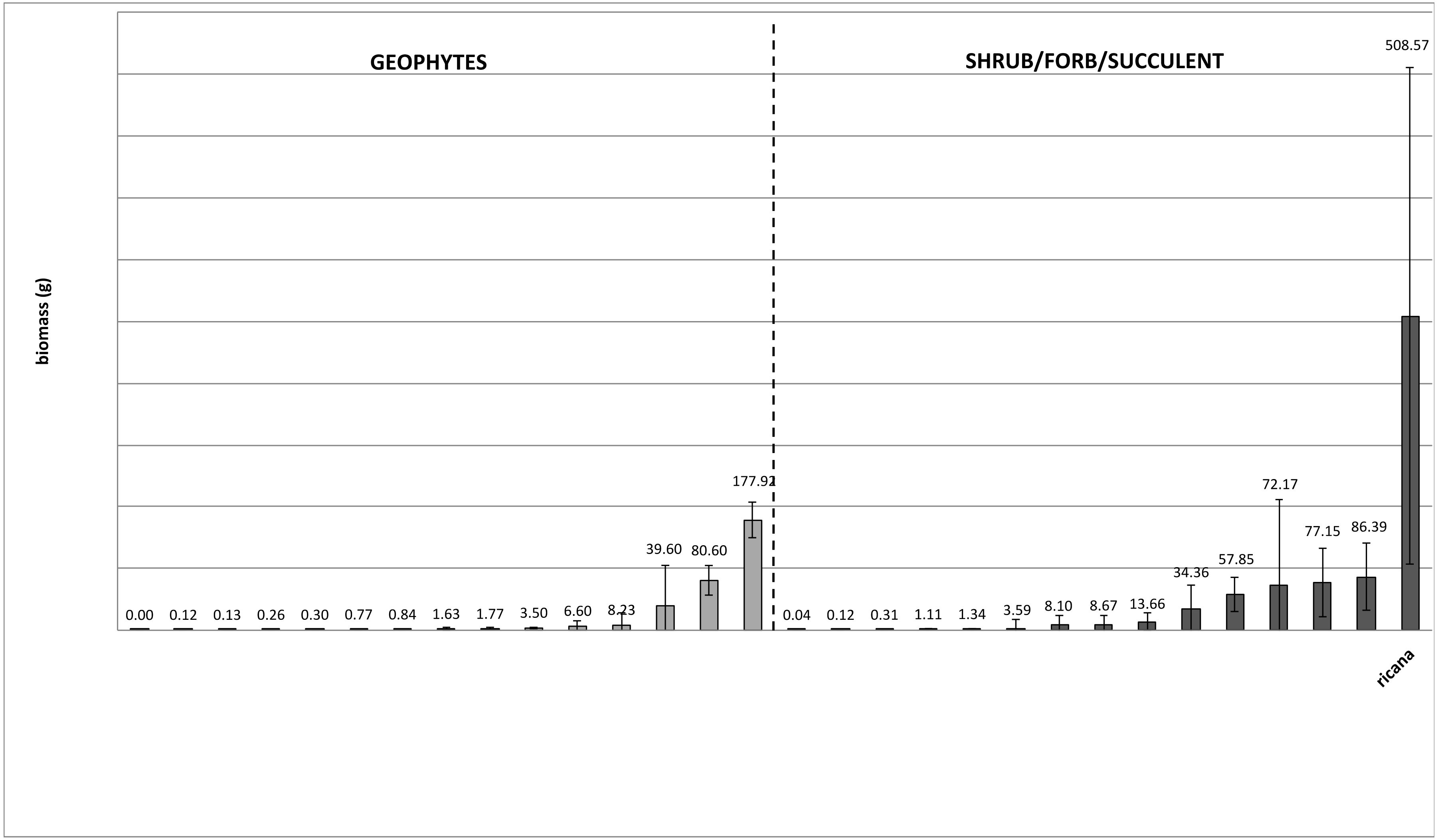


Fig. 5.20 Total mean biomass of all geophytes and shrubs/forbs/succulents in 2014.

5.3.4.2 Total biomass of individual species

The relative biomass rankings in 2014 were broadly similar to those in 2013, with *Scabiosa Africana* (508.57g) emerging as the largest biomass contributor. Mean total biomass of most low geophytes were higher than in 2013, but still relatively small.

Fig. 5.21 Mean total biomass of individual species in all treatments all replicates in 2014.



5.3.4.3 Biomass of different communities

As might be expexted communities containing only low geophytes C15 still presented the lowest biomass in 2014, which was significantly different from C1, C3, C2 and C4. Communities of tall forbs mixed with tall geophytes achieved highest biomass in 2014. Four communities including tall forb group occupied the top four positions of mean biomass of different communities. Much of this biomass is due to the presence of *Scabiosa africana*.

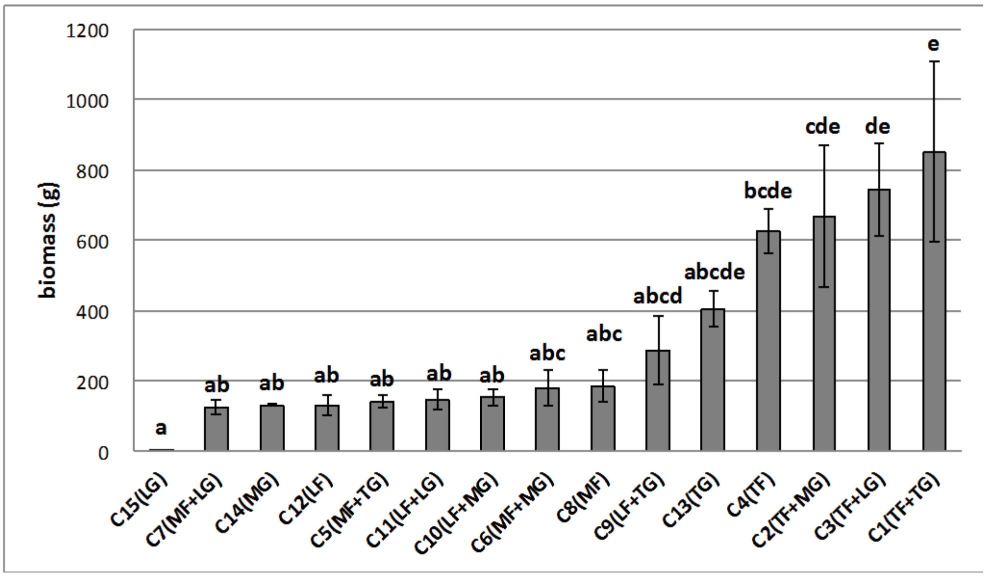


Fig. 5.22 Year Two mean biomass of different communities in all replicates in September 2014 (error bars indicate standard error, biomass of species with “a” indicates it was significant difference from biomass of species with “b” “c” “d” “e” in the same community (Tukey HSD^{ab})).

5.3.4.4 Effect of different communities on biomass of Individual species

At the 2014 harvest, all the shrub/forb species in all canopy groups showed no significant differences when compared on the mean biomass across communities. The shrubby species *Scabiosa africana* was the dominant in tall communities. Many *Dimorphotheca cuneata* white were lost post the August 2013 harvesting, and the biomass of the initially slower-growing, orange form of *Dimorphotheca cuneata* increased as a result in the second growing season. Another dominant species in the first year, *Lessertia frutescens* suffered similar losses post cutting, only two plants were harvested in 2014 in C2 (Tall forb and medium geophyte) and C3 (Tall forb and low geophyte) mixes. The very slow growing shrubby species *Felicia filifolia* was largely eliminated by its neighbours. The medium height forb *Berkheya herbacea* and newly planted *Goniolimon speciosum* almost disappeared during 2013-14 (Table 5.6). Biomass of *Geranium incanum* was much less in the second year relative to the first, but this carpet groundcover species still was the most dominant species in medium forb group. Only a few plants of the low forb/succulent species *Gazania othonities* and *Esterhuysenia alpine* were harvested in 2014. *Gazania krebsiana* continued to produce more biomass than *Gazania rigida* and *Gazania leipoldtii*, and has higher mean biomass in low forb only and low forb low geophyte mixes (Figure 5.23).

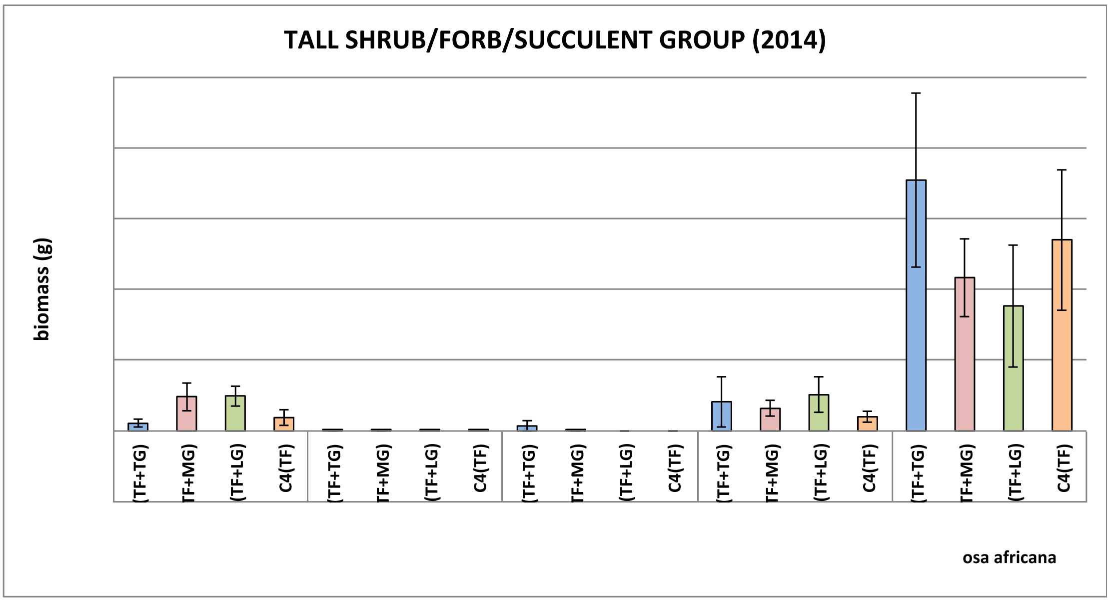
In tall geophyte groups, *Aristea major* showed significant differences ($P<0.05$) in biomass between communities where they were represented, with mean biomass in tall geophytes only communities much higher than when mixed with different species. *Kniphofia sarmentosa* and deciduous *Watsonia borbonica* both were dominant species in tall geophyte communiites. In the medium geophyte group, although *Gladiolus cardinalis, Ixia thomasiae* and *Ixia rapunculoides* still contributed little second year biomass, they survived well in communities when mixed with different canopy height forbs and shrubs. *Romulea komsbergensis* seems to be a shade tolerating low geophyte high survival in all communities. It produced the highest biomass in the low geophyte group with no significant differences in biomass across communities.

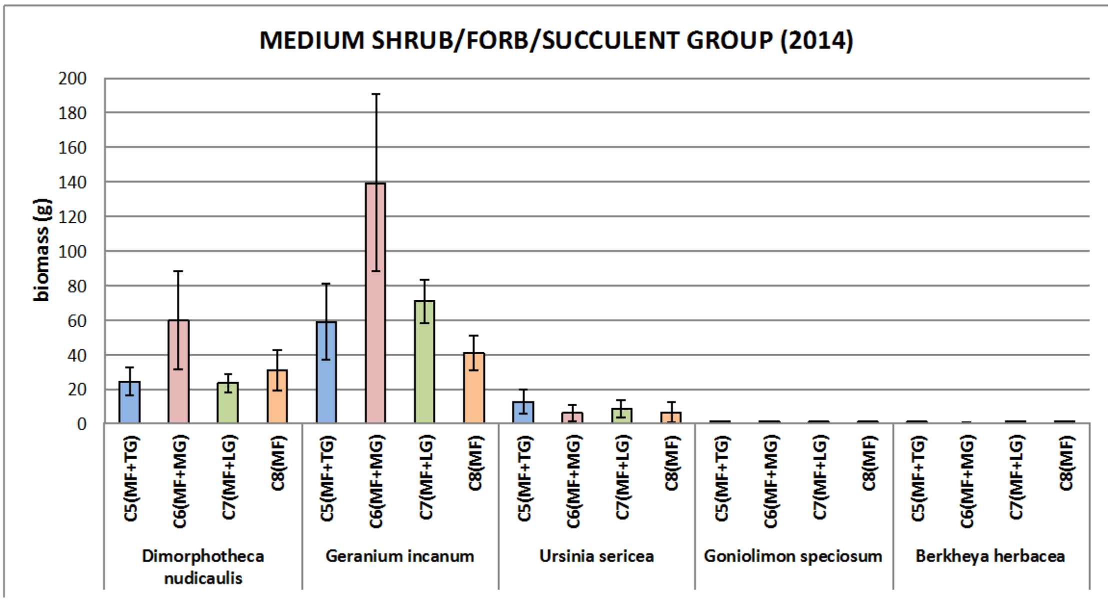
When compared the total mean biomass of all the species in different life form and canopy height groups, the tall forb/shrub group was the biggest contributor in the six groups (see Table 5.6), followed by the tall geophyte group. Medium and low height forb/shrub groups had similar figures in total mean biomass, but much greater than the medium and low height geophyte groups.

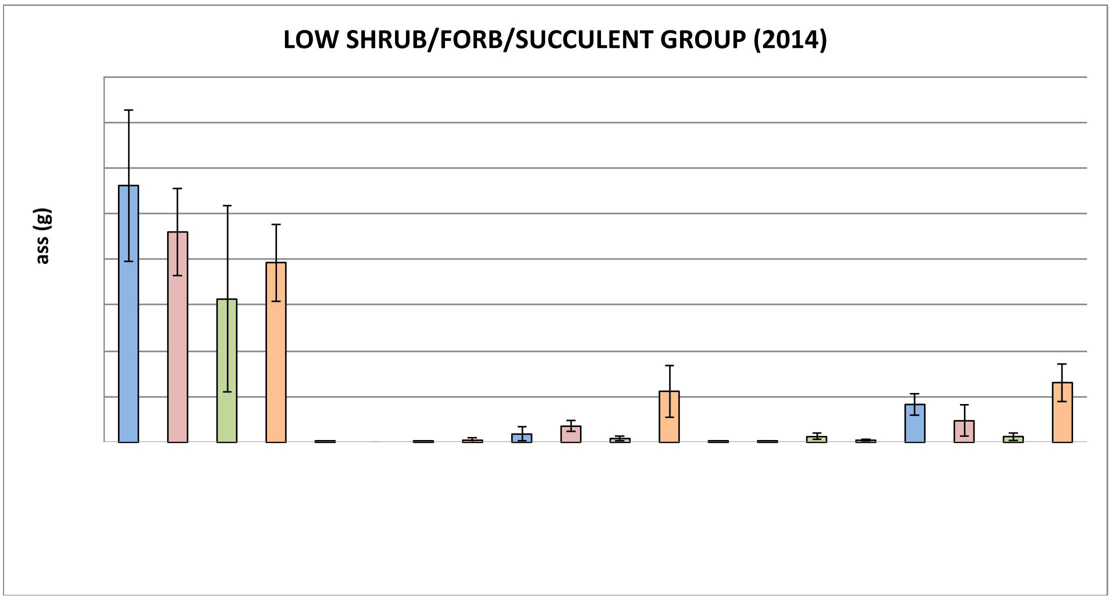
Table 5.6 Total mean biomass of individual species across the experimental communities (biomass of species with “a” indicates it was significant difference from biomass of species with “b” and “c” in other communities where it represented. P-value with “ns” indicates there was no significant difference between individual biomass of the same species in different communities; “*” indicates significant difference (P<0.05) and “**” indicates highly significant difference (P<0.01)).

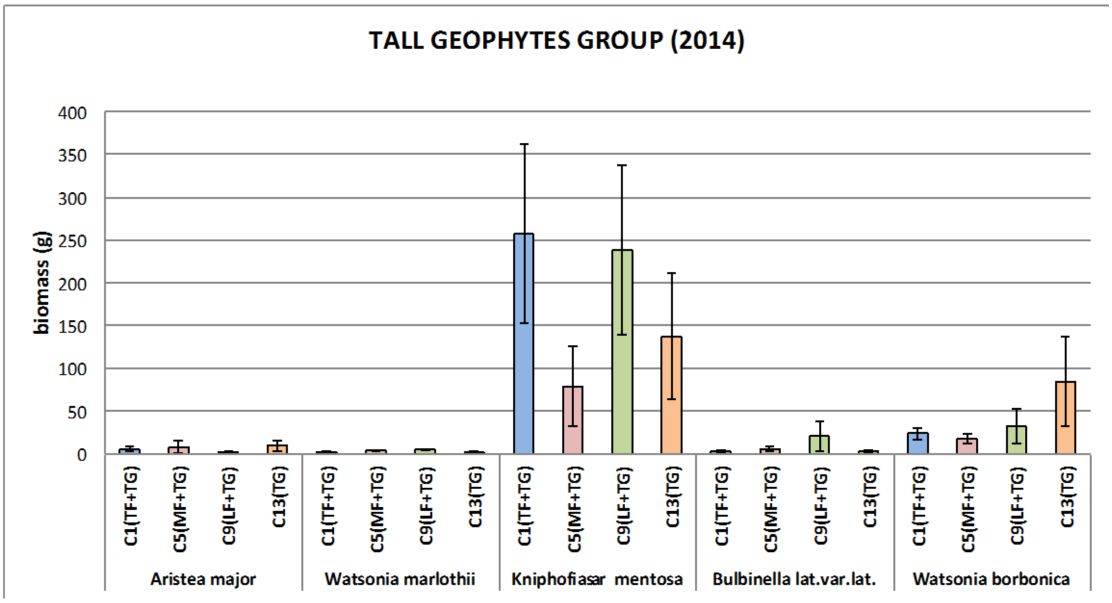
Total biomass for each species in communities in 2014 (g)

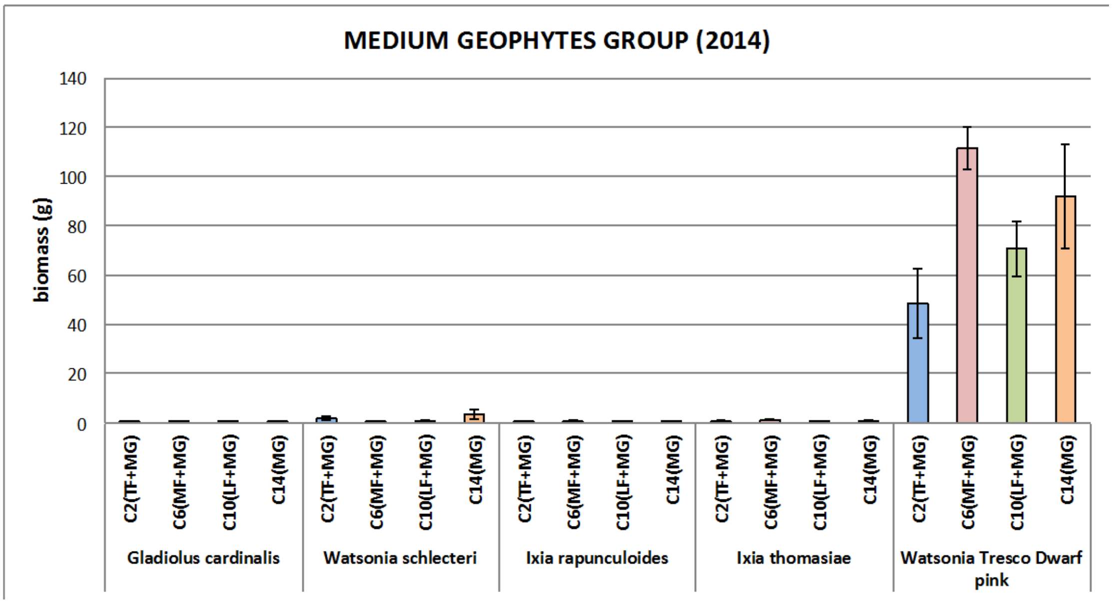
Species Name	Community															Mean	P-value
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
	TF+TG	TF+MG	TF+LG	TF	MF+TG	MF+MG	MF+LG	MF	LF+TG	LF+MG	LF+LG	LF	TG	MG	LG		
Tall forbs/shrubs																	
Dimorphotheca cuneata (white)	18.55a	99.75a	58.42a	54.67a												63.92	0.299ns
Felicia filifolia	0.36a	3.20a	1.81a	0a												1.34	0.078ns
Lessertia frutescsens	0a	0.16a	14.20a	0a												7.18	0.429ns
Dimorphotheca cuneata (orange)	32.70a	110.39a	109.57a	36.04a												72.17	0.401ns
Scabiosa africana	540.30a	403.51a	555.49a	534.99a												508.57	0.944ns
Medium forbs/shrubs																	
Dimorphotheca nudicaulis					18.80a	41.88a	28.29a	48.49a								34.36	0.616ns
Geranium incanum					38.24a	57.47a	80.65a	132.26a								77.15	0.194ns
Ursinia sericea					10.74a	2.45a	12.33a	6.88a								8.10	0.615ns
Goniolimon speciosum					0a	0.03a	0.13a	0.32a								0.12	0.069ns
Berkheya herbacea					0.05a	0a	0.06a	0.04a								0.05	0.781ns
Low forb/shrub																	
Gazania krebsiana									63.11a	56.29a	119.87a	106.29a				86.39	0.294ns
Gazania othonites									1.17a	0a	0.03a	0.04a				0.42	0.175ns
Gazania leipoldtii									3.73a	8.49a	14.98a	7.49a				8.67	0.749ns
Esterhuysenia alpina									0.62a	1.96a	0.76a	1.12a				1.11	0.658ns
Gazania rigida									12.28a	15.15a	10.34a	16.87a				13.66	0.931ns
Tall geophytes																	
Aristea major	6.04a				0.86a				1.87a				17.65b			6.60	0.033*
Watsonia marlothii	4.14a				3.26a				2.17a				4.43a			3.50	0.562ns
Kniphofia sarmentosa	185.40a				50.75a				186.24a				289.31a			177.92	0.271ns
Bulbinella latifolia var. latifolia	20.82a				2.70a				2.22a				7.20a			8.23	0.455ns
Watsonia borbonica	42.72a				15.44a				12.52a				87.70a			39.60	0.227ns
Medium geophytes																	
Gladiolus cardinalis		0.06a				0.25ab				0.18ab				0.57b		0.26	0.016*
Watsonia schlecteri		1.83a				0.73a				0.29a				3.66a		1.63	0.198ns
Ixia rapunculoides		0.08a				0.10a				0.05a				0.96b		0.30	0.000**
Ixia thomasiae		0.71a				0.42a				0.44a				1.49b		0.77	0.001**
Watsonia Tresco Dwarf pink		48.45a				78.03ab				71.02a				124.89b		80.60	0.004**
Low geophytes																	
Babiana cuneata			0.07a				0.07a				0.03a				0.34b	0.13	0.000**
Romulea komsbergensis			2.50a				2.84a				1.29a				0.44a	1.77	0.082ns
Ixia curvata			0.41a				0.38a				0.14a				2.41b	0.84	0.000**
Hesperantha pauciflora			0.001a				0.001a				0.001a				0.02a	0.01	0.117ns
Hesperantha vaginata			0.05a				0.02a				0.01a				0.38b	0.12	0.000**


TALL SHRUB/FORB/SUCCULENT GROUP (2014)
biomass (g)
(TF+TG)
TF+MG)
(TF+LG)
C4(TF)
(TF+TG)
TF+MG)
(TF+LG)
C4(TF)
(TF+TG)
TF+MG)
(TF+LG)
C4(TF)
(TF+TG)
TF+MG)
(TF+LG)
C4(TF)
(TF+TG)
TF+MG)
(TF+LG)
C4(TF)
osa africana


MEDIUM SHRUB/FORB/SUCCULENT GROUP (2014)
biomass (g)
200
180
160
140
120
100
80
60
40
20
0
C5(MF+TG)
C6(MF+MG)
C7(MF+LG)
C8(MF)
Dimorphotheca nudicaulis
Geranium incanum
Ursinia sericea
Goniolimon speciosum
Berkheya herbacea


LOW SHRUB/FORB/SUCCULENT GROUP (2014)
ass (g)


TALL GEOPHYTES GROUP (2014)
biomass (g)
400
350
300
250
200
150
100
50
0
C1(TF+TG)
C5(MF+TG)
C9(LF+TG)
C13(TG)
Aristea major
Watsonia marlothii
Kniphofiasar mentosa
Bulbinella lat.var.lat.
Watsonia borbonica


MEDIUM GEOPHYTES GROUP (2014)
biomass (g)
140
120
100
80
60
40
20
0
C2(TF+MG)
C6(MF+MG)
C10(LF+MG)
C14(MG)
Gladiolus cardinalis
Watsonia schlecteri
Ixia rapunculoides
Ixia thomasiae
Watsonia Tresco Dwarf pink

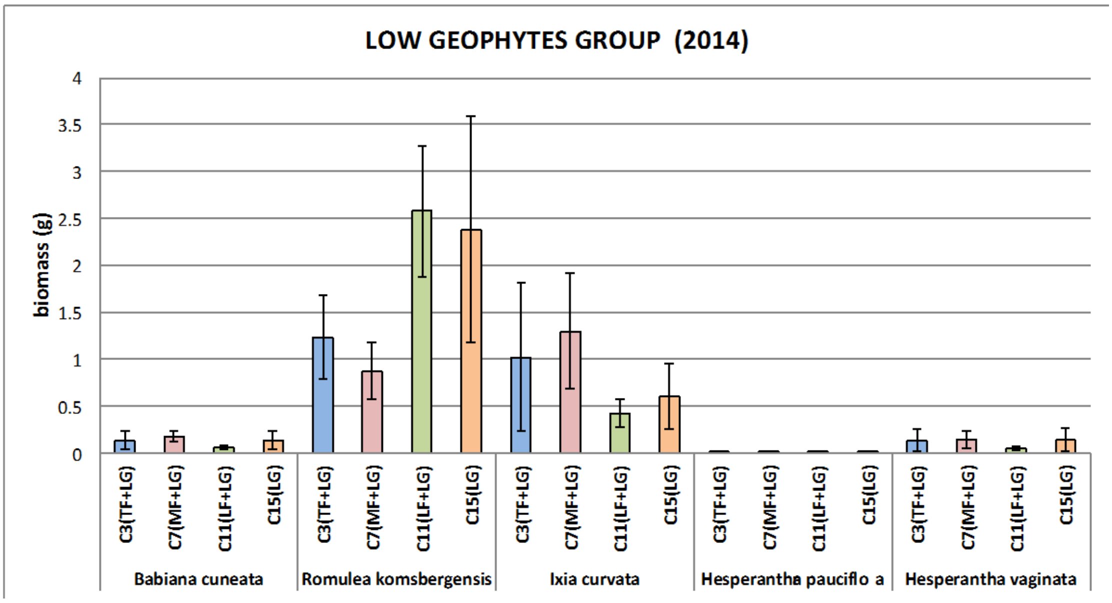

LOW GEOPHYTES GROUP (2014)
biomass (g)
4
3.5
3
2.5
2
1.5
1
0.5
0
C3(TF+LG)
C7(MF+LG)
C11(LF+LG)
C15(LG)
Babiana cuneata
Romulea komsbergensis
Ixia curvata
Hesperantha pauciflo a
Hesperantha vaginata

Fig. 5.23 Mean biomass of individual species in different treatments in all replicates in September 2014. Species was compared within their life form groups and based on height division. These reflect how different communities affected individual species (error bars indicate standard error).

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5.3.4.5 Biomass of Individual species within communities

Similar results were achieved as in the first year comparison (Table 5.3), there were 14 out of 15 communities showing highly significant difference ($P<0.01$) between species within each community in the second year comparison (Table 5.7).

Table 5.7 Individual species mean biomass within the experimental communities (biomass of species with “a” indicates it was significant difference from biomass of species with “b” in the same community. P-value with “ns” indicates there was no significant difference between individual biomass of the same species in different communities; “*” indicates significant difference and “**” indicates highly significant difference).

Mean biomass of individual species within community in 2014 (g)

Species Name	Community														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
	TF+TG	**TF+MG**	**TF+LG**	**TF**	**MF+TG**	**MF+MG**	**MF+LG**	**MF**	**LF+TG**	**LF+MG**	**LF+LG**	**LF**	**TG**	**MG**	**LG**
Tall forbs/shrubs															
Dimorphotheca cuneata (white)	17.519a	29.603a	38.477a	23.905a											
Felicia filifolia	0.360a	2.340a	0.537a												
Lessertia frutescsens		0.162a	14.200a												
Dimorphotheca cuneata (orange)	32.701ab	40.315a	32.692a	15.447a											
Scabiosa africana	143.452b	131.339b	129.364b	72.180b											
Medium forbs/shrubs															
Dimorphotheca nudicaulis					6.794a	9.311a	7.545a	6.764a							
Geranium incanum					38.242b	57.466b	80.650b	132.256b							
Ursinia sericea					2.744a	2.453a	4.466a	2.001a							
Goniolimon speciosum						0.025a	0.053a	0.128a							
Berkheya herbacea					0.049a		0.059a	0.039a							
Low forb/shrub															
Gazania krebsiana									15.037ab	13.324b	31.112b	15.422b			
Gazania othonites									0.723a		0.029a	0.021a			
Gazania leipoldtii									1.563a	3.093a	4.008a	2.016a			
Esterhuysenia alpina									0.31a	0.968a	0.381a	0.205a			
Gazania rigida									3.627a	4.006a	4.160a	3.633a			
Tall geophytes															
Aristea major	1.851a				0.856a				0.934a				4.492a		
Watsonia marlothii	0.828a				0.651a				0.435a				0.501a		
Kniphofia sarmentosa	46.465ab				12.520a				41.044b				42.456b		
Bulbinella latifolia var. latifolia	4.386a				0.563a				0.543a				0.847a		
Watsonia borbonica	11.623a				3.639a				2.71a				11.114a		
Medium geophytes															
Gladiolus cardinalis		0.022a				0.065a				0.045a				0.104a	
Watsonia schlecteri		0.369a				0.175a				0.080a				0.433a	
Ixia rapunculoides		0.022a				0.028a				0.021a				0.108a	
Ixia thomasiae		0.196a				0.091a				0.105a				0.170a	
Watsonia Tresco Dwarf pink		10.038a				17.325a				15.691b				14.537b	
Low geophytes															
Babiana cuneata			0.020a				0.026a				0.017a				0.050a
Romulea komsbergensis			0.554a				0.568a				0.412a				0.044a
Ixia curvata			0.107a				0.077a				0.043a				0.261b
Hesperantha pauciflora			0.001a				0.002a				0.0001a				0.004a
Hesperantha vaginata			0.019a				0.005a				0.005a				0.056a
Mean	28.80	21.44	21.60	37.18	7.34	9.66	9.35	28.24	6.69	4.15	4.02	4.26	11.88	3.07	0.08
P-value	0.007**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.005**	0.016*	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**

(1) One canopy layer only communities (C1, C4, C6, C8, C11, C12, C13, C14, C15)

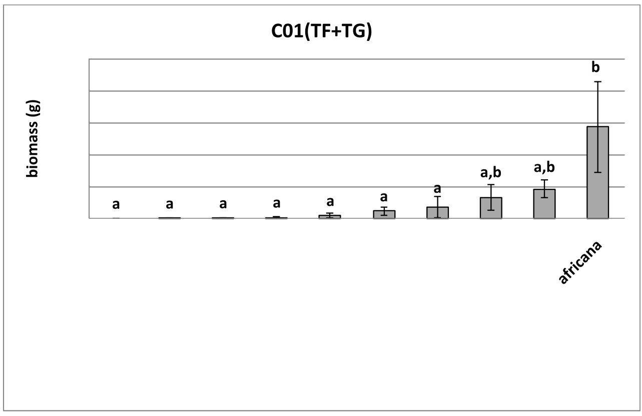
In communities with single life form present, there mainly were one or two dominant species present, for instance, *Scabiosa africana* (72.18g) and *Dimorphotheca cuneata* white (23.9g) in tall forb only community C4, *Geranium incanum* (132.25g) in medium forb only community C8, *Gazania krebsiana* (15.422g) in low forb only communities C12, *Kniphofia sarmentosa* (42.45g) and *Watsonia borbonica* (11.11g) in tall geophyte only community C13, *Watsonia Tresco* dwarf pink (14.5g) in medium geophyte only community C14 and *Ixia curvata* (0.26g) in low geophyte only community C15.

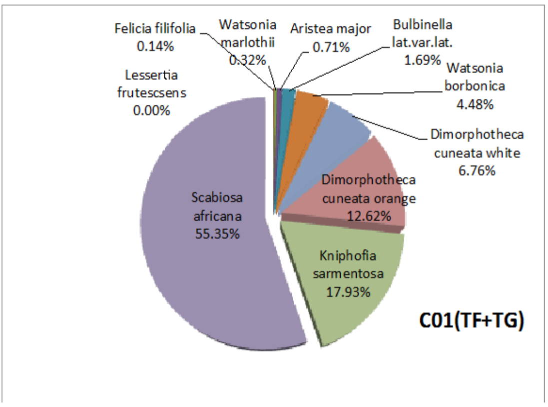
In communities of different life forms with the same canopy heights, results were various. In tall forb and tall geophyte mix C1, the forb *Scabiosa africana*, and the geophyte *Kniphofia sarmentosa* and the two shrubby *Dimorphotheca cuneata* populations occupied most of the space and produced much higher biomass than the other 6 species. In the medium forb and medium geophyte mix C6, the forb *Geranium incanum,* geophyte *Watsonia Tresco* dwarf pink and forb *Dimorphotheca nudicaulis* were the top three in producing biomass. In the C11 low forb and low geophyte mix biomass was largely dominated by forb *Gazania krebsiana.*

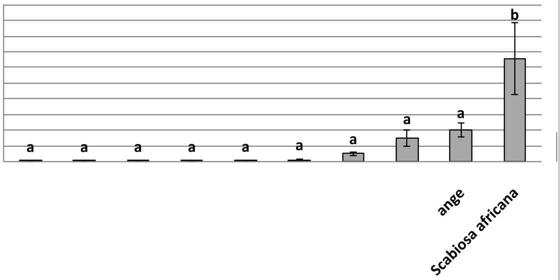
(1) Two canopy layer communities (C2, C3, C5, C7, C9, C10)

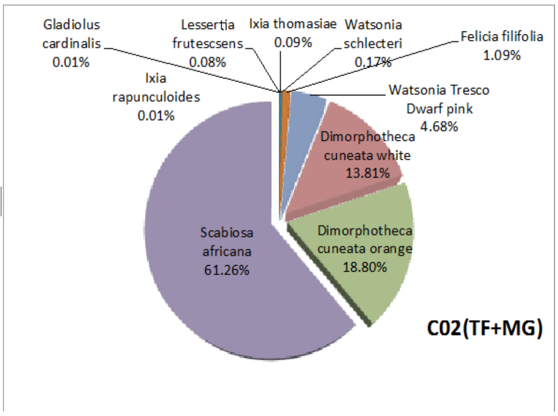
Competition between individual species within these six communities was more complex sue to the different life forms as well as different canopy heights. In the tall forb and medium geophyte mix (C2) and tall forb and low geophyte mix (C3), the tall forb group was clearly more competitive than geophyte groups with lower canopy. In C2, *Watsonia* ‘Tresco Dwarf Pink’ was the fourth in biomass production within the community, which suggests that when some medium height geophyte species become more capable for competing with taller forbs and shrubs as this increase in mass. This slow start but gradual increase in dominance capacity seems to be a trend in geophytes. *Ixia, Gladiolus, Babiana* and *Hesperatha*, which survived the shade generated by the canopies of tall forbs, might possibly produce more biomass from the third year on. Although facing pressure from tall geophytes, *Geranium incanum* still produced the highest biomass in the community C5 (MF+TG). *Dimorphotheca nudicaulis* and *Ursinia sericea* also competed well with tall geophytes in the same community. When mixed with low geophytes (C7), *Geranium incanum* highly restricted the growth of many other species in the community.

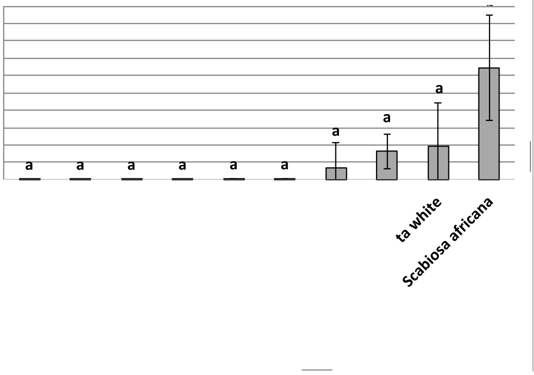
In the communities where forb canopies were lower than those of the geophytes, some geophytes demonstrated their capacity of pushing through from the dense foliage canopies, while others were restricted and declined through competition. Generally speaking, taller and or faster growing geophytes emerged more readily from lower forb canopies. In the low forb and tall geophyte mix (C9), *Kniphofia sarmentosa* and *Watsonia borbonica* performed well and were the first and forth respectively in biomass production. The biomass of *Aristea major* was restricted by frost rather than competition with low forbs as their evergreen foliage was present above the forb layer before winter. In the low forb and medium geophyte mix (C10), geophytes all produced the least biomass except for *Watsonia* 'Tresco Dwarf Pink'.

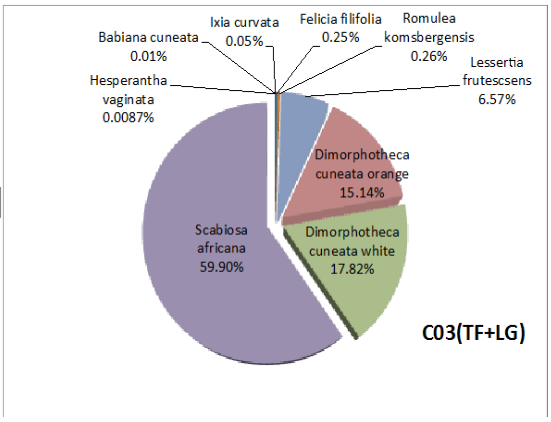


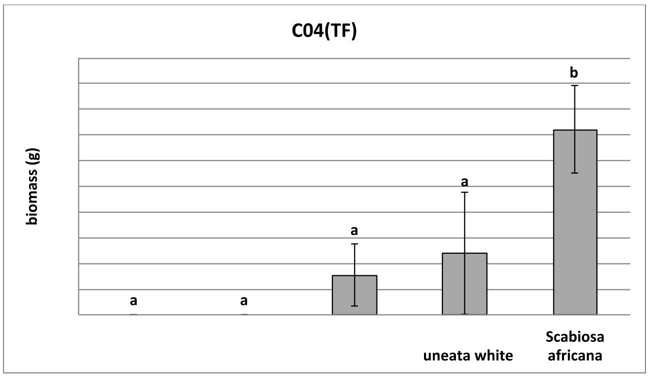


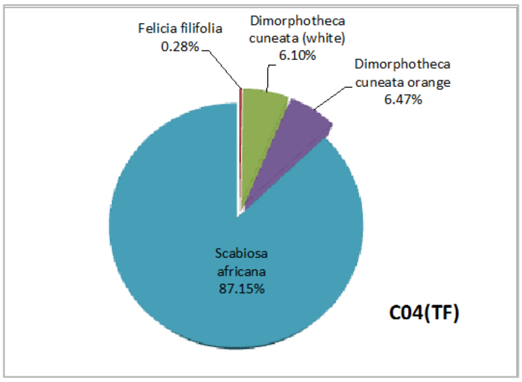


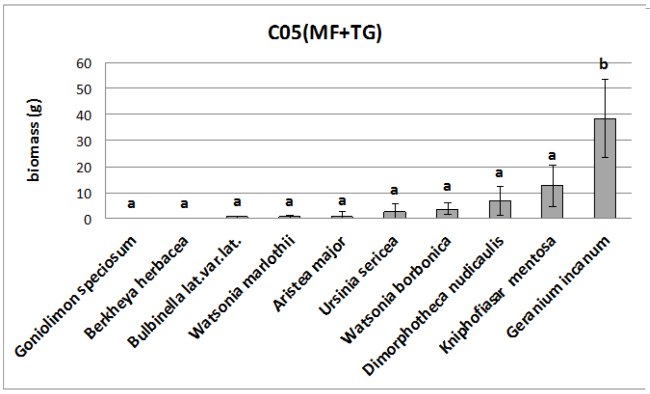


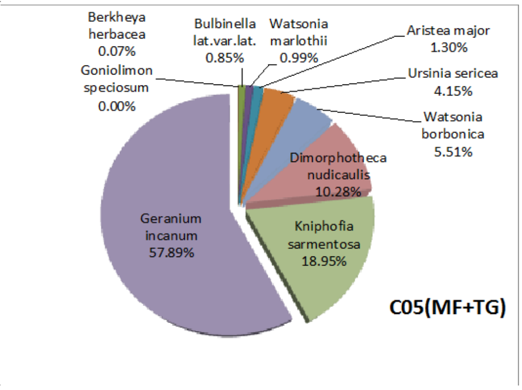

a
a
a
a
a
a
a
a
a
ta white
Scabiosa africana

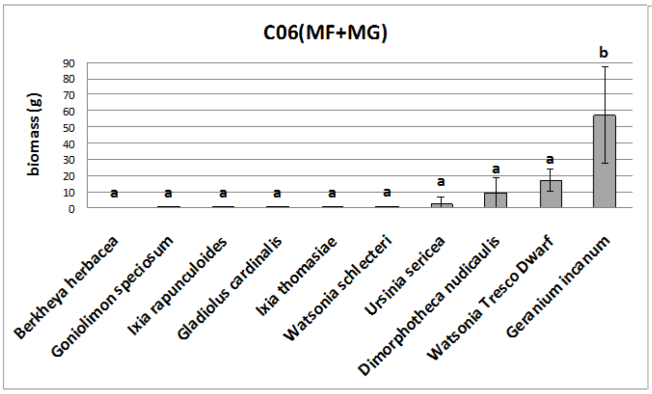

Babiana cuneata 0.01%
Ixia curvata 0.05%
Felicia filifolia 0.25%
Romulea komsbergensis 0.26%
Lessertia frutescsens 6.57%
Hesperantha vaginata 0.0087%
Dimorphotheca cuneata orange 15.14%
Dimorphotheca cuneata white 17.82%
Scabiosa africana 59.90%
C03(TF+LG)

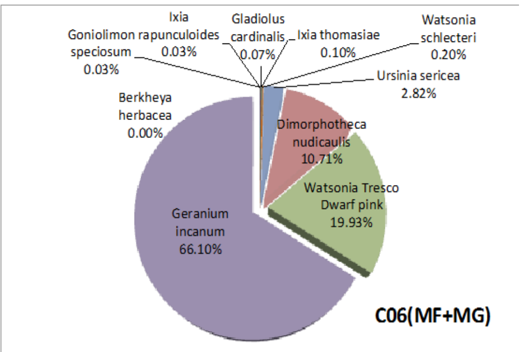

C04(TF)
biomass (g)
a
a
a
a
b
uneata white
Scabiosa africana

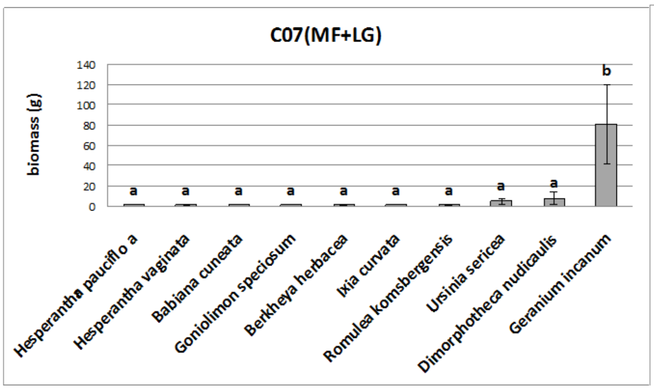

Felicia filifolia 0.28%
Dimorphotheca cuneata (white) 6.10%
Dimorphotheca cuneata orange 6.47%
Scabiosa africana 87.15%
C04(TF)

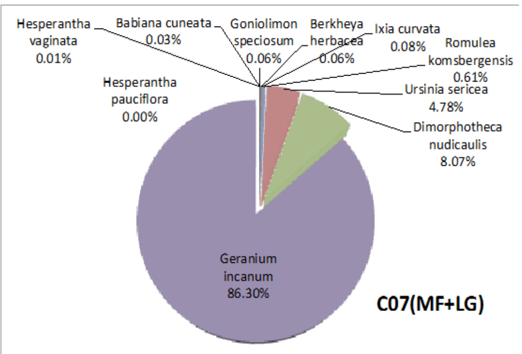

C05(MF+TG)
biomass (g)
60
50
40
30
20
10
0
a
a
a
a
a
a
a
a
a
b
Goniolimon Speciosum
Berkheya herbacea
Bulbinella lat.var.lat.
Watsonia marlothii
Aristea major
Ursinia sericea
Watsonia borbonica
Dimorphotheca nudicaulis
Kniphofiasar mentosa
Geranium incanum

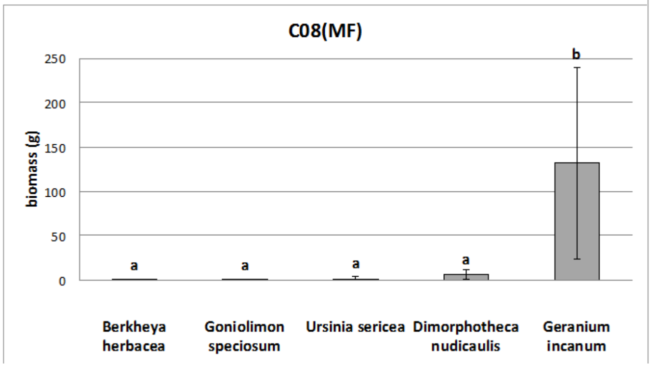

Berkheya herbacea 0.07%
Bulbinella lat.var.lat. 0.85%
Watsonia marlothii 0.99%
Aristea major 1.30%
Goniolimon speciosum 0.00%
Ursinia sericea 4.15%
Watsonia borbonica 5.51%
Dimorphotheca nudicaulis 10.28%
Geranium incanum 57.89%
Kniphofia sarmentosa 18.95%
C05(MF+TG)

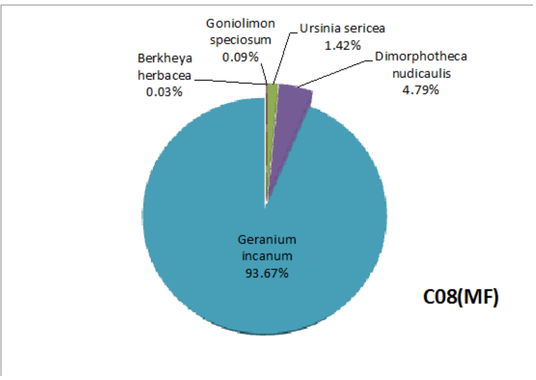

C06(MF+MG)
biomass (g)
90
80
70
60
50
40
30
20
10
0
a
a
a
a
a
a
a
a
a
b
Berkheya herbacea
Goniolimon speciosum
Ixia rapunculoides
Gladiolus cardinalis
Ixia thomasiae
Watsonia schlecteri
Ursinia sericea
Dimorphotheca nudicaulis
Watsonia Tresco Dwarf
Geranium incanum

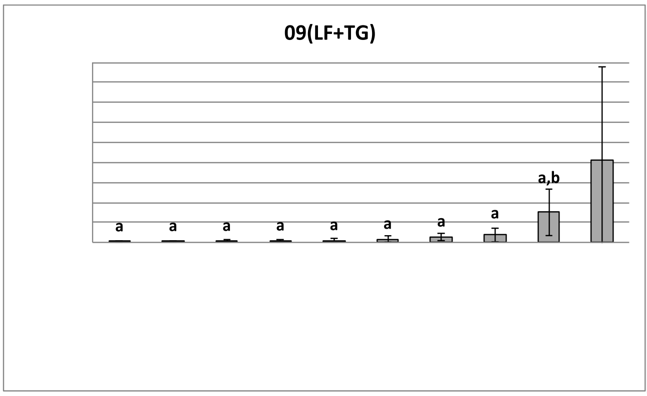

Ixia rapunculoides 0.03%
Goniolimon speciosum 0.03%
Gladiolus cardinalis 0.07%
Ixia thomasiae 0.10%
Watsonia schlecteri 0.20%
Ursinia sericea 2.82%
Berkheya herbacea 0.00%
Dimorphotheca nudicaulis 10.71%
Watsonia Tresco Dwarf pink 19.93%
Geranium incanum 66.10%
C06(MF+MG)

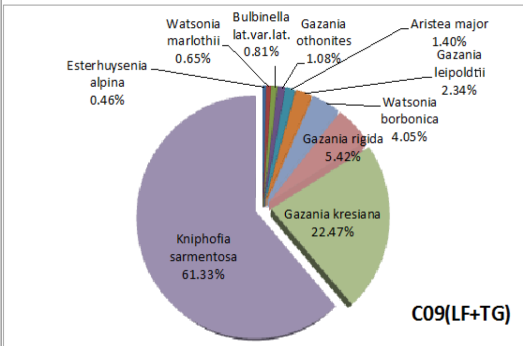

C07(MF+LG)
biomass (g)
140
120
100
80
60
40
20
0
a
a
a
a
a
a
a
a
a
b
Hesperantha pauciflo a
Hesperantha vaginata
Babiana cuneata
Goniolimon speciosum
Berkheya herbacea
Ixia curvata
Romulea komsbergensis
Ursinia sericea
Dimorphotheca nudicaulis
Geranium incanum

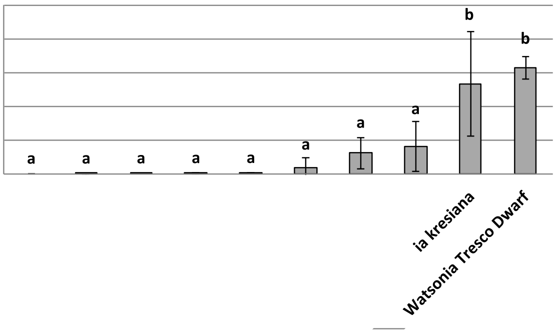

Hesperantha vaginata 0.01%
Babiana cuneata 0.03%
Goniolimon speciosum 0.06%
Berkheya herbacea 0.06%
Ixia curvata 0.08%
Romulea komsbergensis 0.61%
Hesperantha pauciflora 0.00%
Ursinia sericea 4.78%
Dimorphotheca nudicaulis 8.07%
Geranium incanum 86.30%
C07(MF+LG)

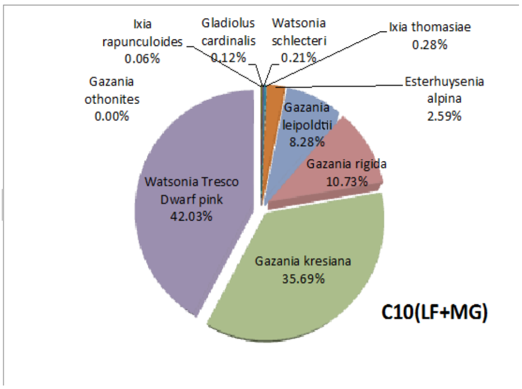

C08(MF)
biomass (g)
250
200
150
100
50
0
a
a
a
a
b
Berkheya herbacea
Goniolimon speciosum
Ursinia sericea
Dimorphotheca nudicaulis
Geranium incanum

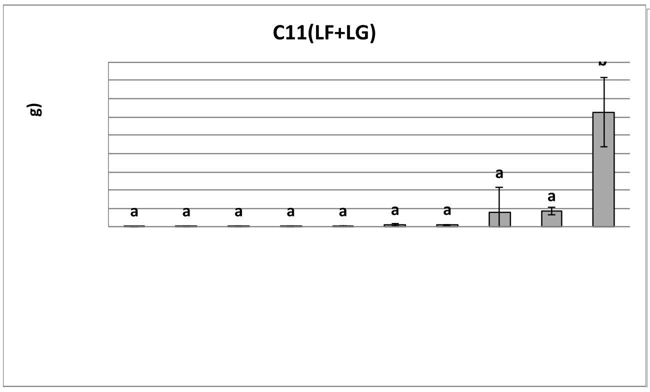

Goniolimon speciosum 0.09%
Ursinia sericea 1.42%
Berkheya herbacea 0.03%
Dimorphotheca nudicaulis 4.79%
Geranium incanum 93.67%
C08(MF)

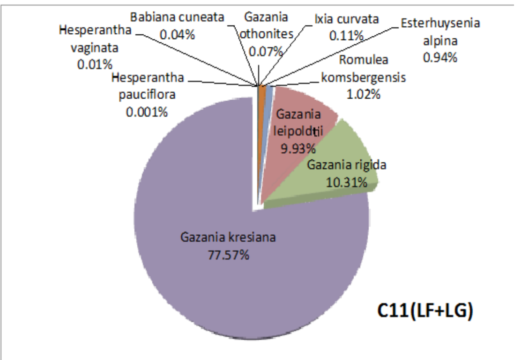

09(LF+TG)
a
a
a
a
a
a
a
a
a,b

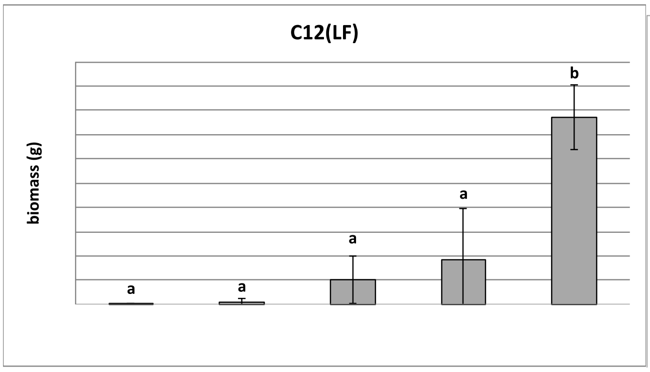

Watsonia marlothii 0.65%
Bulbinella lat.var.lat. 0.81%
Gazania othonites 1.08%
Aristea major 1.40%
Gazania leipoldtii 2.34%
Esterhuysenia alpina 0.46%
Watsonia borbonica 4.05%
Gazania rigida 5.42%
Gazania kresiana 22.47%
Kniphofia sarmentosa 61.33%
C09(LF+TG)

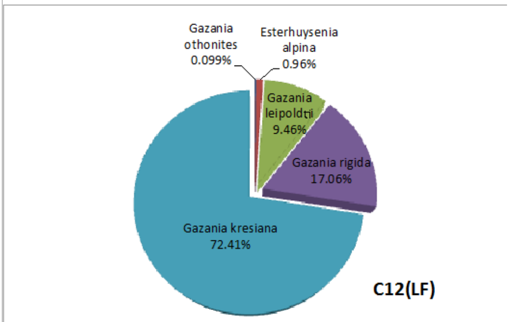

a
a
a
a
a
a
a
a
b
b
ia kresiana
Watsonia Tresco Dwarf

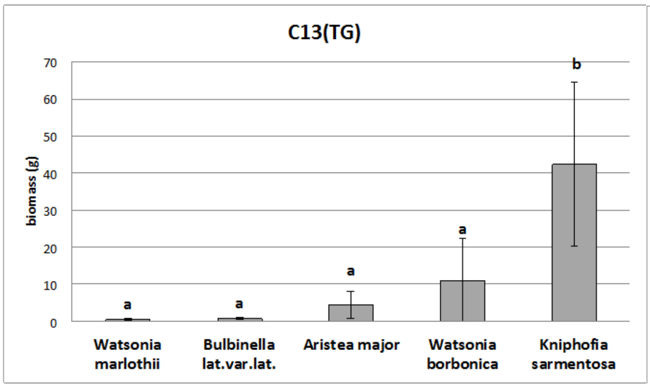

Ixia rapunculoides 0.06%
Gladiolus cardinalis 0.12%
Watsonia schlecteri 0.21%
Ixia thomasiae 0.28%
Gazania othonites 0.00%
Esterhuysenia alpina 2.59%
Gazania leipoldtii 8.28%
Gazania rigida 10.73%
Watsonia Tresco Dwarf pink 42.03%
Gazania kresiana 35.69%
C10(LF+MG)

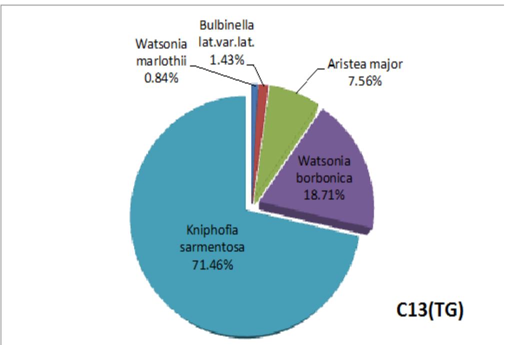

C11(LF+LG)
g)
a
a
a
a
a
a
a
a
a
b

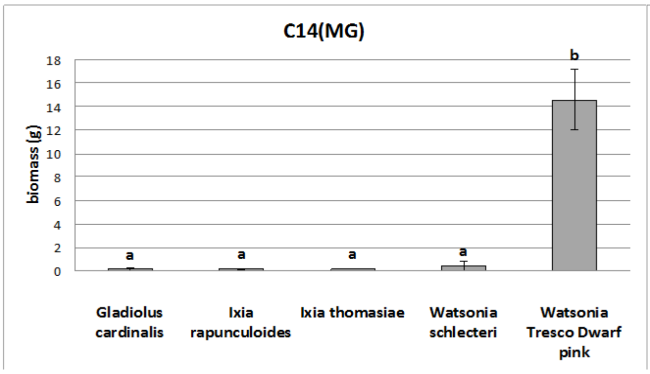

Hesperantha vaginata 0.01%
Babiana cuneata 0.04%
Gazania othonites 0.07%
Ixia curvata 0.11%
Esterhuysenia alpina 0.94%
Romulea komsbergensis 1.02%
Hesperantha pauciflora 0.001%
Gazania leipoldtii 9.93%
Gazania rigida 10.31%
Gazania kresiana 77.57%
C11(LF+LG)

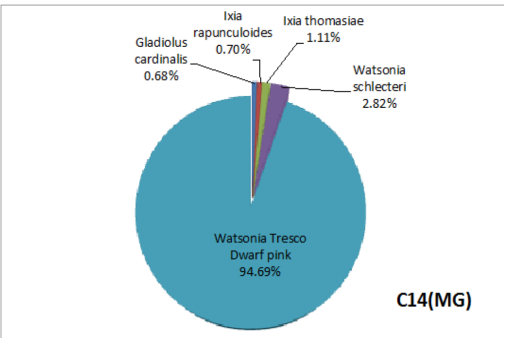

C12(LF)
biomass (g)
a
a
a
a
b


Gazania othonites 0.099%
Esterhuysenia alpina 0.96%
Gazania leipoldtii 9.46%
Gazania rigida 17.06%
Gazania kresiana 72.41%
C12(LF)


C13(TG)
biomass (g)
70
60
50
40
30
20
10
0
a
a
a
a
b
Watsonia marlothii
Bulbinella lat.var.lat.
Aristea major
Watsonia borbonica
Kniphofia sarmentosa


Watsonia marlothii 0.84%
Bulbinella lat.var.lat. 1.43%
Aristea major 7.56%
Watsonia borbonica 18.71%
Kniphofia sarmentosa 71.46%
C13(TG)


C14(MG)
biomass (g)
18
16
14
12
10
8
6
4
2
0
a
a
a
a
b
Gladiolus cardinalis
Ixia rapunculoides
Ixia thomasiae
Watsonia schlecteri
Watsonia Tresco Dwarf pink


Gladiolus cardinalis 0.68%
Ixia rapunculoides 0.70%
Ixia thomasiae 1.11%
Watsonia schlecteri 2.82%
Watsonia Tresco Dwarf pink 94.69%
C14(MG)

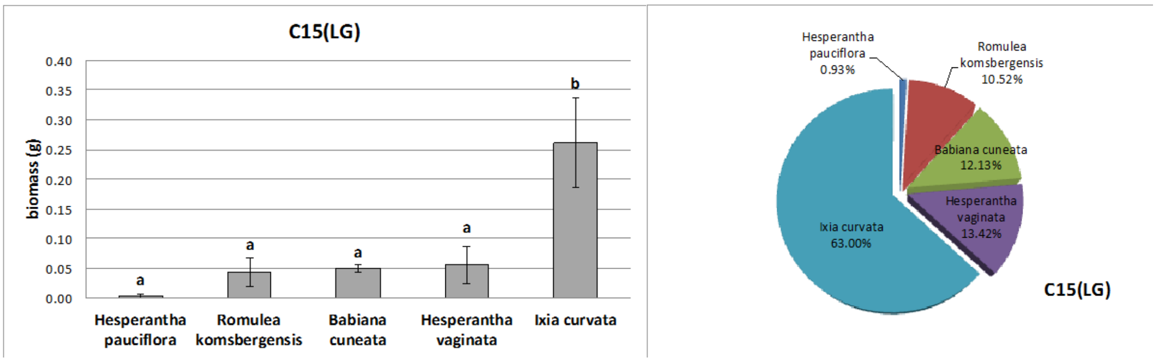


Fig. 5.24 Mean biomass of individual species within different treatments in all replicates in September 2014. Bar chats describe mean biomass of individual species in grams (error bars indicate standard error); Pie charts describe the proportion of biomass of individual species within each community.

5.3.5 Biomass comparison between 2013 and 2014

Repeated Measures ANOVA showed highly significant differences (P<0.01) for biomass between 2013 and 2014. Total mean biomass of all the species in 2014 (4782g) was clearly more than total mean biomass produced in 2013 (3079g) (Figure 5.25). In figure 5.26, mean biomass of all geophytes and shrubs/forbs/succulents in all treatments all replicates were compared between two observation years. Although shrubs/forbs/succulents group produced much more biomass than geophyte group in both years, increase in geophyte biomass was much greater between 2013 and 2014, than for forbs and shrubs, suggesting that the former are "catching up".

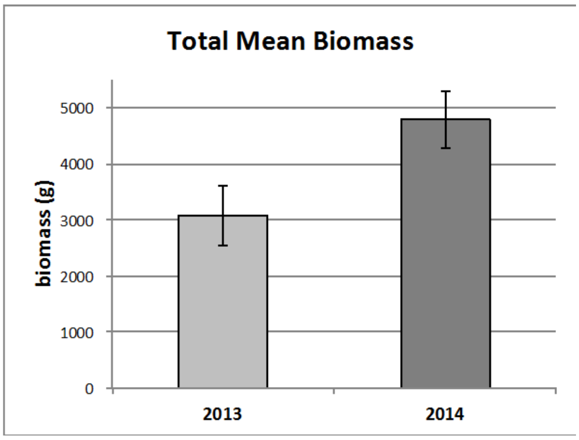


Fig. 5.25 Mean total biomass of all species in all treatments all replicates in 2013 and 2014.

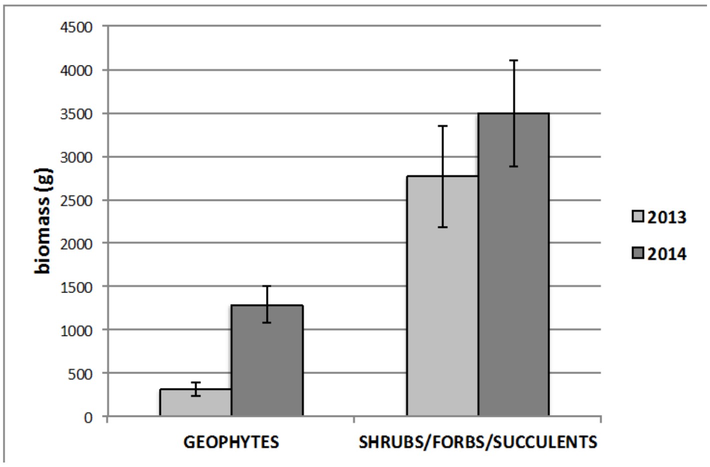


Fig. 5.26 Mean biomass of all geophytes and shrubs/forbs/succulents in all treatments all replicates in 2013 and 2014.

In the Test of between-subject effects, individual species showed highly significant difference in biomass between 2013 and 2014 (P<0.01). The forb species *Lessertia frutescens, Berkheya herbacea, Gazania othonities, Gazania leipoldtii, Geranium incanum, Gazania rigida, Gazania krebsiana and Dimorphotheca cuneata* all showed declining biomass in 2014 as a percentage of that in 2013. Most geophyte species grew faster in the second year with the low and medium geophytes *Hesperantha vaginata, Ixia curvata, Ixia rapunculoides, Hesperantha pauciflora* and *Gladiolus cardinalis* presenting highest change in biomass. The mean total biomass of individual species and mean biomass of individual species within communities in 2013 and 2014 can be found in Table 5.3, 5.4, 5.5 and 5.6.

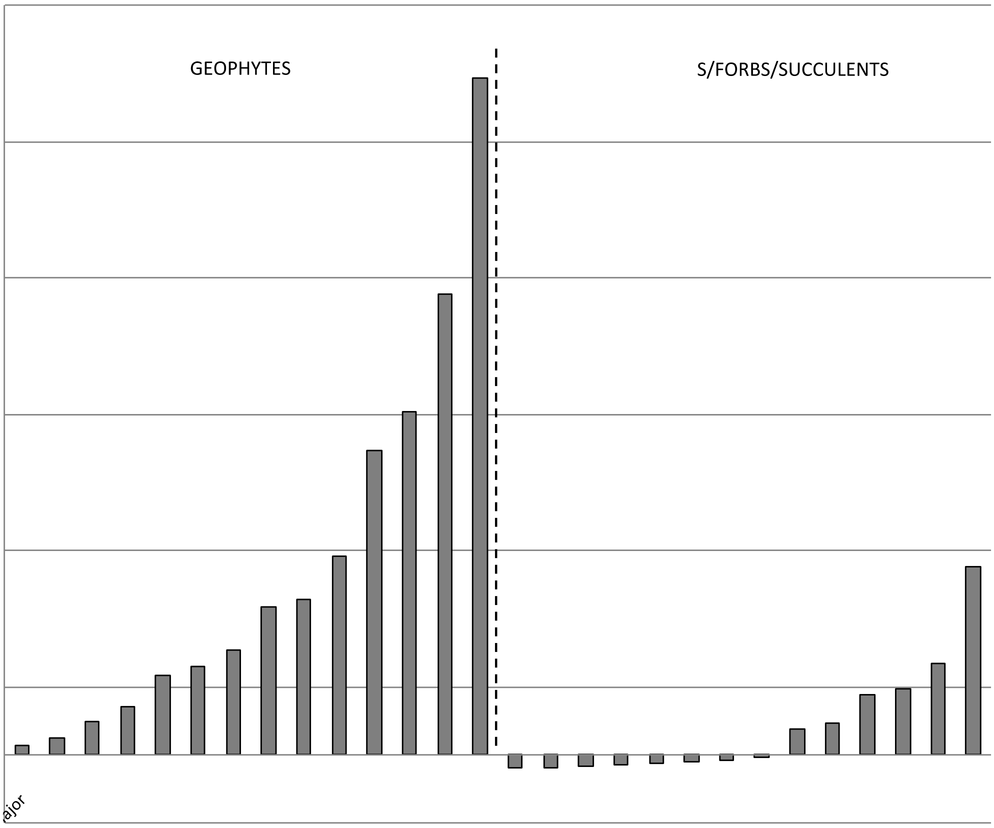


Fig. 5.27 Changed biomass from 2013 to 2014 of all geophytes and shrubs/forbs/succulents in all treatments all replicates, expressed as a % of the grams of biomass harvested in 2014 to that of 2013.

5. 4 Discussion

5.4.1 Community canopy coverage

Generally speaking, by themselves, geophytes and in particular small geophytes produced very open, highly weed invasive communities (see Figure 6.9 in Chapter 6 Phenology). Communities dominated by forbs, which were typically much larger with lateral spreading growth, were much less weed invasive. Community coverage values summarised in Figure 5.11 confirm that coverage was mainly contributed by forbs and tall geophytes. Coverage increased quickly when forb species began to grow, these species were also evergreen, hence shading was continuous. Deciduous geophytes such as *Bulbinella* and *Watsonia* species went into dormancy although some stems and some senescent leaf tissue was retained over summer. This senescent plant material contributed to community coverage. The other deciduous medium geophytes typically just disappeared as they entered dormancy and had little significant effect on community coverage during this time.

The forb species used in the experiment were paradoxical from a community design perspective as although very valuable in terms of preventing weed invasion, they largely died out for various reasons, particularly in the low to medium canopy height communities. Species such as *Geranium incanum* performed well initially to form a carpet-like ground cover, however, it seems to be short-lived with some big clumps dying back from the second year, whilst simultaneously it self-seeded within its treatment blocks. Low canopy height *Gazania* had the same problem. *Gazania krebsiana, Gazania leipoldtii* and *Gazania rigida* used in the experiment formed large evergreen foliage clumps and displayed very attractive large orange flowers. By the third year many had died out but continued to be present through the newly established seedlings. This trait for self-seeding suggests that these four re-seeder species may still be useful components of these types of communities. This dying out phenomena appears to be linked to growing in relatively productive, and at times very moist soils. The same genotypes have proved to be long persistent in Sheffield as vegetative plants growing in crushed brick rubble on a green roof in Sheffield (Hitchmough and Cummins, 2011). The experimental site, despite its south-west facing orientation has a tendency to remain wetter than might be expected. This may be due to a localized subterranean spring, these are common on sloping sites in Sheffield. Such problems were not anticipated when designing the plant communities. The study has however been useful in highlighting these traits, but clearly there is a need to identify additional forb species that are capable of creating a more persistent forb layer.

The situation in medium to tall shrubby species was different. The species were larger and in relative terms had a greater capacity to re-sprout post harvesting. They were generally more persistent within the community and maintained coverage values.

The forb layer, however, was less important in the community mixes with tall geophytes. By the second year the biomass of the latter was substantial and beginning to play the same role as that of the forbs.

5.4.2 Mortality and competition within the community

5.4.2.1 Mortality of species

Mortality of individual species is a critical factor in designed communities; it reflects the species tolerance of both the site environment, and tolerance of competition with other neighboring plants and species, which also affects its biomass contribution to the community. Large-growing plants are generally presumed to eliminate small plants by shading them, as on productive soils light is the resource that is most finite. In this study, however, mortality is also very strongly affected by plant tolerance of the site, or in some cases lack of. This is to be expected in an experiment that utilised Western Cape species, a flora that has no history as an outdoor vegetation in Britain. In terms of fitness for this specific site, what this study has shown is that at least some of the species are remarkably well fitted to urban northern Britain, not withstanding a likelihood of addition mortality under more severe winter conditions than experienced in the years of this study. Some species for example *Berkheya herbacea*, was just too cold sensitive for the site, and the replacement, non South African species *Goniolimon speciosum* failed presumably because the site was too wet.

A major source of mortality in the shrubs was due to intolerance of canopy removal; most of these species are naturally post fire re-seeders, rather than post fire re-sprouters. Therefore, cutting in August as a management approach is problematic for this group of species. Some of these species, for example the *Scabiosa*, do tolerate severe pruning, although they are naturally post fire re-seeders. The effect of flash burning in August as a management technique instead of cutting, as used in North American prairie meadows (Hitchmough, 2004), would be even more catastrophic for these forbs and shrubs. Geophytes in these communities are however very tolerant to flash burning and this would rapidly result in geophyte dominance in the taller more robust geophytes.

Within communities with mixed canopy layers, mortality was not simply related to canopy layers, but also to other characteristics such as life form, canopy position in space as well as canopy density. The general assumption underpinning the research was that most species used were shade intolerant, and hence when a small stature species was heavily shaded by a dense tall species, it was more prone to be restricted in growth and eventually be eliminated. This was demonstrated by *Felicia filifolia* and *Babiana cuneata.* In the tall shrub/forb group, the fast-growing, dense, large-leaved species *Scabiosa africana* was very competitive*.* As a result, only few plants of *Felicia filifolia* survived the two-year experimental window, and all of these were in communities with a more open taller canopy layer. *Babiana cuneata* proved too sensitive even compete with low canopy *Gazania*. The four *Gazania* species initially created a very dense fused canopy strongly restricting the small geophytes between/underneath to intercept enough light. The mortality of *Babiana cuneata* was less in the medium height forb community than in the low forb low geophyte mix, because despite being taller, the canopy was more open.

The small geophyte species also showed a diversity of tolerance of shade; *Romulea komsbergensis* showed high survival (only 5% mortality) in tall forb low geophyte mix. In its habitat in winter wet Renosterveld in the Roggeveld, it sometimes occurs amongst dwarf shrubs, which suggests it is potentially shade tolerant. Alternatively, the reason might be due to phonological differences in the growth of *Romulea komsbergensis* and tall forb/shrub species in this community. *Romulea komsbergensis* comes into growth in autumn and therefore escapes some of the competition for light later emerging geophytes experience. When *Scabiosa africana, Dimorphotheca cuneata* and *Lessertia frutescsens* had formed a dense summer canopy, *Romulea komsbergensis* had already entered into dormancy. The other small deciduous geophyte *Ixia curvata* was also worthy of mention. It has as low mortality figures as *Romulea komsbergensis* in all the communities where it represented (see Table 5.3) This is also a shade tolerant species which survived well from low dense canopies to tall b shady canopies. Again this species is often found in combination with dwarf shrubs in its habitat, so a degree of shade tolerance is to be expected. The tolerance of shade of these species is not highlighted in the horticultural literature, but is a valuable characteristic in designed Mediterranean communities. In the winter cold tolerance experiment phase 1, *Romulea komsbergensis* and *Ixia curvata* both showed low mortality prior to this competition experiment, and their very high tolerance of cold has been confirmed in other experiments (Cummins, 2010).

In the low forb only mix, the succulent *Esterhuysenia alpine* was largely eliminated by *Gazania*. *Esterhuysenia* proved to be one of the slowest growing species and the *Gazania* simply overtook it and shaded all but the upper most leaves. Although in the Roggeveld escarpment, where there is typically co-existance within communityies combining a low growing evergreen ground forb layer, such as *Arctotis, Gazania* and *Ursinia*, and succulent species such as *Aloinopsis*, the competition on unproductive land, subject to very high levels of sterss is very different. Forbs have smaller canopies and grow at wide spacings, thus allowing low growing succulents to capture sufficient light. Many of the species in the low canopy layers in this experiment would be much more stable if used on highly unproductive substrates such as green roofs. On highly productive soil they are inevitable going to be subject either to loss of diversity by the fastest growing sown or planted species or eliminated by weedy species from outside the community.

Tall evergreen geophyte *Aristea capitata* had much less mortality in the tall geophyte only community and communities where it was mixed with tall forbs in this competition experiment. This may related to its habitat environment conditions. It comes form sandstone Fynbos in Cedarberg, where it grows amongst shrubby species Proteaceae and Ericaceae and tall grasses, which provide more protection during winters. The hardiness experiments showed that *Aristea* as a genus are much more cold intolerant that many other genera drawn from exactly the same habitat. In mixes with lower forb layers, *Aristea capitata* the foliage of the other species reduced long wave radiation loss from the soil, hence the basal meristems were subjected to less severe winter temperatures.

Plants with erect form, or with leafless flowering stems are usually less competitive with lower growing plants in mixtures. Tall erect foliaged geophytes such as *Watsonia* cause less shade compared to big clump growing *Kniphofia* with typically swirling mounds for foliage*.* When low-medium forbs were mixed with tall geophytes, some forbs survived under canopy of *Watsonia* rather than *Kniphofia.*

The competitive outcomes are likely to have been different had the experiment been able to be extended for another year. Within a two year period, most medium height geophytes had insufficient time to form a typical canopy, and their competition capacity was much reduced. As in the case of *Watsonia* 'Tresco Dwarf Pink', species like *Gladiolus cardinalis* and *Watsonia schlecteri* will become much more competitive with other species as they become bigger in size (see Table 5.3).

Fig. 5.28 *Gladiolus cardinalis* forms a substantial biomass three years after planting. (photo taken by James Hitchmough)

5.4.2.2 Biomass production

Biomass and competition are inextricably linked especially on productive soils. High above ground biomass is generally a pre-requisite for high competitive capacity. Mortality within the population of a species reduces its total biomass, and its competitive capacity. In the first two growing season, shrubs and forbs typically produced more biomass than geophytes, particularly low to medium geophytes. This is because these competitive plants grew more rapidly and produced bigger leaves or more leaves. This is a very common pattern in natural vegetation where evergreen geophytes in particular are an important part of the flora. After a disturbance event such as a severe fire, the vegetation tends to be dominated by often relatively short lived forbs and shrubs, but over time these are then dominated by initially slow growing geophytes. As these geophytes getting bigger, especially tall geophytes, they accrue large amounts of biomass which becomes a weapon in competition with forbs and other species. This was seen the experiments where tall forb biomass was less when it was mixed with tall geophytes.

Tall geophyte *Kniphofia,* and in particular *K. sarmentosa* produced the highest biomass in the geophyte groupings. This species is a very useful species but is likely to dominate all other species because it possesses a number of key biomass-competitive traits. It is fast growing, evergreen, that emerges from the soil early in autumn, retains its voluminous foliage even when dead and forms short rhizomes by which it closes down space in the community. Such species are essentially immortal, potential clone formers. Such species need to be either used with taller species in designed communities or used at very low densities to prevent their eliminating the other species.

Kniphofia sarmentosa was also dominant because it could recover the loss of biomass soon after cutting. In reverse, most other species only could recover the biomass till the next growing period even if they are evergreen species. For instance, *Gazania* returned to their pre harvest biomass by early spring, *Scabiosa africana, Lessertia frutescsens, Dimorphotheca cuneata* recovered back in summer. These phenological variations in the production of biomass were very evident in the study, and can be exploited to allow co-existence in designed plantings that at given levels of biomass and high soil productivity otherwise would not be possible. Species with tall erect leaves such as Watsonia.

As Figure 6.9 shown in Chapter 6, *Gazania krebsiana* and *Gazania othonites* in Roggeveld region Rooiwal near Middelpos grow as isolated clumps, and the biomass produced is less subject to the massive annual variations such as seen in *Kniphofia.* When introduced to more fertile soils and wetter conditions, they grew quickly, bigger in size and produced much more biomass. In designed planting community, reducing the nutrient content of the soil is often used to restrict some fast-growing species in order to balance the growth rate of other species in the designed planting community to better ensure co-existence. The use of low fertility materials such as sand and crushed building rubble is an interesting avenue to explore to find ways of managing these process with South African species.

Species with strong ability for self-seeding were able to maintain a significant biomass even when there was significant loss of adults plants. Many seedlings of *Gazania krebsiana* and *Geranium incanum* established in the second and subsequent years potentially allowing the species to continue to persist and maintain sufficiently high levels of biomass to prevent weed colonization.

5.4.3 Management

These forb layers are ephemeral in the habitat, and mainly relatively shade intolerant. They tend to develop in the first few years after a fire, then die out when taller canopy re-developed. In designed community, annually removal of the top canopy to permit light ingress will allow them to be more persistent in the community, however many of these species are also intolerant of the severe pruning that this entails. This regular cutting would however allow small geophytes to potentially bloom every year.

Cutting was used too in this experiment to harvest biomass, but also as a way to “re-set the community clock”. Generally speaking, cutting is acceptable for all the geophytes as a management method undertaken. In late summer just before the new growing season of winter-growing geophytes, when these species are just coming out of summer dormancy. Evergreen geophytes are tolerant of cutting of this nature despite their basal leaves. To make this system of management feasible, additional species of forbs, shrubs need to be evaluated that are long lived post fire re-sprouters. These species exist in South African Fynbos and Rennosterveld, but tend to be slower growing and more difficult to germinate and were not viable species to work with in this relatively short study. With these species the use of fire as a management too becomes a realistic scenario.

5. 5 Conclusion

This study has shown that it is possible to design naturalistic plant communities based upon Mediterranean Western Cape species. The most successful communities in terms of potential application to the UK urban landscape were generally those composed of tall canopy layer geophytes and forbs and shrubs, although some of the species used in the medium canopy layers were also potentially useful, but require more time to develop sufficient biomass to fulfill this role than was possible in this study.

The lowest growing layer proved to be problematic in the productive soils of the experiment, with many of the forbs being lost and the geophytes growing so slowly as to offer no competition to incoming weeds. The key element missing from the communities were long lived, reliably re-sprouting shrubs and forbs, and or evergreen geophytes, that also have some degree of shade tolerance. These are necessary for functional reasons to be able to achieve year round light suppression and also to be capable of withstanding the annual canopy removal either by cutting or cutting and burning necessary to ensure the geophytes present are able to flower reliably every year.

CHAPTER 6: PHENOLOGY OF GROWTH, FLOWER CHARACTERISTICS AND VIEWS FROM DESIGN PERSPECTIVE

6.1 Introduction

As previously discussed in Chapter 2, section 2.3.1, clearly not only germination data is crucial to a designed Mediterranean planting community, phenology of these winter-growing western cape species is also necessary to understand. However, very little knowledge has been gained through observation and practice of the growth and flowering characteristics of these species in the field, and none whatsoever when established by sowing. The early stage growth rate is particularly important, as in designed planting communities, species in the mix have to avoid early extreme competition from fast-growing species if slow-growing species are to survive.

6.1.1 Objectives

The Specific research questions associated with this study were:

I. To evaluate the growth phenology and mortality on a range of species;

II. To understand the flower phenology of these species, visual impact and duration;

III. To evaluate the effect of community structure in Competition Experiment on appearance in year 3.

6.2 Methodology

6.2.1 Foliage senescence

The Winter Cold Tolerance Experiment Phase 1 commenced on 16th December 2011. Leaf and shoot phenology was observed throughout the experiment. The foliage quality of seedlings was assessed through a five point scale: 1 = 0% foliage senescent (green and growing), 2 = 25% foliage senescent, 3 = 50% foliage senescent, 4 = 75% foliage senescent and 5 = 100% foliage senescent/necrotic.

Scoring these levels was done continuously every month from the time of onset of foliage senescence, with a final assessment in middle March 2012.

6.2.2 Growth and Flower phenology

Growth and Flower phenology of these species was observed through site observation and photo recordings. The time taken for seedling emergency, seedling leaf presence, and the dormancy of seedlings (i.e. absence) were recorded every 10 days in the first year after sowing in March 2010 in preliminary experiment with 3 different sown substrates. Reshooting period, foliage present period, flowering period and dormancy period of individual species was tested in the Winter Cold and Summer Wetness Tolerance Experiment phase 1. These observations were recorded in the second testing year from August 2012 to July 2013. Cover conditions in summer 2012 were considered and allowed to compare the impact of summer wetness on geophytes during their dormancy. The hypothesis was that species in summer uncovered treatment might delay their reshooting period in the next growing season.

6.2.3 Community structure

Evaluation of the effect of community structure in the Competition Experiment was mainly through photo recording. Images of the performance of individuals were continuously taken at different period of time to show the change in plant size and competitive capacity in the communities. The change of each combination was captured every two months to allow analysis from a design perspective.

Heights of leaves (and flower stems) where present of species in the competition experiment were measured in July 2014. If there were no flowers, the data was recorded as the height of tallest leaf; if there were some flowers, the data was recorded as the height of tallest leaf or inflorescence depended on which was taller. Spread was measured based on the radius of the basal foliage.

6.3 Results

6.3.1 Foliage senescebce/necrosis caused by forst

The following images from the preliminary experiment show performance of individual deciduous geophyte species in 3 substrates (75mm sand, 75mm soil and 150mm sand) sown in spring 2010. Different species performed differently in each substrate and showed various degree of foliage senescent due to frost damage in winters in Sheffield.

Fig.6.1 (Left) *Aristea confusa* died in 75mm sand; (middle) *Wachendorfia paniculata* was surprising good in 75mm soil and 150mm sand, this image shows its performance in 75mm soil; (right) *Bulbinella nutans* survived in 150mm sand. All the images were taken on 20th Febuary 2011 after the extremely cold winter 2010 with a minimum air temperature -8.9^{o}C, and nearly -10 ^{o}C at the ground surface.

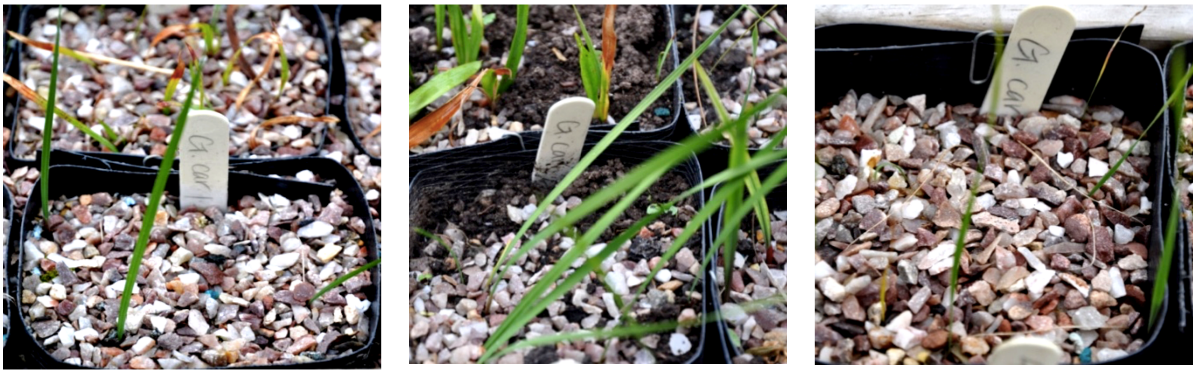


Fig.6.2 *Gladiolus carneus* after extreme cold winter 2010 and re-shooting on 15th May 2011. Left: 75mm sand, middle 75mmsoil, right 150mm sand.

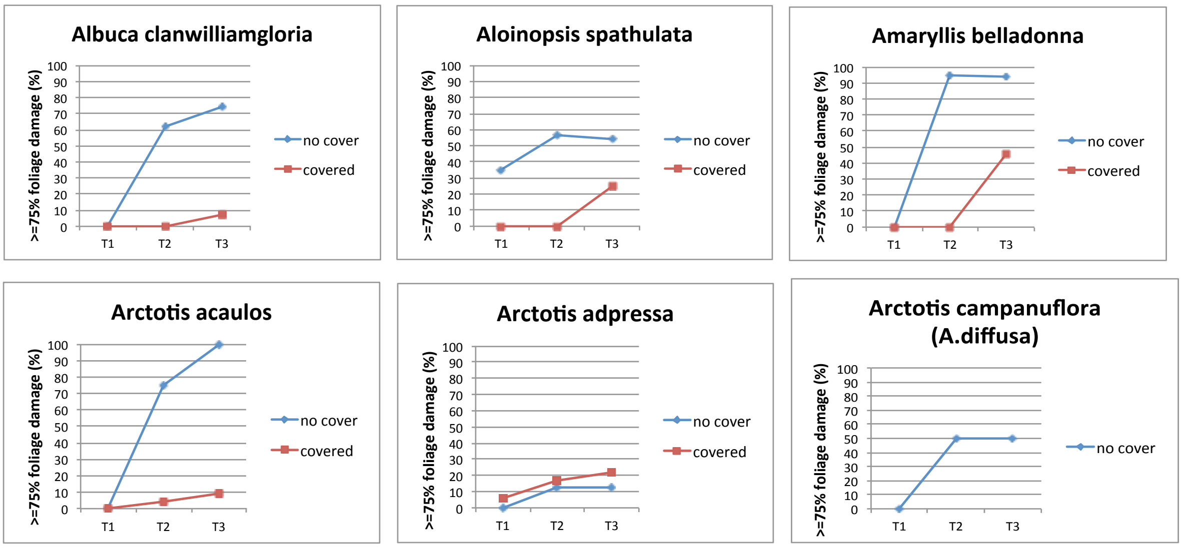
Fig.6.3 (Left) *Gladiolus tristis* after the extremely cold winter 2010 and re-shooting on 15th May 2011 in 75mm sand. (middle) *Gladiolus tristis* recorded on 15th May 2011 in 75mm soil; (right) *Watsonia alethroides* recorded on 15th May 2011 in 75mm soil.

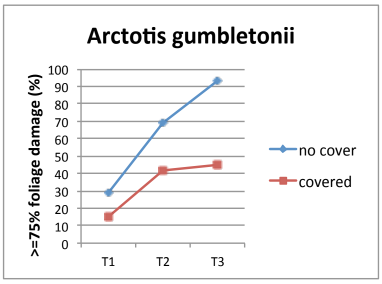
Fig.6.4 *Sparaxis elegans* re-shooting on 15th May 2011. Left: 75mm sand, middle 75mmsoil, right 150mm sand.

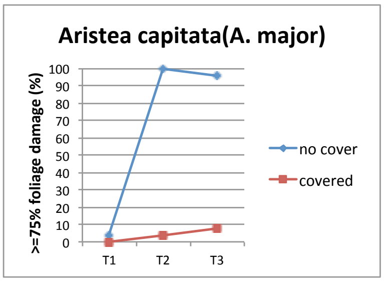
Fig.6.5 In the preliminary experiment, (top left) after the extremely cold and wet Winter of 2010, in the very dry spring 2011, the lowest mortality was recorded in 75mm soil and the highest mortality in 150mm sand (photo taken on 27th November 2011); (top right) the preliminary experiment was exposed to ambient temperatures without any protection even during cold winter (photo taken in late January 2012, Sheffield experienced 18cm snow on 18th January); (bottom left) Many species survived the extremely wet summer of 2012 (photo taken on 8th December 2012); (bottom right) Although many species died out in 150mm sand, the survivors however, produced more biomass each year and wonderful flowers, such as bright yellow *Bulbinella latifolia var. latifolia* in the picture (photo taken on 21th March 2014).

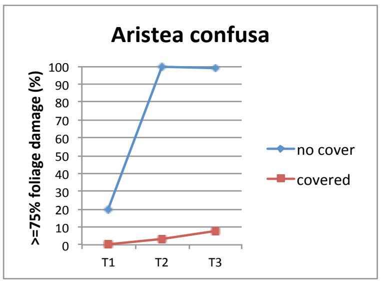
There were three typical responses within these observations i) little or no difference between covered and non covered: ii) intermediate; iii) large differences between covered and non-covered. Examples of response group i) were *Bulbinella nutans, Dimorphotheca cuneata, Gazania krebsiana, Hesperantha cucullatus, Kniphofia uvaria*; iii) were *Aristeas confusa, Babiana ringens, Crassula coccinea, Freesia fergusoniae, Tritoniopsis triticea*.

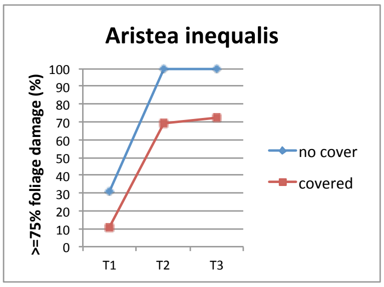
Fig. 6.6 The following graphs record foliage senescence/necrosis for of all the tested species in Winter Cold Tolerance Experiment Phase 1.Observations were taken on 15th January (T1), 15th Febuary (T2) and 15th March 2012 (T3). The numbers of seedlings with >=75% foliage senescence (including 100% foliage senescent/necrotic) were counted and converted into % to create line chart as below.

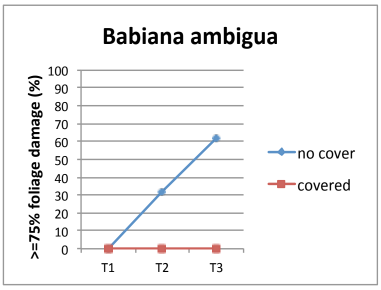


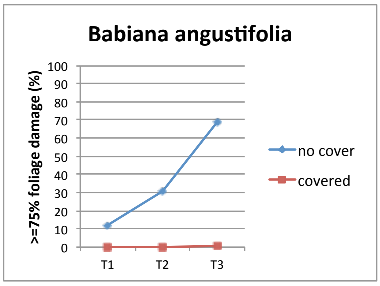

Arctotis gumbletonii
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

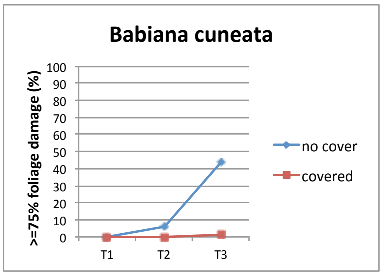

Aristea capitata(A. major)
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

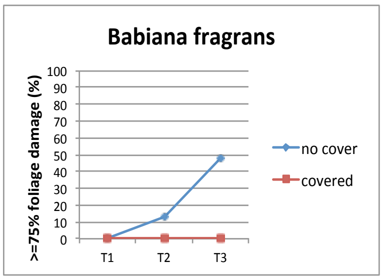

Aristea confusa
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

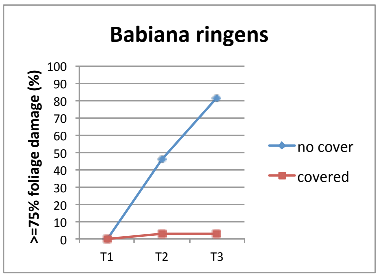

Aristea inequalis
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

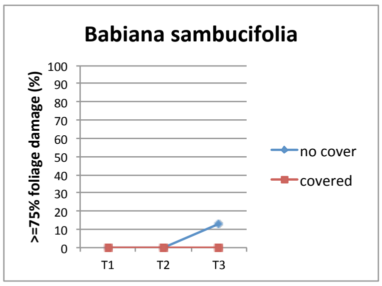

Babiana ambigua
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

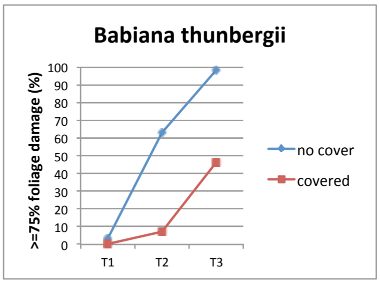

Babiana angustifolia
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

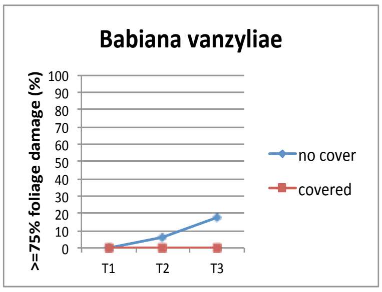

Babiana cuneata
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

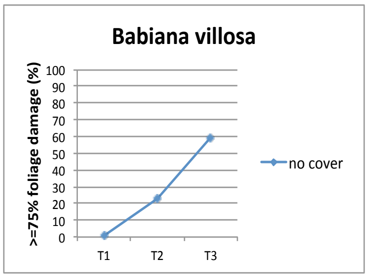

Babiana fragrans
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

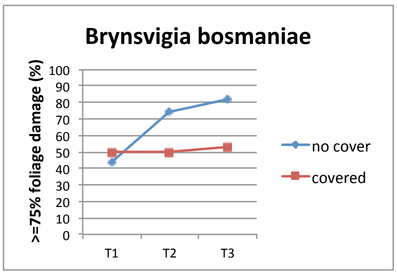

Babiana ringens
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

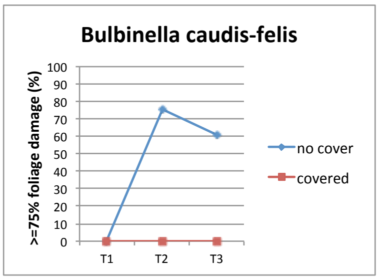

Babiana sambucifolia
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

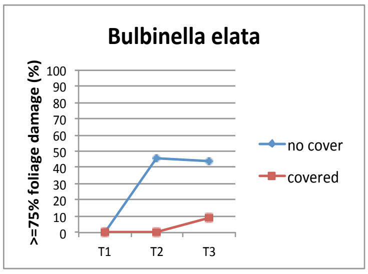

Babiana thunbergii
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

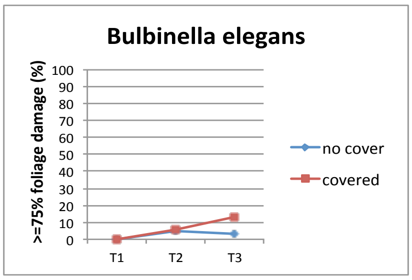

Babiana vanzyliae
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

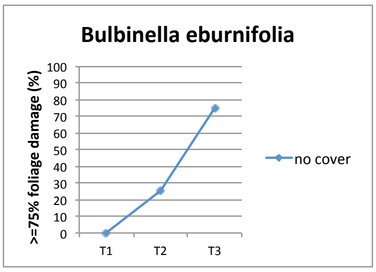

Babiana villosa
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover

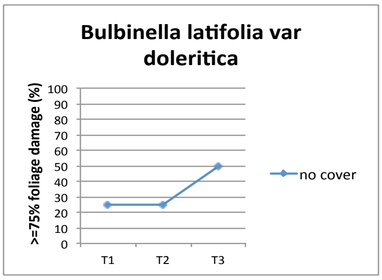

Brynsvigia bosmaniae
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

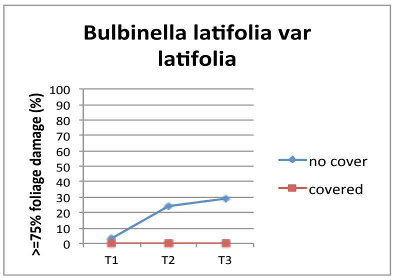

Bulbinella caudis-felis
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

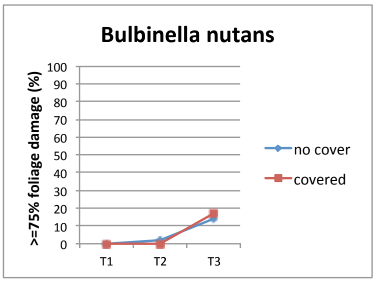

Bulbinella elata
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

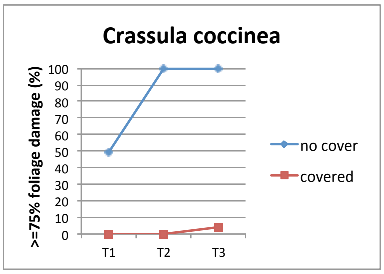

Bulbinella elegans
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

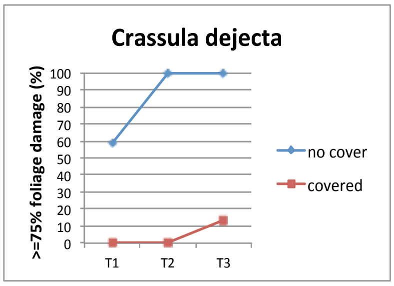

Bulbinella eburnifolia
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover

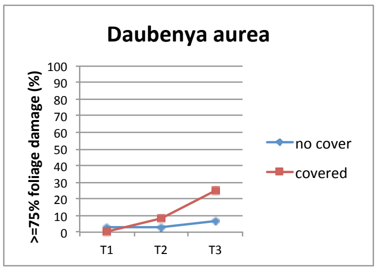

Bulbinella latifolia var doleritica
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover

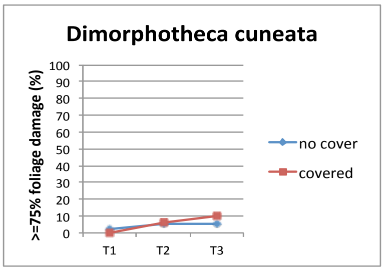

Bulbinella latifolia var latifolia
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

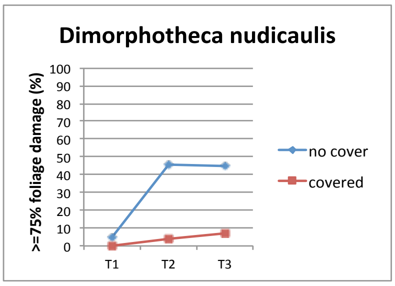

Bulbinella nutans
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

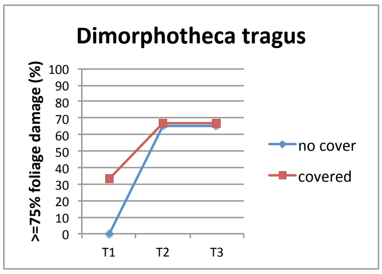

Crassula coccinea
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

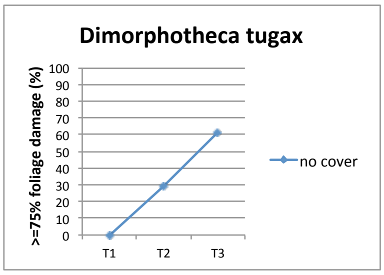

Crassula dejecta
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

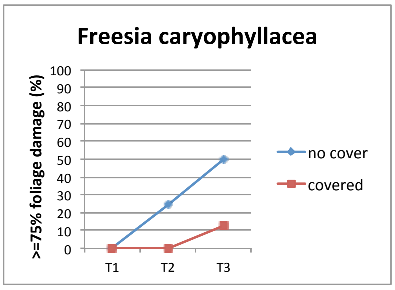

Daubenya aurea
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

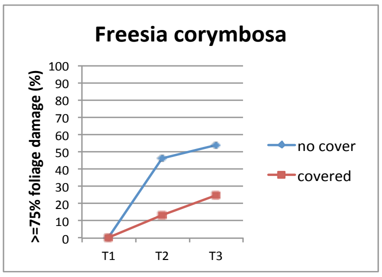

Dimorphotheca cuneata
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

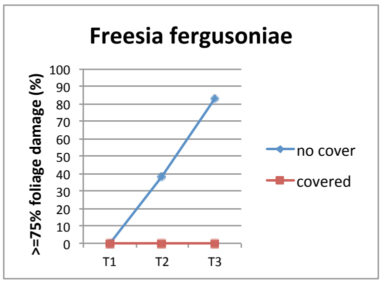

Dimorphotheca nudicaulis
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

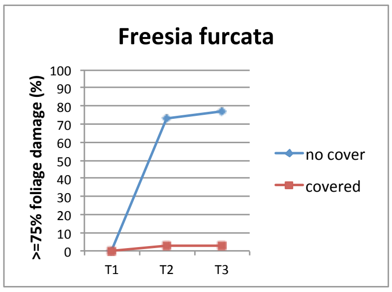

Dimorphotheca tragus
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

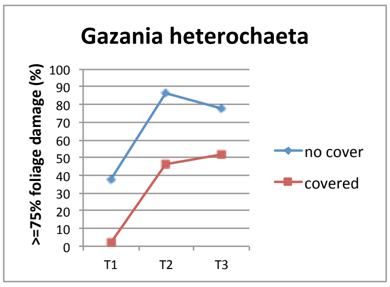

Dimorphotheca tugax
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover

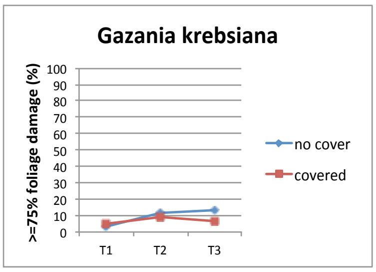

Freesia caryophyllacea
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

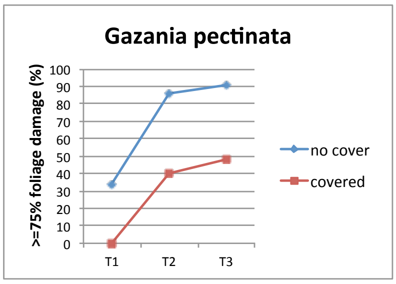

Freesia corymbosa
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

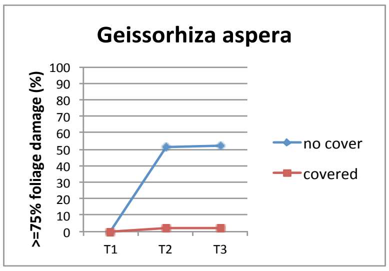

Freesia fergusoniae
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

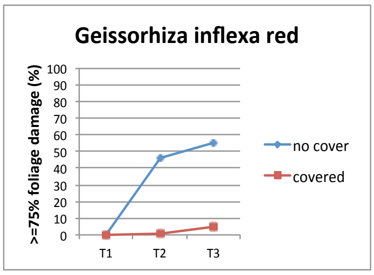

Freesia furcata
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

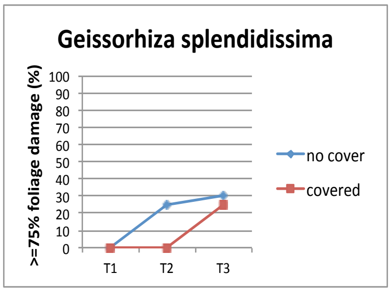

Gazania heterochaeta
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

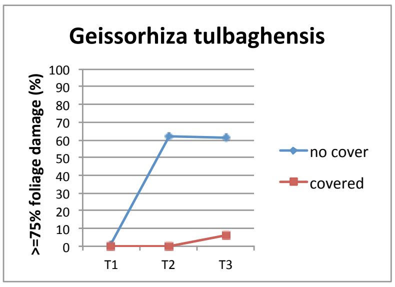

Gazania krebsiana
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

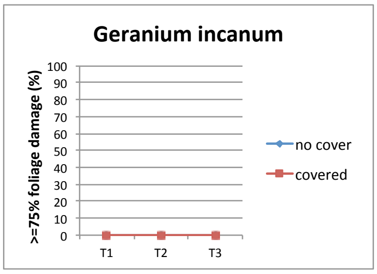

Gazania pectinata
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

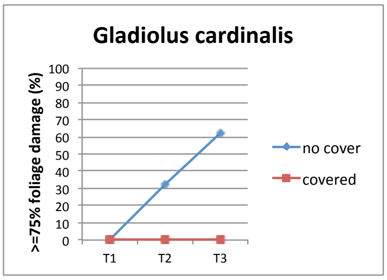

Geissorhiza aspera
>=75% foliage damage (%)
0
10
20
30
40
50
60
70
80
90
100
T1
T2
T3
no cover
covered

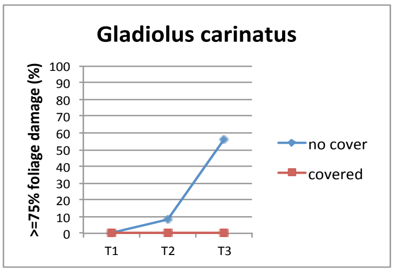

Geissorhiza inflexa red

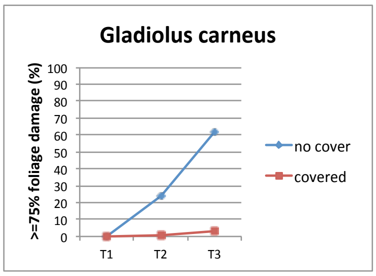

Geissorhiza splendidissima

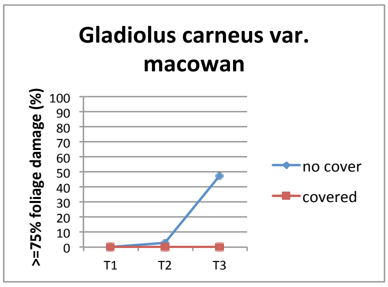

Geissorhiza tulbaghensis

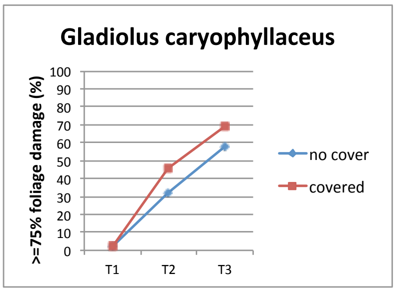

Geranium incanum

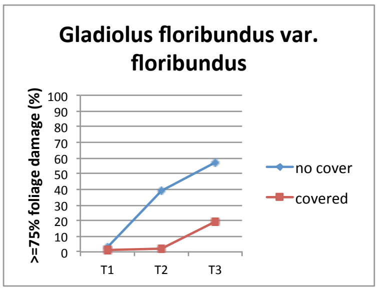

Gladiolus cardinalis

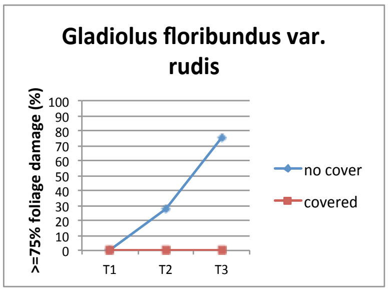

Gladiolus carinatus

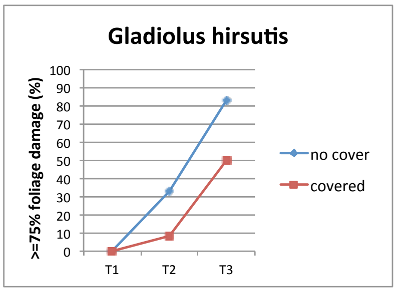

Gladiolus carneus

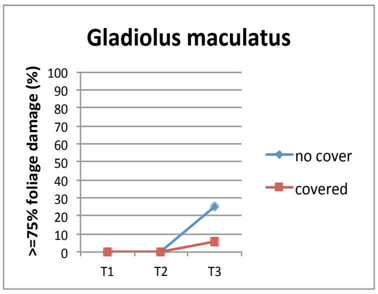

Gladiolus carneus var. macowan

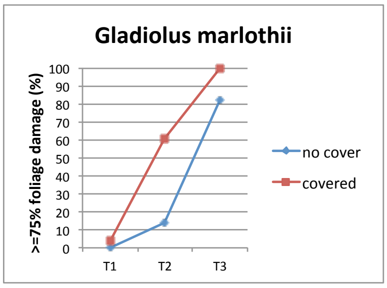

Gladiolus caryophyllaceus

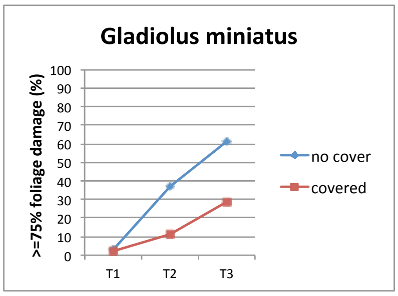

Gladiolus floribundus var. floribundus

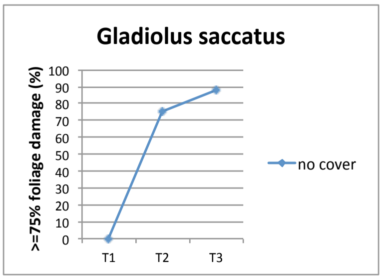

Gladiolus floribundus var. rudis

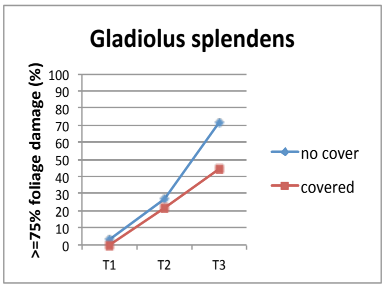

Gladiolus hirsutis

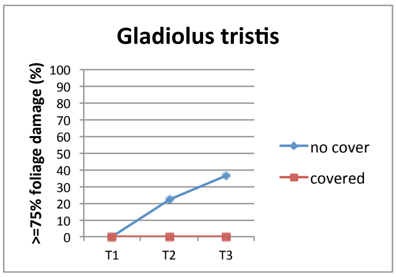

Gladiolus maculatus

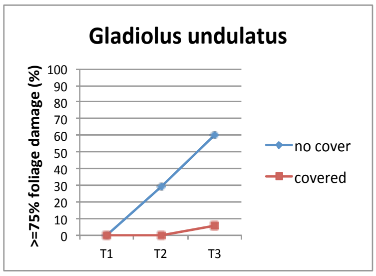

Gladiolus marlothii

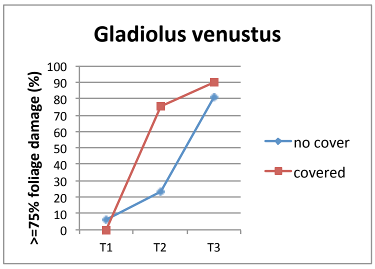

Gladiolus miniatus

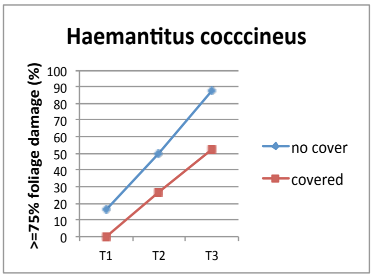

Gladiolus saccatus

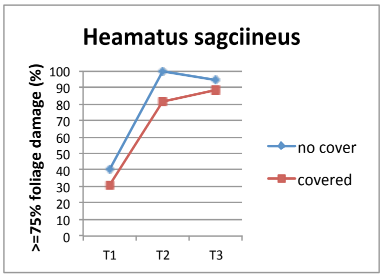

Gladiolus splendens

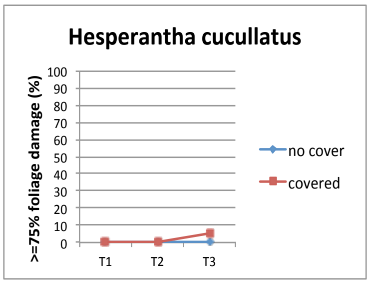

Gladiolus tristis

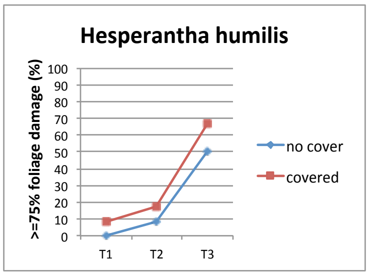

Gladiolus undulatus
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

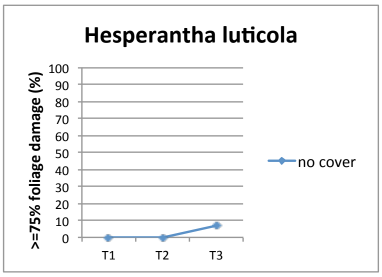

Gladiolus venustus
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

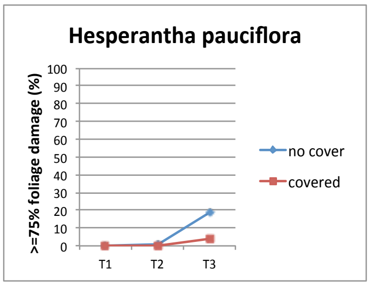

Haemantitus cocccineus
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

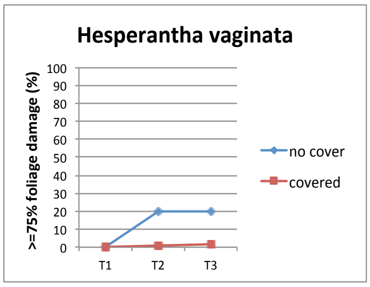

Heamatus sagciineus
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

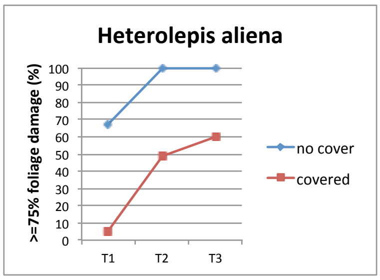

Hesperantha cucullatus
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

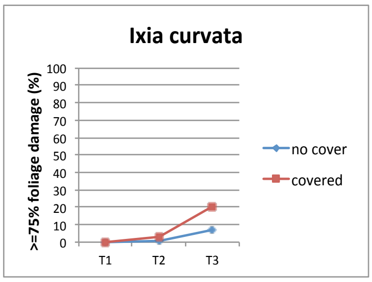

Hesperantha humilis
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

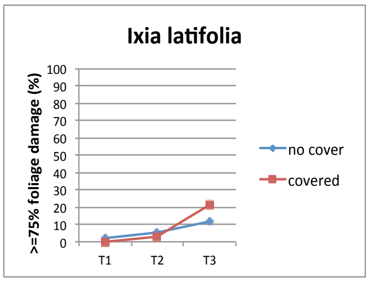

Hesperantha luticola
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover

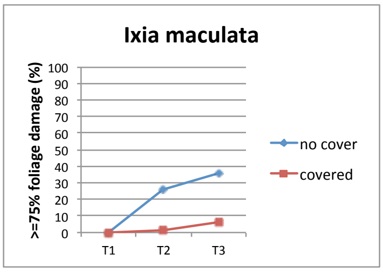

Hesperantha pauciflora
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

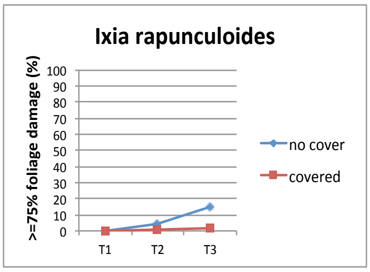

Hesperantha vaginata
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

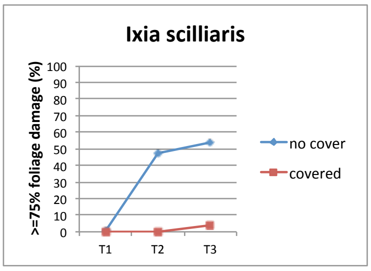

Heterolepis aliena
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

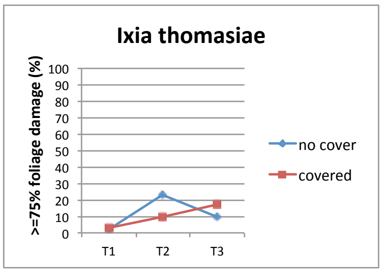

Ixia curvata
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

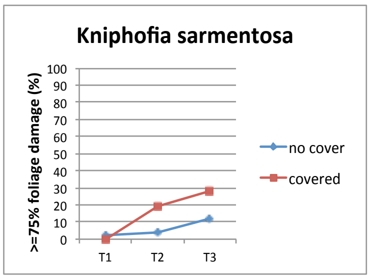

Ixia latifolia
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

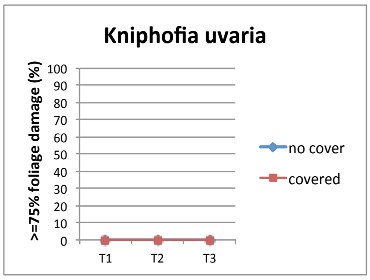

Ixia maculata
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

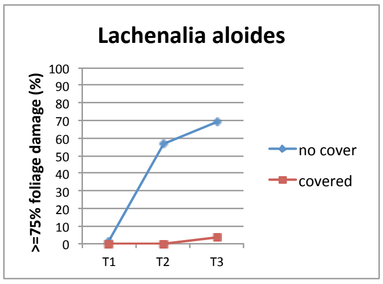

Ixia rapunculoides
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

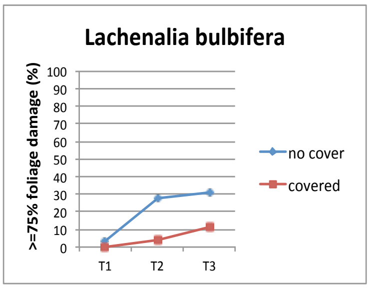

Ixia scilliaris
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

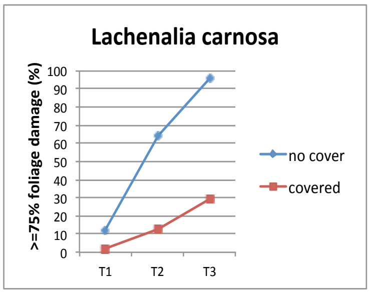

Ixia thomasiae
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

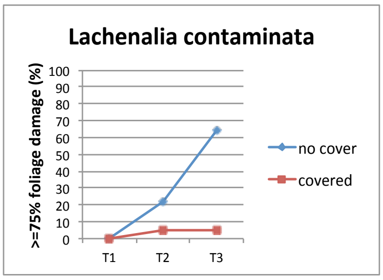

Kniphofia sarmentosa
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

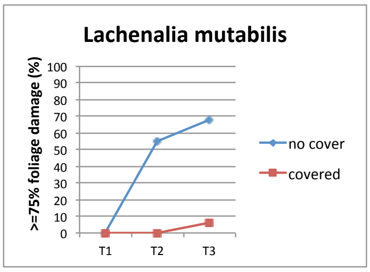

Kniphofia uvaria
>=75% foliage damage (%)
100 90 80 70 60 50 40 30 20 10 0
T1 T2 T3
no cover
covered

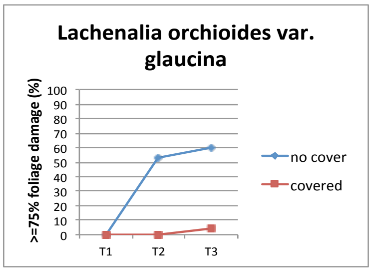

Lachenalia aloides
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

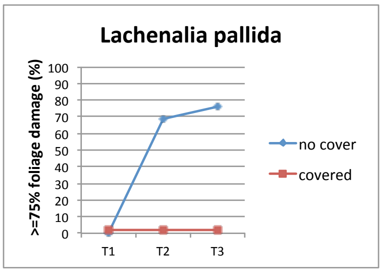

Lachenalia bulbifera
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

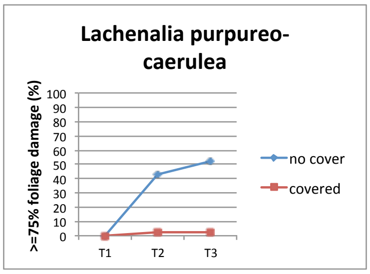

Lachenalia carnosa
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

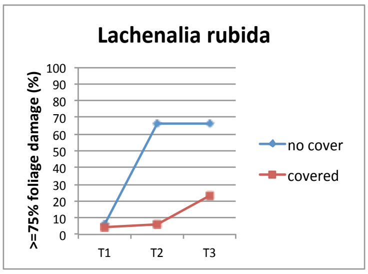

Lachenalia contaminata
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

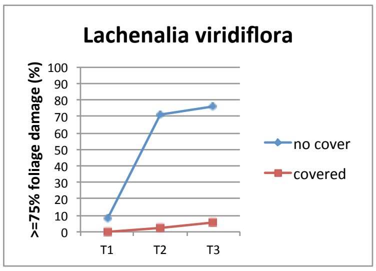

Lachenalia mutabilis
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

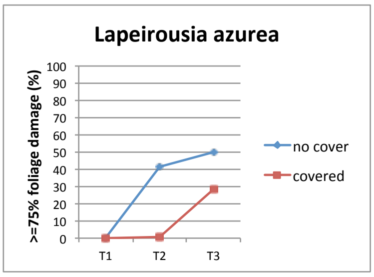

Lachenalia orchioides var. glaucina
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

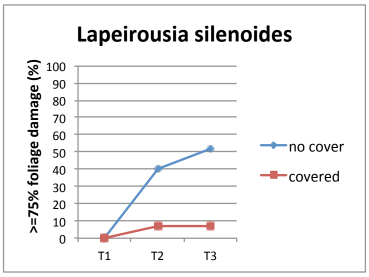

Lachenalia pallida
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

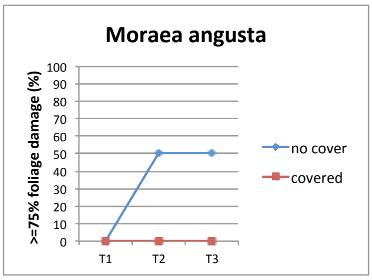

Lachenalia purpureo-caerulea
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

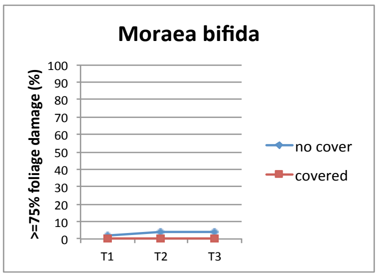

Lachenalia rubida
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

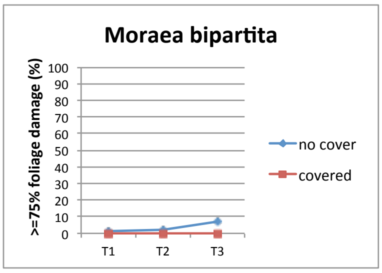

Lachenalia viridiflora
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

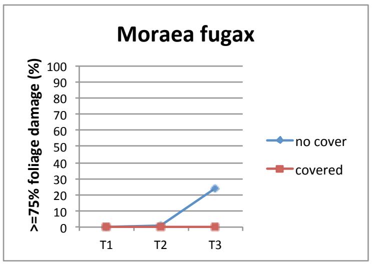

Lapeirousia azurea
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

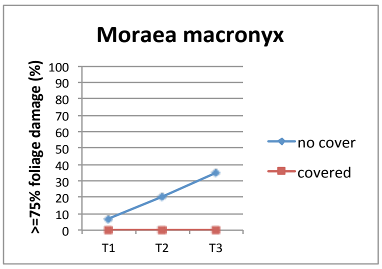

Lapeirousia silenoides
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

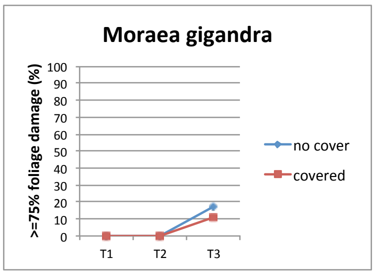

Moraea angusta
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

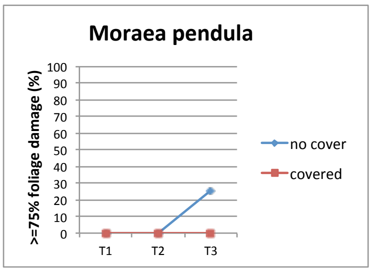

Moraea bifida
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

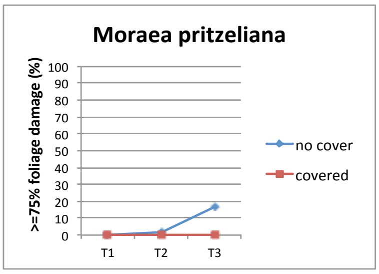

Moraea bipartita
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

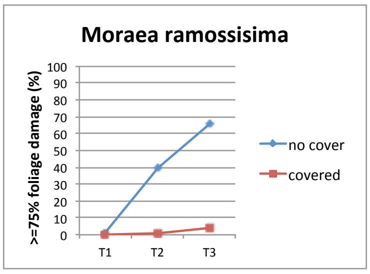

Moraea fugax
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

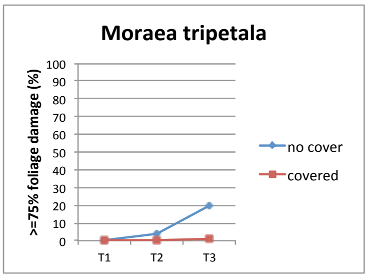

Moraea macronyx
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

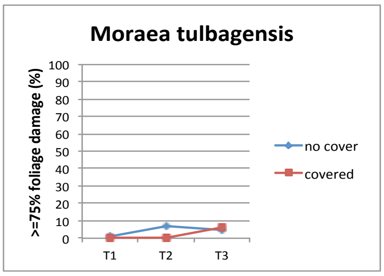

Moraea gigandra
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

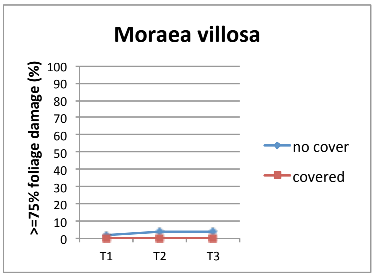

Moraea pendula

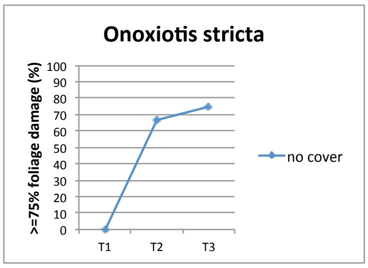

Moraea pritzeliana

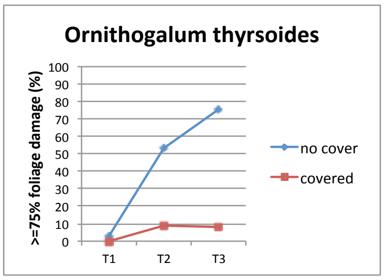

Moraea ramossisima

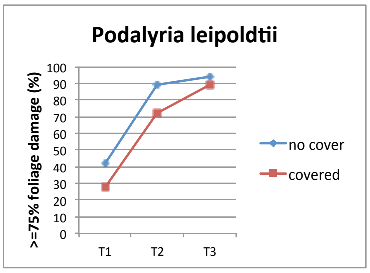

Moraea tripetala

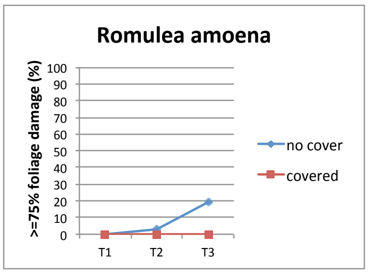

Moraea tulbagensis

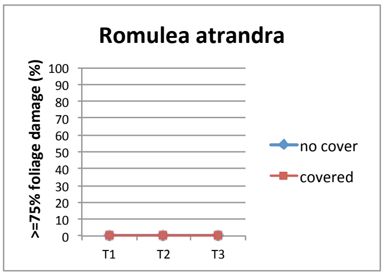

Moraea villosa

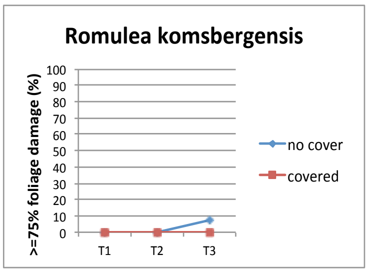

Onoxiotis stricta

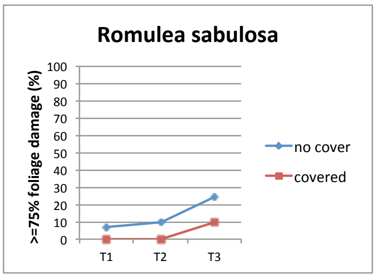

Ornithogalum thyrsoides

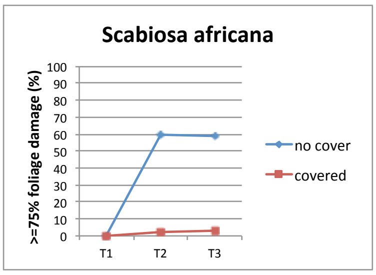

Podalyria leipoldtii

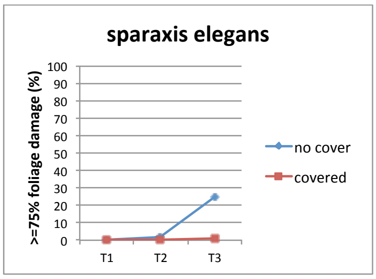

Romulea amoena

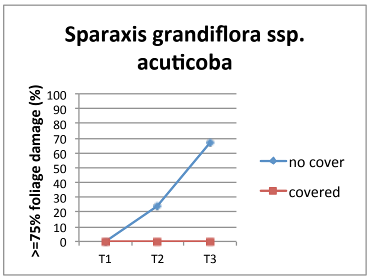

Romulea atrandra

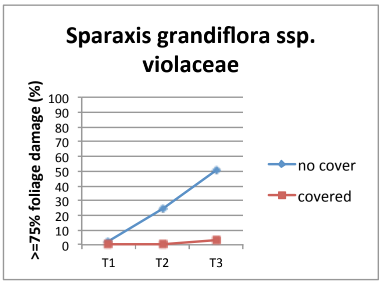

Romulea komsbergensis

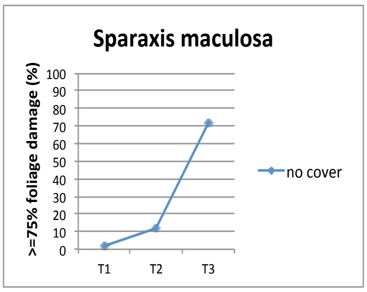

Romulea sabulosa

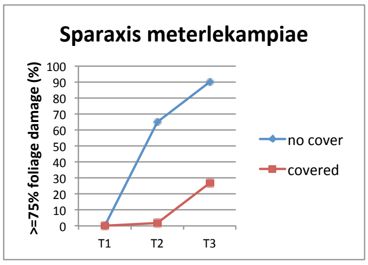

Scabiosa africana

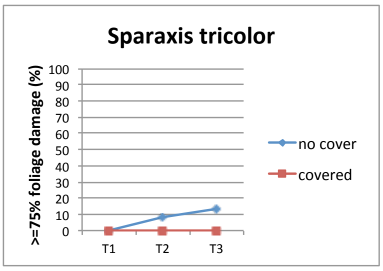

sparaxis elegans

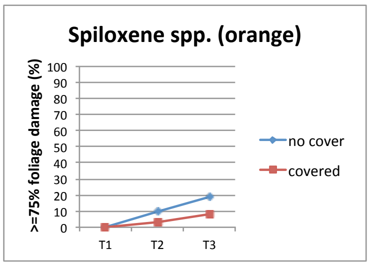

Sparaxis grandiflora ssp. acuticoba

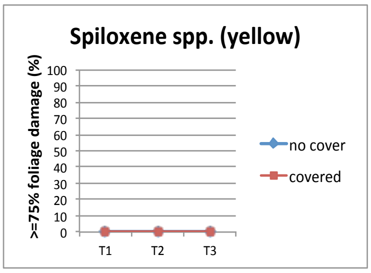

Sparaxis grandiflora ssp. violaceae

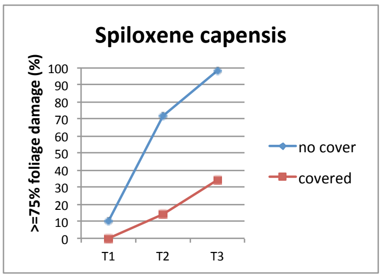

Sparaxis maculosa

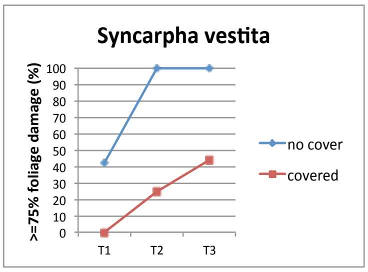

Sparaxis meterlekampiae
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

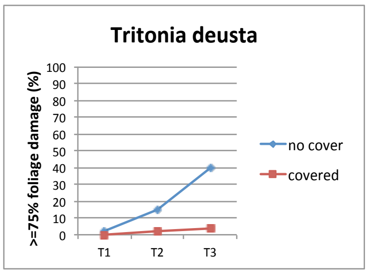

Sparaxis tricolor
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

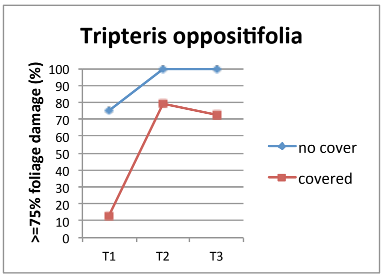

Spiloxene spp. (orange)
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

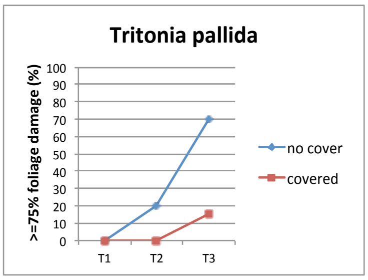

Spiloxene spp. (yellow)
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

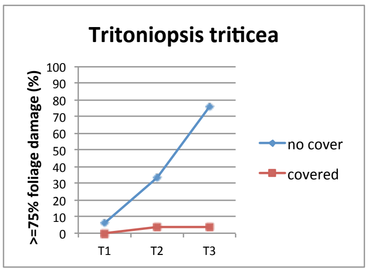

Spiloxene capensis
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

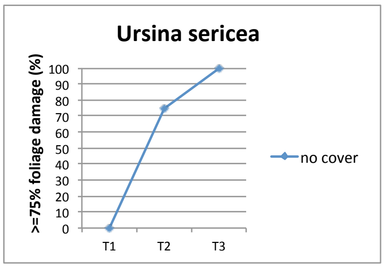

Syncarpha vestita
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

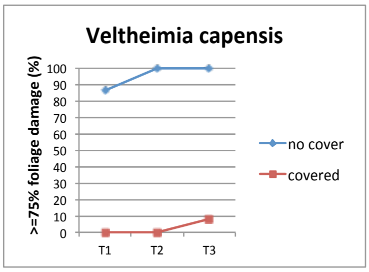

Tritonia deusta
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

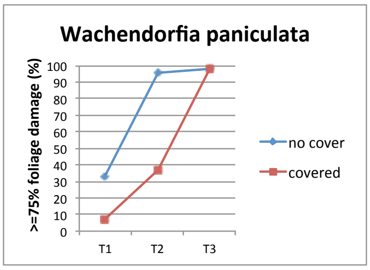

Tripteris oppositifolia
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

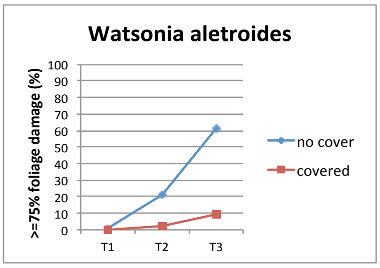

Tritonia pallida
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

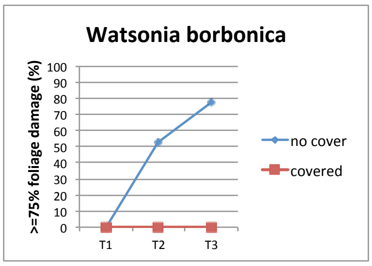

Tritoniopsis triticea
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

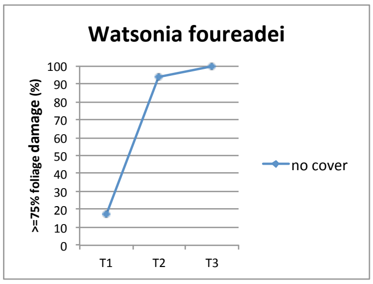

Ursina sericea
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover

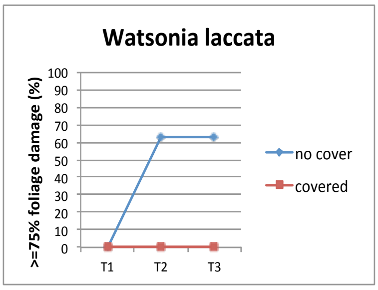

Veltheimia capensis
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

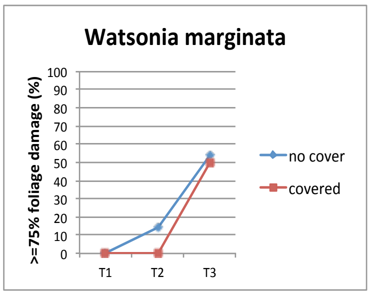

Wachendorfia paniculata
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

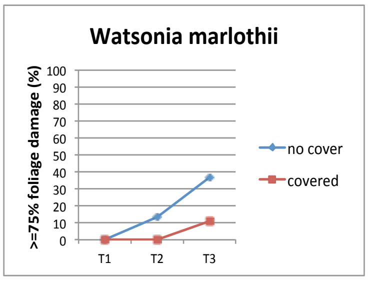

Watsonia aletroides
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

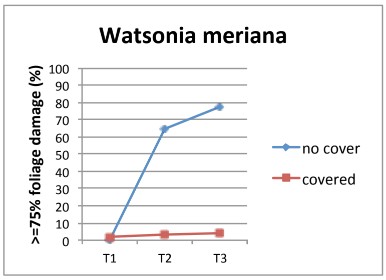

Watsonia borbonica
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

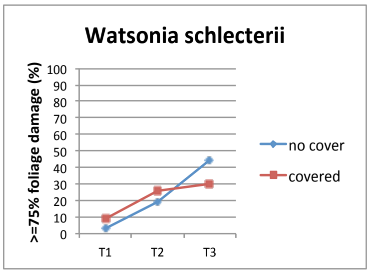

Watsonia foureadei
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover

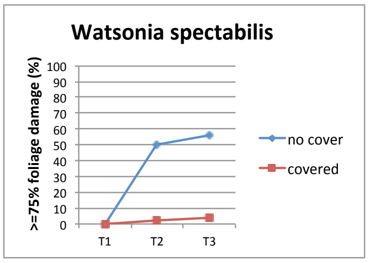

Watsonia laccata
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

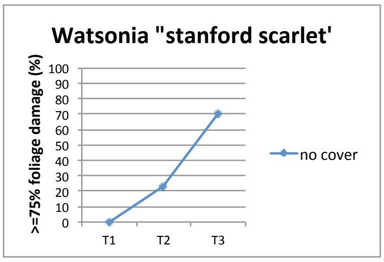

Watsonia marginata
>=75% foliage damage (%)
100
90
80
70
60
50
40
30
20
10
0
T1
T2
T3
no cover
covered

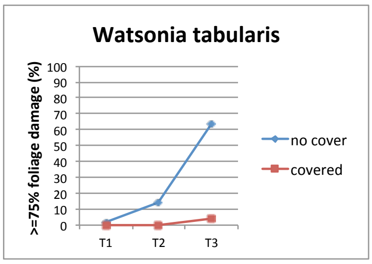


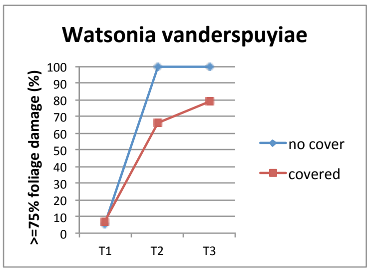


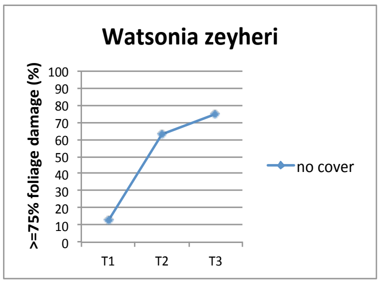












6.3.2 Growth and Flower Phenology of species tested in all these experiments

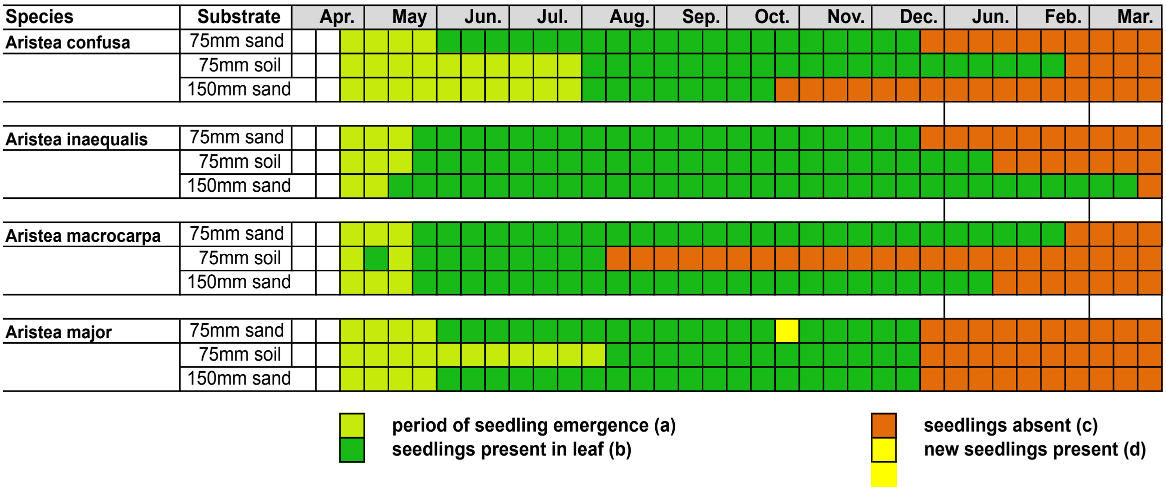
Based on the observations of Cummins (2010) and the author's preliminary experiments (Hang 2010), some forbs produce new leaves in autumn, this process de-accelerates in winter and is then boosted again in the following summer. This was the pattern in *Dimorphotheca*, while some other forbs produced most of their above ground growth in spring and summer, such as *Gazania*. Small wither-growing deciduous geophytes largely completed their growth in winter and flowered in spring before entered into dormancy in early summer, such as *Romulea* and *Sparaxis*. Large winter-growing deciduous geophytes grew in winter and spring, flowered in spring to summer (i.e. *Bulbinella*).

Fresh leaves of *Bulbinellas* were very attravtive to slugs and snails, with tips of which were eaten frequently. Applying slug and snail killers every 2 weeks to the seedlings helped reducing the damage. Aphids were found attacking the seedlings of many geophytes, especially *Romuleas*.

Ladybugs were collected to deal with the issue as they are natural predators of aphids.

In the preliminary experiment, all the everygreen *Aristea* species were sensitive to winter cold died out during their first winter in Sheffield in 2010 (see Table 6.1). In Table 6.2, seeds of most deciduous geophyte species that didn't germinate in spring sowing germinated in autumn when the temperature declined (represented as pale green in the table). Some spring growing species stretched their growing season till summer and reshooted after a very short dormancy period in autumn, such as *Watsonia borbonica*. Individuals of some others even didn't experience any dormancy if sown in spring, such as *Gladiolus tristis* and *Bulbinella nutans*.

Table 6.1 Germination, Growth and Flower phenology of evergreen geophyte species (*Aristea*) in preliminary experiment. The seeds were sown on 8th March 2010, and the observation window was between 1st April 2010 and 30th March 2011.



Germination and growing periods of evergreen species (Aristeas) **(recored from 01/04/2010 to 30/03/2011)**

Species	Substrate	Apr.			May			Jun.			Jul.			Aug.			Sep.			Oct.			Nov.			Dec.			Jun.			Feb.			Mar.		
Aristea confusa	75mm sand			a	a	a	a	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	c	c	c	c	c	c	c	c	c	c
	75mm soil			a	a	a	a	a	a	a	a	a	a	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	c	c	c	c
	150mm sand			a	a	a	a	a	a	a	a	a	a	b	b	b	b	b	b	b	b	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c
Aristea inaequalis	75mm sand			a	a	a	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	c	c	c	c	c	c	c	c	c	c
	75mm soil			a	a	a	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	c	c	c	c	c	c	c
	150mm sand			a	a	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	c
Aristea macrocarpa	75mm sand			a	a	a	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	c	c	c	c
	75mm soil			a	b	a	b	b	b	b	b	b	b	b	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c
	150mm sand			a	a	a	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	c	c	c	c	c	c	c
Aristea major	75mm sand			a	a	a	a	b	b	b	b	b	b	b	b	b	b	b	b	b	b	d	b	b	b	b	b	c	c	c	c	c	c	c	c	c	c
	75mm soil			a	a	a	a	a	a	a	a	a	a	a	b	b	b	b	b	b	b	b	b	b	b	b	b	c	c	c	c	c	c	c	c	c	c
	150mm sand			a	a	a	a	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	c	c	c	c	c	c	c	c	c	c

period of seedling emergence (a)
seedlings present in leaf (b)
seedlings absent (c)
new seedlings present (d)

(note: 24th Dec.2010 min. night temp. in Sheffield city -8°C)
(a)=during this time new seedlings continued to be found in at least one replicate.
(b)=during this period seedlings maintained green leaves, but no additional emergence recorded in any replicate.
(c)=all seedlings were died.
(d)=during this period additional emergence from seed occurred in some species.

Table 6.2 Germination, Growth and Flower phenology of deciduous geophyte species in preliminary experiment. The seeds were sown on 8th March 2010, and the observation window was between 1st April 2010 and 30th March 2011.

Dormancy and germination periods of deciduous species (recored from 08/03/2010 to 20/05/2011)

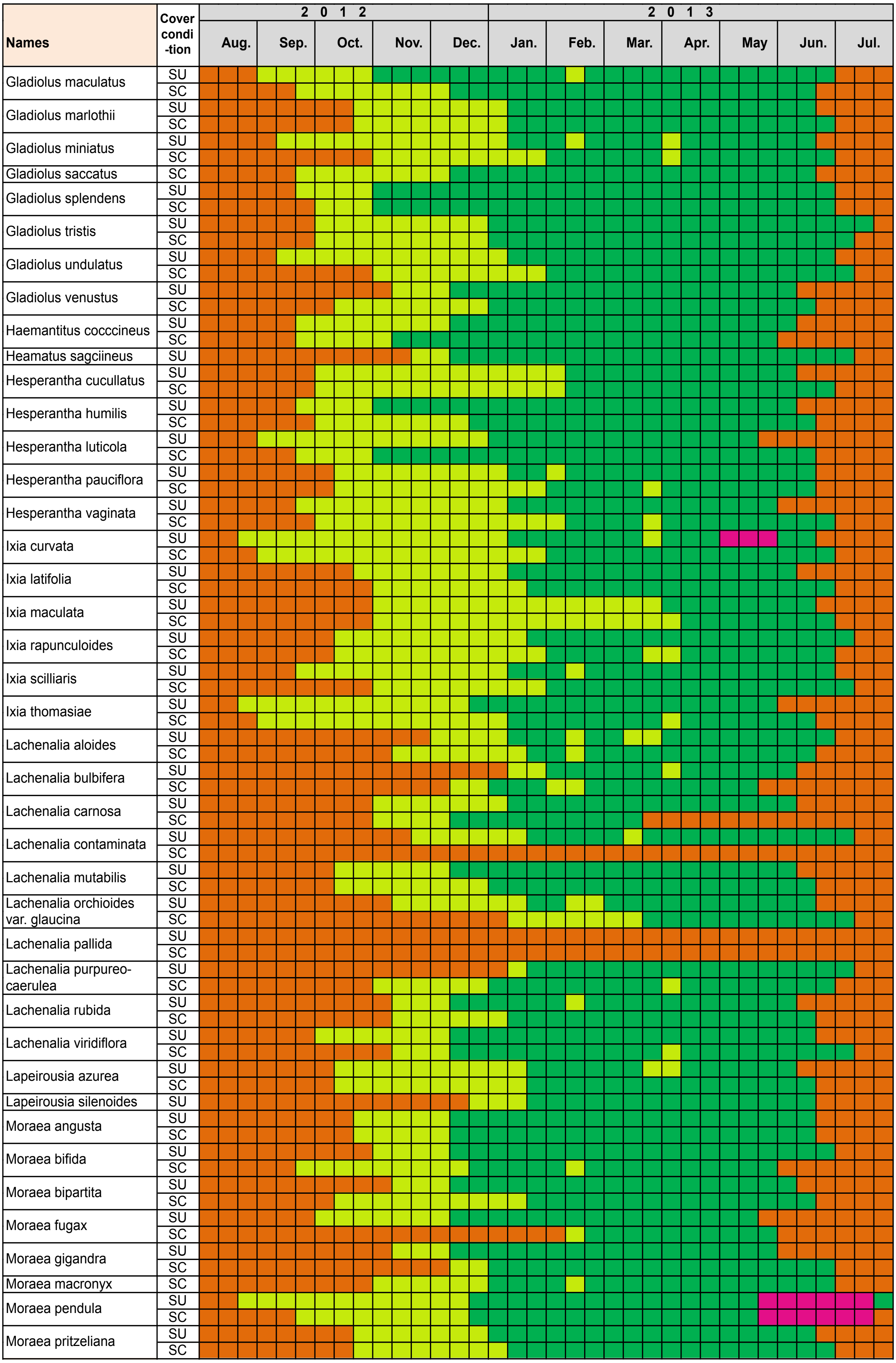
Species	Substrate	Jan.			Feb.			Mar.			Apr.			May			Jun.			Jul.			Aug.			Sep.			Oct.			Nov.			Dec.			Jan.			Feb.			Mar.			Apr.			May		
Babiana villosa	75mm sand							●				🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟧	🟧	🟧	🟧	🟫	🟫	⬜	⬜	🟫	
	75mm soil							●				🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	
	150mm sand							●				🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟫	⬜	⬜	🟧	🟧	🟧	🟫	⬜	⬜	⬜	⬜	⬜	
Bulbinella latifolia	75mm sand							●				🟨	🟨	🟩	🟩	🟨	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	🟧	
	75mm soil							●						🟨	🟨	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	
	150mm sand							●				🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟧	🟧	
Bulbinella nutans	75mm sand							●				🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟧	🟧	
	75mm soil							●				🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟫	🟩	🟩	🟩	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟫	
	150mm sand							●					🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟧	🟧	
Geissorhiza splendidissima	75mm sand							●				🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟧	🟧	
	75mm soil							●				🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟧	🟧	
	150mm sand							●				🟨	🟨	🟨	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟧	🟧	
Gladiolus carneus	75mm sand							●				🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	🟫	🟫	⬜	⬜	⬜	⬜	🟫	🟫	🟫	🟫	⬜	
	75mm soil							●				🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	
	150mm sand							●					🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟫	🟩	🟩	🟩	🟩	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	
Gladiolus floribundus	75mm sand							●				🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟫	🟫	⬜	⬜	⬜	⬜	⬜	🟫	
	75mm soil							●				🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	
	150mm sand							●				🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟫	🟫	⬜	⬜	⬜	
Gladiolus tristis	75mm sand							●				🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	🟫	🟫	🟫	🟫	🟫	🟫	
	75mm soil							●				🟨	🟨	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	🟫	🟫	🟫	🟫	⬜	
Ixia curvata	75mm sand							●					🟨	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	
	75mm soil							●					🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	
	150mm sand							●						🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	
Lachenalia orchioides var. glaucina	75mm sand							●					🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	🟧	🟧	🟧	🟧	
	75mm soil							●					🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	
	150mm sand							●					🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	⬜	⬜	⬜	⬜	⬜	🟧	🟧	🟧	🟧	
Sparaxis elegans	75mm sand							●				🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	🟫	
	75mm soil							●			🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	🟫	
	150mm sand							●				🟨	🟨	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	🟫	⬜	⬜	🟫	
Wachendorfia paniculata	75mm sand							●			🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	🟫	🟫	
	75mm soil							●			🟨	🟨	🟨	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	🟫	
	150mm sand							●			🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	
Watsonia alethroides	75mm sand							●			🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	
	75mm soil							●			🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	
	150mm sand							●			🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	🟫	
Watsonia borbonica	75mm sand							●			🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	🟫	⬜	⬜	⬜	⬜	⬜	🟫	🟫	🟫	🟫	⬜	
	75mm soil							●			🟨	🟨	🟨	🟩	🟩	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	
	150mm sand							●			🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	
Watsonia fergusoniae	75mm sand							●			🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	
	75mm soil							●			🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	🟫	
	150mm sand							●			🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟧	🟧	🟫	⬜	🟧	🟧	🟧	
Watsonia laccata	75mm sand							●			🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟫	🟫	🟫	🟫	⬜	
	75mm soil							●			🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	🟫	🟫	🟫	🟫	⬜	⬜	🟫	🟫	🟫	🟫	
	150mm sand							●			🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	🟫	🟫	🟫	⬜	
Watsonia marginata	75mm sand							●			🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟫	⬜	
	75mm soil							●			🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	🟫	🟫	🟫	🟫	🟫	🟫	🟫	⬜	⬜	⬜	⬜	⬜	🟫	
	150mm sand							●			🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	⬜	⬜	⬜	⬜	⬜	🟫	🟫	⬜	⬜	⬜	⬜	⬜	🟫	🟫	🟫	🟫	⬜	⬜	⬜	
Watsonia vanderspuyiae	75mm sand							●			🟨	🟨	🟨	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	
	75mm soil							●			🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	
	150mm sand							●			🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟫	🟫	🟫	🟫	⬜	

● seeds were sown on 8th March, 2010
🟨 period of seedling emergence (a)
🟩 seedlings present in leaf (b)
🟧 seedlings absent (c)
🟫 old and new seedlings present (d)
⬜ yr.1 seedlings present but no new seedlings appear

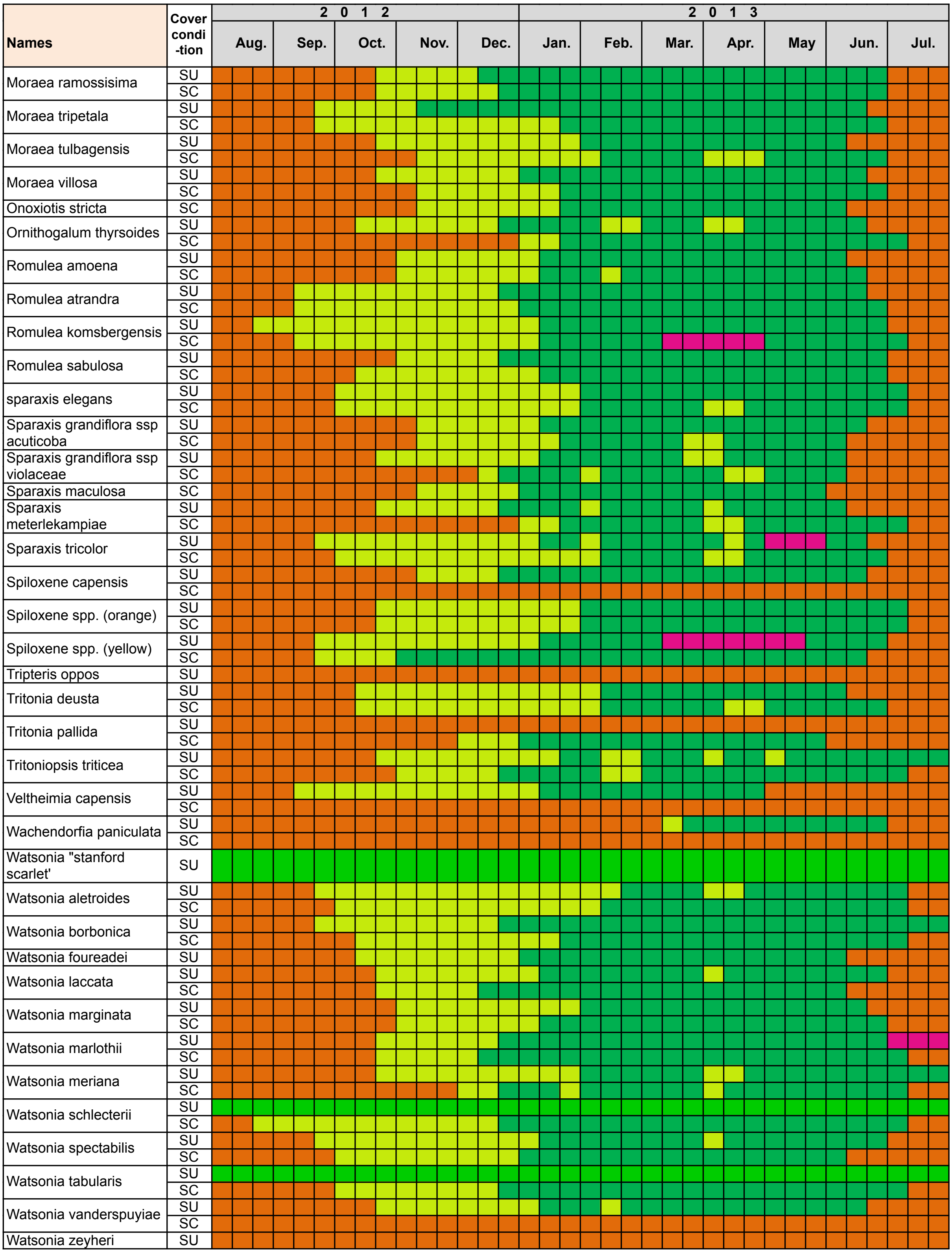
(note: 24th Apr.2011 hailstone occurred in Sheffield city)
(a)=during this time new seedlings continued to be found in at least one replicate.
(b)=during this period seedlings maintained green leaves, but no additional emergence recorded in any replicate.
(c)=seedlings were died, or went into dormancy.
(d)=during this period new leaves were produced for existing corms and additional emergence from seed occurred in some species.

Table 6.3 Re-emergence, growth and flowering phenology of species in Winter Cold and Summer Wetness Experiment Phase 1. The seeds were sown in various time before winter 2011, and the observation window was between 1st August 2012 and 31th July 2013.

Names	Cover condi -tion	2012															2013																				
		Aug.			Sep.			Oct.			Nov.			Dec.			Jan.			Feb.			Mar.			Apr.			May			Jun.			Jul.		
Albuca clanwilliamgloria	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Amaryllis belladonna	SU	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Babiana ambigua	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Babiana angustifolia	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Babiana cuneata	SU	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Babiana fragrans	SU	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟨	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Babiana ringens	SU	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Babiana sambucifolia	SU	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟪	🟩	🟩	🟩	🟧	🟧	🟧
	SC	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Babiana thunbergii	SU	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Babiana vanzyliae	SU	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Babiana villosa	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Brynsvigia bosmaniae	SU	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Bulbinella caudis-felis	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧
Bulbinella eburnifolia	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Bulbinella elata	SU	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
Bulbinella elegans	SU	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Bulbinella latifolia var doleritica	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Bulbinella latifolia var latifolia	SU	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Bulbinella nutans	SU	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧
	SC	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Daubenya aurea	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Freesia caryophyllacea	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Freesia corymbosa	SU	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Freesia fergusoniae	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
Freesia furcata	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Geissorhiza aspera	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟨	🟩	🟩	🟩	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
Geissorhiza inflexa red	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Geissorhiza splendidissima	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Geissorhiza tulbaghensis	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Gladiolus cardinalis	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Gladiolus carinatus	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
Gladiolus carneus	SU	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟪	🟪	🟩	🟩	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Gladiolus carneus var. macowan	SU	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Gladiolus caryophyllaceus	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Gladiolus floribundus var floribundus	SU	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Gladiolus floribundus var rudis	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Gladiolus hirsutis	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧



Names	Cover condi-tion	2012															2013																				
		Aug.			Sep.			Oct.			Nov.			Dec.			Jan.			Feb.			Mar.			Apr.			May			Jun.			Jul.		
Gladiolus maculatus	SU	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Gladiolus marlothii	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Gladiolus miniatus	SU	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Gladiolus saccatus	SC	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Gladiolus splendens	SU	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Gladiolus tristis	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Gladiolus undulatus	SU	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Gladiolus venustus	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Haemantitus cocccineus	SU	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧
Heamatus sagciineus	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Hesperantha cucullatus	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Hesperantha humilis	SU	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Hesperantha luticola	SU	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Hesperantha pauciflora	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Hesperantha vaginata	SU	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Ixia curvata	SU	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟪	🟪	🟪	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Ixia latifolia	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Ixia maculata	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Ixia rapunculoides	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Ixia scilliaris	SU	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Ixia thomasiae	SU	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Lachenalia aloides	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Lachenalia bulbifera	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Lachenalia carnosa	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Lachenalia contaminata	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Lachenalia mutabilis	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Lachenalia orchioides var. glaucina	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Lachenalia pallida	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Lachenalia purpureo-caerulea	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Lachenalia rubida	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Lachenalia viridiflora	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧
Lapeirousia azurea	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Lapeirousia silenoides	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Moraea angusta	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Moraea bifida	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧
Moraea bipartita	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
Moraea fugax	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧
Moraea gigandra	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Moraea macronyx	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧
Moraea pendula	SU	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟪	🟪	🟪	🟪	🟪	🟪	🟩
	SC	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟪	🟪	🟪	🟪	🟪	🟪	🟧
Moraea pritzeliana	SU	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧
	SC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟧



Names	Cover condi -tion
Moraea ramossisima	SU SC
Moraea tripetala	SU SC
Moraea tulbagensis	SU SC
Moraea villosa	SU SC
Onoxiotis stricta	SC
Ornithogalum thyrsoides	SU SC
Romulea amoena	SU SC
Romulea atrandra	SU SC
Romulea komsbergensis	SU SC
Romulea sabulosa	SU SC
sparaxis elegans	SU SC
Sparaxis grandiflora ssp acuticoba	SU SC
Sparaxis grandiflora ssp violaceae	SU SC
Sparaxis maculosa	SC
Sparaxis meterlekampiae	SU SC
Sparaxis tricolor	SU SC
Spiloxene capensis	SU SC
Spiloxene spp. (orange)	SU SC
Spiloxene spp. (yellow)	SU SC
Tripteris oppos	SU
Tritonia deusta	SU SC
Tritonia pallida	SU SC
Tritoniopsis triticea	SU SC
Veltheimia capensis	SU SC
Wachendorfia paniculata	SU SC
Watsonia "stanford scarlet'	SU
Watsonia aletroides	SU SC
Watsonia borbonica	SU SC
Watsonia foureadei	SU
Watsonia laccata	SU SC
Watsonia marginata	SU SC
Watsonia marlothii	SU SC
Watsonia meriana	SU SC
Watsonia schlecterii	SU SC
Watsonia spectabilis	SU SC
Watsonia tabularis	SU SC
Watsonia vanderspuyiae	SU SC
Watsonia zeyheri	SU

SU	blocks uncovered in Sumer 2012
SC	blocks covered in summer 2012
🟧	dominant period
🟨	reshooting period
🟩	evergreen species stay green
🟩	foliages present period without any more reshooting foliage coming out
🟪	flowering period

Note: coveres were taken away on 15th August 2012, summer covered blocks were watered and soaked immedietly on the day, and once a week if there was not any significant rain weekly.

Fig. 6.7 The preliminary experiment was sown on 8th March 2010, and: (left) *Gladiolus tristis* first flowered in July 2011 (16 months after sowing), and still performed well in the 4th growing season in all treatments and was particularly good in 75mm sand and soil. Image taken on 28th April 2014); (middle) *Sparaxis elegans* first time flowered in April 2012 with leaves and petals damaged by frost (photo taken on 30th April 2014); (right) *Gladiolus carneus* produced first flowers in summer 2012 (photo taken on 21st June 2012).

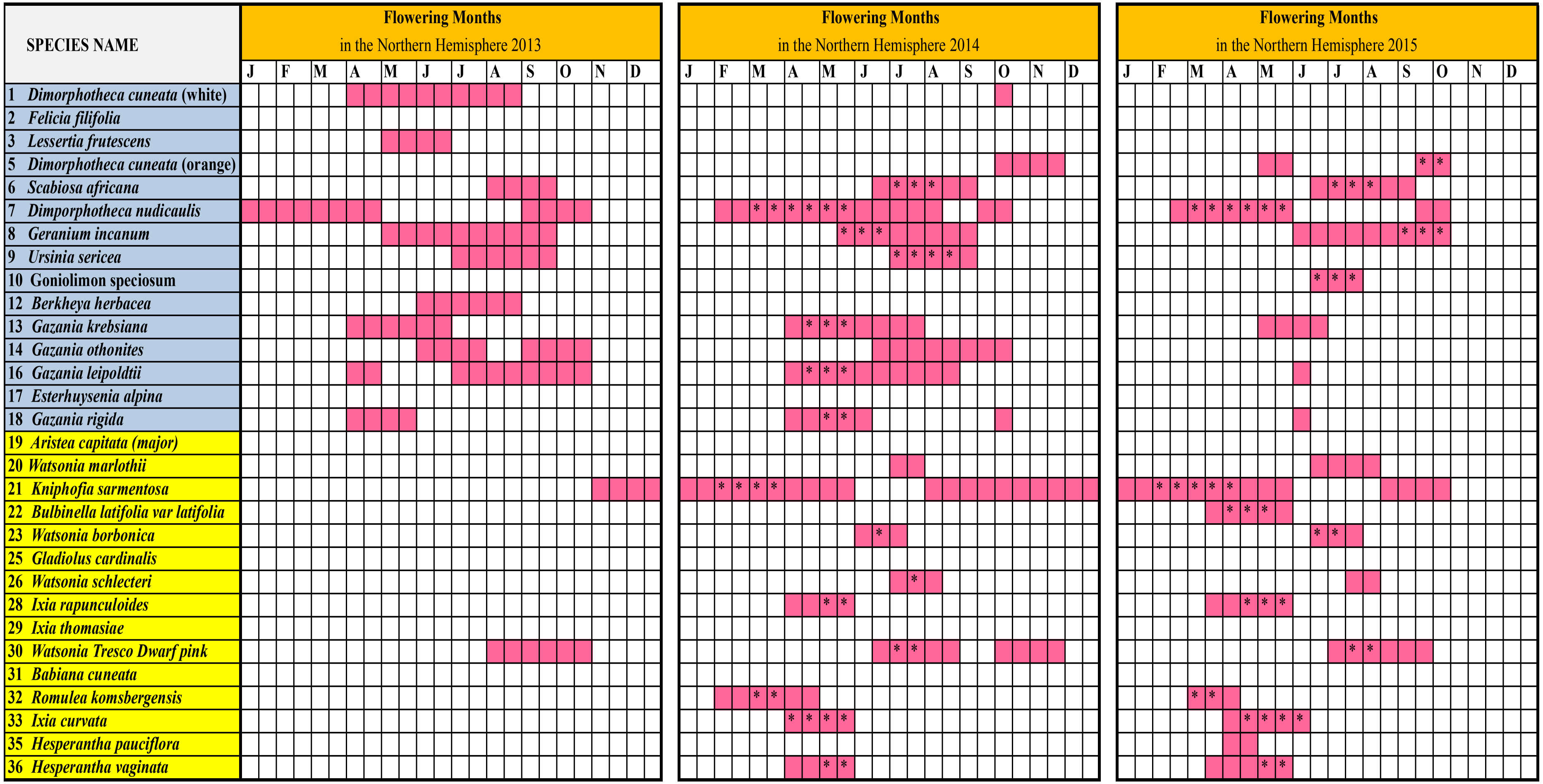
Gladiolus tristis and *Gladiolus carneus* normally grow in winter and produce flowers in spring. However, in Sheffield because the conditions much wetter then their habitats they extend their growing season and shorten their dormant period.

In the competition experiment, soon after establishment, fast growing plants began to expand the foliage coverage and occupy the space. Winter growing geophytes produced new vegetative growth rapidly as soon as temperatures begin to drop in autumn, which extended into winter. When the weather warmed and daylight lengthened, flowers started to display. The initial flowering species was *Kniphofia sarmentosa* with its main blooming period in January and February 2014 (sown in autumn 2012), although few individuals flowered in November and December 2013. *Romulea komsbergensis* then bloomed from February to April 2014, however, the main display was in March, which followed by *Ixia curvata, Ixia rapunculoides, Hesperantha vaginata,* and evergreen daises *Gazania krebsiana, Gazania leipoldtii, Gazania rigida.* Meanwhile, *Kniphofia sarmentosa* and *Dimporphotheca nudicaulis* were still flowering. Evergreen species

Kniphofia sarmentosa continued growing and the latest flower was recorded at the end of May 2014 (Fig.6.8), while few plants of which performed as more or less semi-evergreens after fruiting.

Fig. 6.8 Tall geophytes *Kniphofia* and *Bulbinella* produced very long inflorescences which support the flowers to start flowering from the bottom to the top, providing a much longer display season. (left) image taken on 23th March 2013, *Kniphofia sarmentosa* started flowering in November 2012 and had flowered for nearly 7 months; (right) *Bulbinella latifolia* var. *latifolia* produced inflorescence upto 35cm long and flowered from mid-March to the end of May (image taken on 4th May 2015).

Table 6.4 Flowering period recorded in Competition Experiment. The communities were established in 2012, the observation of flowering display windows were recorded in year one (2013), year two (2014) and year three (2015).



SPECIES NAME	Flowering Months in the Northern Hemisphere 2013																							
	J		F		M		A		M		J		J		A		S		O		N		D	
1 *Dimorphotheca cuneata* (white)							🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥								
2 *Felicia filifolia*																								
3 *Lessertia frutescens*									🟥	🟥	🟥	🟥												
5 *Dimorphotheca cuneata* (orange)																								
6 *Scabiosa africana*															🟥	🟥	🟥	🟥						
7 *Dimporphotheca nudicaulis*	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥									🟥	🟥	🟥	🟥				
8 *Geranium incanum*									🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥						
9 *Ursinia sericea*													🟥	🟥	🟥	🟥	🟥	🟥						
10 Goniolimon speciosum																								
12 *Berkheya herbacea*											🟥	🟥	🟥	🟥	🟥	🟥								
13 *Gazania krebsiana*							🟥	🟥	🟥	🟥	🟥	🟥												
14 *Gazania othonites*											🟥	🟥	🟥	🟥			🟥	🟥	🟥	🟥				
16 *Gazania leipoldtii*							🟥	🟥					🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥				
17 *Esterhuysenia alpina*																								
18 *Gazania rigida*							🟥	🟥	🟥	🟥														
19 *Aristea capitata (major)*																								
20 *Watsonia marlothii*																								
21 *Kniphofia sarmentosa*																					🟥	🟥	🟥	🟥
22 *Bulbinella latifolia var latifolia*																								
23 *Watsonia borbonica*																								
25 *Gladiolus cardinalis*																								
26 *Watsonia schlecteri*																								
28 *Ixia rapunculoides*																								
29 *Ixia thomasiae*																								
30 *Watsonia Tresco Dwarf pink*															🟥	🟥	🟥	🟥	🟥	🟥				
31 *Babiana cuneata*																								
32 *Romulea komsbergensis*																								
33 *Ixia curvata*																								
35 *Hesperantha pauciflora*																								
36 *Hesperantha vaginata*																								

SPECIES NAME	Flowering Months in the Northern Hemisphere 2014																							
	J		F		M		A		M		J		J		A		S		O		N		D	
1 *Dimorphotheca cuneata* (white)																			🟥					
2 *Felicia filifolia*																								
3 *Lessertia frutescens*																								
5 *Dimorphotheca cuneata* (orange)																			🟥	🟥	🟥	🟥		
6 *Scabiosa africana*												🟥	🟥*	🟥*	🟥*	🟥	🟥							
7 *Dimporphotheca nudicaulis*			🟥	🟥	🟥*	🟥*	🟥*	🟥*	🟥*	🟥*	🟥	🟥	🟥	🟥	🟥			🟥	🟥					
8 *Geranium incanum*										🟥*	🟥*	🟥*	🟥	🟥	🟥	🟥	🟥							
9 *Ursinia sericea*													🟥*	🟥*	🟥*	🟥*	🟥							
10 Goniolimon speciosum																								
12 *Berkheya herbacea*																								
13 *Gazania krebsiana*							🟥	🟥*	🟥*	🟥*	🟥	🟥	🟥	🟥										
14 *Gazania othonites*												🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥					
16 *Gazania leipoldtii*							🟥	🟥*	🟥*	🟥*	🟥	🟥	🟥	🟥	🟥	🟥								
17 *Esterhuysenia alpina*																								
18 *Gazania rigida*							🟥	🟥	🟥*	🟥*	🟥								🟥					
19 *Aristea capitata (major)*																								
20 *Watsonia marlothii*													🟥	🟥										
21 *Kniphofia sarmentosa*	🟥	🟥	🟥*	🟥*	🟥*	🟥*	🟥	🟥	🟥	🟥					🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
22 *Bulbinella latifolia var latifolia*																								
23 *Watsonia borbonica*											🟥	🟥*	🟥											
25 *Gladiolus cardinalis*																								
26 *Watsonia schlecteri*													🟥	🟥*	🟥									
28 *Ixia rapunculoides*							🟥	🟥	🟥*	🟥*														
29 *Ixia thomasiae*																								
30 *Watsonia Tresco Dwarf pink*												🟥	🟥*	🟥*	🟥	🟥			🟥	🟥	🟥	🟥		
31 *Babiana cuneata*																								
32 *Romulea komsbergensis*			🟥	🟥	🟥*	🟥*	🟥	🟥																
33 *Ixia curvata*							🟥*	🟥*	🟥*	🟥*														
35 *Hesperantha pauciflora*																								
36 *Hesperantha vaginata*							🟥	🟥	🟥*	🟥*														

SPECIES NAME	Flowering Months in the Northern Hemisphere 2015																							
	J		F		M		A		M		J		J		A		S		O		N		D	
1 *Dimorphotheca cuneata* (white)																								
2 *Felicia filifolia*																								
3 *Lessertia frutescens*																								
5 *Dimorphotheca cuneata* (orange)									🟥	🟥								🟥*	🟥*					
6 *Scabiosa africana*												🟥	🟥*	🟥*	🟥*	🟥	🟥							
7 *Dimporphotheca nudicaulis*				🟥	🟥*	🟥*	🟥*	🟥*	🟥*	🟥*								🟥	🟥					
8 *Geranium incanum*											🟥	🟥	🟥	🟥	🟥	🟥	🟥*	🟥*	🟥*					
9 *Ursinia sericea*																								
10 Goniolimon speciosum												🟥*	🟥*	🟥*										
12 *Berkheya herbacea*																								
13 *Gazania krebsiana*									🟥	🟥	🟥	🟥												
14 *Gazania othonites*																								
16 *Gazania leipoldtii*											🟥													
17 *Esterhuysenia alpina*																								
18 *Gazania rigida*											🟥													
19 *Aristea capitata (major)*																								
20 *Watsonia marlothii*												🟥	🟥	🟥	🟥									
21 *Kniphofia sarmentosa*	🟥	🟥	🟥*	🟥*	🟥*	🟥*	🟥*	🟥	🟥	🟥						🟥	🟥	🟥	🟥					
22 *Bulbinella latifolia var latifolia*						🟥	🟥*	🟥*	🟥*	🟥														
23 *Watsonia borbonica*												🟥*	🟥*	🟥										
25 *Gladiolus cardinalis*																								
26 *Watsonia schlecteri*														🟥	🟥									
28 *Ixia rapunculoides*						🟥	🟥	🟥*	🟥*	🟥*														
29 *Ixia thomasiae*																								
30 *Watsonia Tresco Dwarf pink*													🟥	🟥*	🟥*	🟥	🟥	🟥						
31 *Babiana cuneata*																								
32 *Romulea komsbergensis*					🟥*	🟥*	🟥																	
33 *Ixia curvata*							🟥	🟥*	🟥*	🟥*	🟥*													
35 *Hesperantha pauciflora*							🟥	🟥																
36 *Hesperantha vaginata*						🟥	🟥	🟥	🟥*	🟥*														

6.3.3 Community structure

The interval image recordings showed the change in plant size and their competitive capacity in the communities. The spatial change of each combination was various. As shown in Figure 6.9 (left) below, phenology of weed invension was recorded in low geophytes only mix in summer 2014. The plants were too small and foliage disappeared during the summer dormancy period, which allowed weeds to quickly occupy the space and dominate this community. In Figure 6.9 (right), the following year, the community was still very weedy but many small geophytes in the mix grew through the weed layer and displayed their flowers in May.

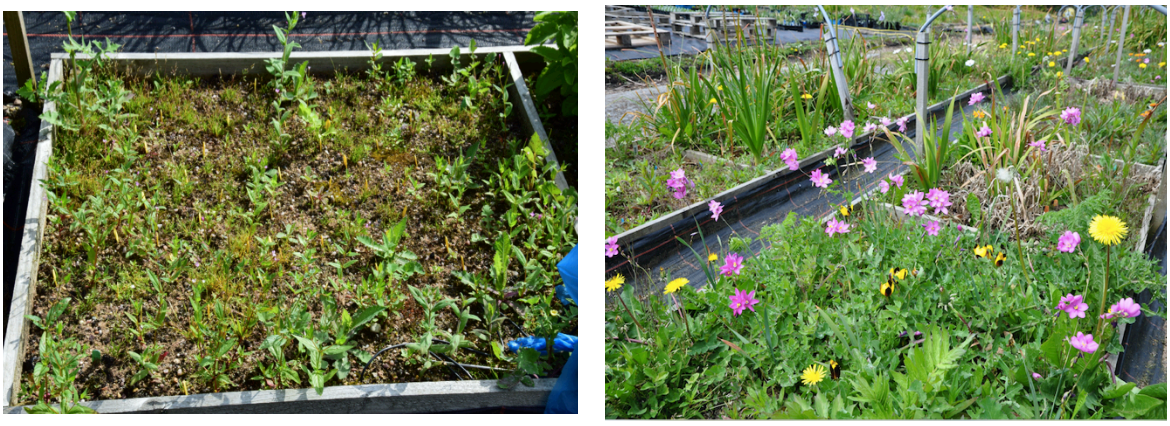


Fig. 6.9 In the competition experiment, (left) the low geophytes only mix was on open and weedy (photo taken on 21th July 2014); (right) the same community recorded on 4th May 2015. It was weedy but surprisingly many low-growing geophytes were shade-tolerant and pushed through weed canopies.

Fig. 6.10 The community of low forb mixed with medium geophytes. (left) Image was taken on 2nd May 2013 (it was established in autumn 2012). The community was dorminated by the low forb *Gazania*; (right) the same community recorded on 2nd May 2014 (same day one year later). More medium height geophytes grew bigger in size and became more obvious compared to the first growing year and contributed more in community biomass.

Fig. 6.11 Tall canopy geophytes *Watsonia* and *Kniphofia* species with naked stems are potentially good species for tall geophyte layer.

Fig. 6.12 The tall canopy geophyte *Watsonia marlothii* is very attractive in colour and a good species for tall geophyte layer in competition experiment. (photo taken on 14th July 2015)

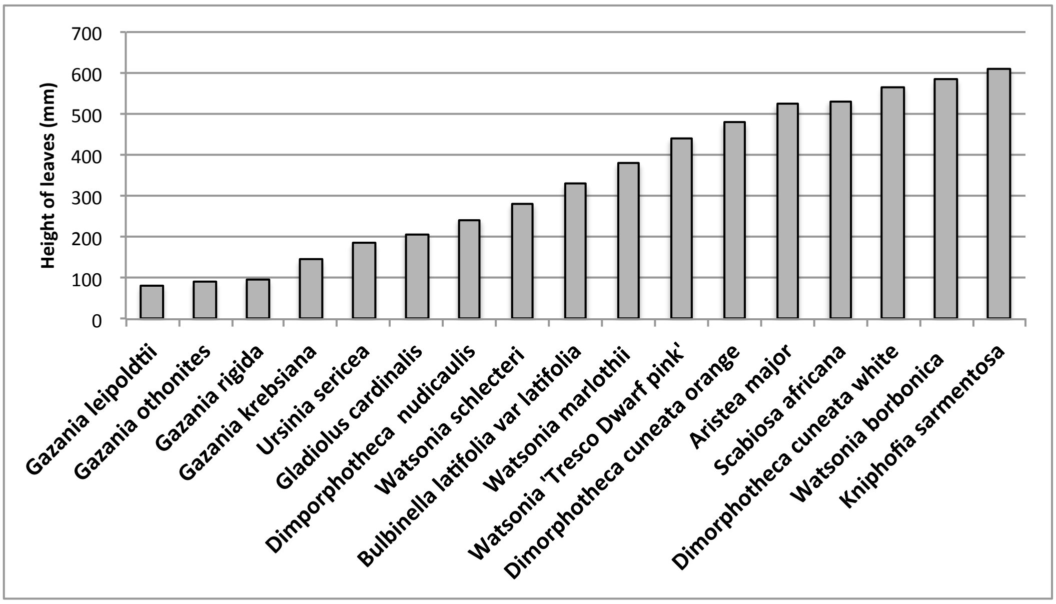
Although it was limited by seed availability when establishing the competition experiment, some inspiration could be gained from the Winter Cold and Summer Wetness Tolerance Experiment Phase 1 and Phase 2. Many more valuable medium to high evergreen and summer deciduous geophyte species flowered during the study. As shown in Figure 6.11, *Watsonia stokoei* (light red) and *Kniphofia uvaria* were both good for the tall geophyte layer. *Watsonia marlothii* (scarlet colour in Figure 6.11, and Figure 6.12) took three years in the competition experiment to flower, however, their flower colours are extremely attractive. From the design perspective, it is one of the best choices for the tall geophyte layer in practice.

Fig. 6.13 The communities within the competition experiment in summer 2015. The tall species with pale mauve flowers was the sub-shrubby *Scabiosa africana*, and the flowering geophyte species in front was *Watsonia* 'Tresco Dwarf Pink'. (photo taken on 23th July 2015)

The design of planting communities focus on four-season display. Although many summer-dormant deciduous geophytes were used in the combinations, some evergreen geophyte species and shrubs, forbs still grew and flowered in summer period. Because summer in the UK is much wetter than their habitat, certain summer-dormant deciduous geophytes stretched their display window into early-mid summer and bloomed when other deciduous geophytes went into dormancy, such as *Watsonia* ‘Tresco Dwarf Pink’ in Figure 6.13.

Heights of leaves, flower stems and the spread of the following species in the competition experiment were measured in July, August 2014 (Fig. 6.14). Because the communities were established in autumn 2012, and by the end of second observation year (August 2014), there were many species not yet mature in size and did not produce any flowers. The tall evergreen geophyte *Kniphofia sarmentosa* was 610mm in average height in leaf but over 1000mm when in flower. *Watsonia borbonica* was 583mm on average in leaf but 1238mm when flowering. *Watsonia marlothii* was in the same geophyte group as *Watsonia borbonica* but grew slower. The average height of leaves was only 380mm. There were only two individual plant of *Watsonia marlothii* flowered in 2014, and the heights of flower stems were 1060mm and 640mm. In the medium height geophyte group, *Watsonia schlecteri* and *Watsonia* ‘Tresco Dwarf Pink’ were 545mm and 793mm tall respectively when flowering. The spread of species was difficult to measure at this time of the year as many of them were restricted for lateral space in the communities. When comparing the spread of three *Gazania* species in low forb group, *Gazania leipoldtii* (212mm) and *Gazania rigida* (250mm) were similar. *Gazania krebsiana* (300mm) was much more wide spreading.

Fig. 6.14 The comparison of the height of leaves between some tested species in the competition experiment before harvesting 2014 (measured in July, August 2014, second observation year). Six samples of each individual species were chosen to get the averge height.



6.4 Conclusion

From the design perspective, growth, flower phenology of the tested species and weed phenology in the competition experiment was useful information to design and adjust planting communities in practice. Long-term observation in the field station will continuously provide more messages of these Meditteranean species in Sheffield. Attractive species from the Winter Cold and Summer Wetness Experments could be added into the Competition Experiment, and their performance in growth and flowering could be recorded to allow comparison with the current tested species in each plant type and heigh group.

CHAPTER 7: CONCLUSION

This research has shown that a wide range of South African shrub, forb, succulent and geophyte species (over 200 amongst a total of 300 species) are capable of being established and grown outside in Sheffield (Northern UK) and tolerating cold winters and summer wet soils. Competiveness of plants within various designed plant communities were observed and some of the communities demonstrated high potential to be used in landscape design as part of sustainable, multi-layered, flowering Mediterranean plant communities in the warming cities of maritime Western Europe. The following research questions were proposed prior to this study, and the key issues to come out of the experiments in relation to research questions are discussed below.

I. Survival in relation to winter cold
  - Is mortality increased by exposure to sub-zero temperatures?
  - How do individual species and sub-specific variants of those species differ in their response to winter sub-zero temperatures?
  - Are there any patterns related to genus, or the origins of the species in response to winter cold?

II. Survival in relation to summer wetness
  - Does summer wetness increase mortality?
  - How do individual species and sub-specific variants of those species differ in their response to summer wetness?
  - Are there any patterns related to genus, or the origins of the species in response to summer wetness?

In general, winter mortality of tested species did increase with sub-zero temperatures. Mortality of these species also tended to increase when exposed to summer wetness. The most successful species in response to combinations of winter cold and summer wet in Sheffield are summarised below. The geophytes species listed in Table 7.1 were tested from March 2010 to April 2014 proved to be particularly successful. In general non-geophytes were less successful, the best performing shrub, forb species are listed in Table 7.2. It is not clear why geophytes in general seemed to be more robust, and presumably better fitted to the very non-Mediterranean climate of Sheffield? The dicots tended to be more sensitive to cold and also to sudden decline. The latter looked as if it was related to the intolerance of year round wet soils in combination with soil fungal pathogens, but no pathological research was undertaken. In some cases it seems to be related to the cycles of cutting in summer and early autumn involved in maintenance of the experiments. Only a few of the dicots used were obligate re-sprouters, where as all of the geophytes have the intrinsic capacity to re-sprout in autumn when the above ground parts are abscised or cut off in maintenance.

Table 7.1 Geophytes with particularly high survival rate (all in unprotected treatment).

Species Name	Degree of winter cold tolerance and summer wetness tolerance
Gladiolus carneus	-8^{o}C in winter 2010-11 (<5% mortality) 2012 summer (<10% mortality)
Gladiolus tristis	-8^{o}C in winter 2010-11 (<20% mortality) 2012 summer (<30% mortality)
Sparaxis elegans	-8^{o}C in winter 2010-11 (<25% mortality) 2012 summer (<20% mortality)
Ixia curvata	-8^{o}C in winter 2010-11 (<35% mortality) (0% mortality at -5 ^{o}C) 2012 summer (<10% mortality)
Watsonia borbonica	-8^{o}C in winter 2010-11 (<40% mortality) 2012 summer (<5% mortality)
Moraea tripetala	-5^{o}C in winter 2011-12 (0% mortality) 2012 summer (0% mortality)
Kniphofia uvaria	-5^{o}C in winter 2011-12 (0% mortality) 2012 summer (0% mortality)
Bulbinella nutans	-8^{o}C in winter 2010-11 (<90% mortality) (0% mortality at -5 ^{o}C) 2012 summer (0% mortality)
Bulbinella elata	-5^{o}C in winter 2011-12 (0% mortality) 2012 summer (0% mortality)
Bulbinella elegans	-5^{o}C in winter 2011-12 (0% mortality) 2012 summer (0% mortality)
Romulea atrandra	-5^{o}C in winter 2011-12 (0% mortality) 2012 summer (0% mortality)
Romulea sabulosa	-5^{o}C in winter 2011-12 (0% mortality) 2012 summer (0% mortality)
Bulbinella latifolia var. *latifolia*	-8^{o}C in winter 2010-11 (<70% mortality) (<5% mortality at -5 ^{o}C) 2012 summer (<5% mortality)
Romulea komsbergensis	-5^{o}C in winter 2011-12 (<5% mortality) 2012 summer (<15% mortality)
Hesperantha humilis	-5^{o}C in winter 2011-12 (<10% mortality) 2012 summer (0% mortality)
Hesperantha luticola	-5^{o}C in winter 2011-12 (<10% mortality) 2012 summer (<20% mortality)
Hesperantha vaginata	-5^{o}C in winter 2011-12 (<10% mortality) 2012 summer (<20% mortality)

Kniphofia sarmentosa	-5°C in winter 2011-12 (<10% mortality) 2012 summer (<15% mortality)
Hesperantha cucullatus	-5°C in winter 2011-12 (<15% mortality) 2012 summer (<10% mortality)
Ixia rapunculoides	-5°C in winter 2011-12 (<15% mortality) 2012 summer (<10% mortality)
Babiana sambucifolia	-5°C in winter 2011-12 (<15% mortality) 2012 summer (<25% mortality)
Sparaxis tricolor	-5°C in winter 2011-12 (<15% mortality) 2012 summer (<10% mortality)

Table 7.2 Particularly successful shrubs, forbs with high survival rate (all in unprotected treatment).

Species Name	Degree of winter cold tolerance and summer wetness tolerance
Arctotis adpressa	-5°C in winter 2011-12 (0% mortality) 2012 summer (0% mortality)
Geranium incanum	-5°C in winter 2011-12 (0% mortality)
Gazania krebsiana	-5°C in winter 2011-12 (0% mortality) 2012 summer (<5% mortality)
Dimorphotheca cuneata (white flowered forms)	-5°C in winter 2011-12 (0% mortality) 2012 summer (0% mortality)
Dimorphotheca cuneata (orange flowered forms)	-5°C in winter 2011-12 (<5% mortality) 2012 summer (0% mortality)
Dimorphotheca nudicaulis	-5°C in winter 2011-12 (<5% mortality)
Scabiosa africana	-5°C in winter 2011-12 (<20% mortality) 2012 summer (0% mortality)

In the botanical and horticultural literature plus the anecdotal experiences of experts and researchers, summer-dormant deciduous geophytes from Mediterranean Cape Flora Region are uniformly described as sensitive to winter cold/wetness and summer wetness. Whilst to some degree this view is in part supported by the research, in general these plants are much more cold and summer wet tolerant than suggested. Nearly all species survive -1/-2°C. The experiment revealed that some genera were significant more cold tolerant than others, with *Bulbinella, Romulea* and *Hesperantha* displaying the most winter cold tolerance capacity amongst summer deciduous geophyte genera, with many species undamaged at -5°C in winter 2011-12. *Watsonia* is a much less cold tolerant genus, with *W. marlothii* and *W. schlecterii* performed best in cold winters in Sheffield. Although some species showed high mortality in the experiment, in many cases a few seedlings survived relatively undamaged. More cold tolerant individuals in these species or populations are most likely be found when many seeds are sown.

The most successful species in response to winter cold in Sheffield were collected from colder, more inland, and high elevation (>1200m) regions of the Roggeveld Plateau, including Sutherland, Rooiwal, and the Komsberg, which naturally experience many frost days. Altitude and frost days in the habitat appear to correlate reasonably well with observed tolerance of specific genotypes to winter cold. The most cold tolerant populations of species are likely to be associated with frost hollows that form in depressions at high altitude plateau and which experience much lower absolute minimum temperatures. This is the case for example with many wet growing *Romulea*, such as *R. komsbergensis.*

Species from heavier more moisture retentive soils (Renosterveld) from either coastal plains to inland mountains showed lowest mortality in response to summer wetness in Sheffield. The most successful genera in response to summer wet, *Bulbinella, Kniphofia, Gazania* and *Romulea*, are mainly associated with renosterveld, and in some case drainage lines in this community. Some geophyte species from high permeable sandy soil in Fynbos which is subject to high annual rainfall survived well in summer 2012 in Sheffield as well, such as *Watsonia foureadei* and *W. marginata* collected in Stellenbosch. In our study the upper 90mm of soil was very well drained, being composed of either sand or a gritty compost, although the soil beneath this was a clay loam that was relatively compacted and subject to anaerobosis. On poorly drained soils the species that tolerate summer wetness is likely to decrease. Conversely in Southern England on sandy or chalky soils the range of species that tolerate summer wetness is likely to expand.

III. Seed ecology and establishment;

-- Is it possible to germinate perennial South African species outside in the UK?

-- How does sowing time affect field emergence?

-- What are typical values for species in terms of field emergence?

-- How do different species differ in their ease of establishment and persistence?

Perennial South African species sown outside in the UK were perfectly able to geminate and emerge, particularly in response to late summer and autumn sowing. Almost all of the species tested showed their highest emergence in autumn, as would be expected in a Mediterranean flora which has evolved to utilise declining day temperatures and an increasingly diurnal gap to cue germination. This preponderance of autumn germination is problematic in practice in temperate climates as it means that seedlings have to potentially encounter lethal winter temperatures soon after they germinate. Most shrub/forb species showed greater capacity for spring germination when pre-treated with aqueous smoke treatments. This may allow spring sowing as a means to establish these species and gain an extra growing season before experiencing cold winters. (Table 3.3)

In both the smoke and non-smoke pre-sowing treatments there was no marked improvement in emergence in most geophyte species. In shrubs and forbs performance was greatly improved in many species by smoke (Table 3.3).

Field emergence values varied hugely between the different populations and species, but in general terms was often (when sown in the preferred time of year) relatively high (i.e. >40%) and in some cases very high (> 60%).

IV. Establishment and longer-term competition

-- How does life form, canopy architecture and foliage height influence establishment of multi-species communities?

-- How does life form, canopy architecture and foliage height influence competition and long term survival of species within multi-species communities?

Establishment was initially little affected by architecture and life form, as plants were too small in use their height etc. to shade their neighbors. By the end of the first year however the fast growing low forbs, *Gazania* and *Geranium* had formed a dense canopy over the plots they were present in and this had a marked affect on subsequent cover values, and competition with seedling weeds and planted/sown geophytes and other forbs and shrubs.

This situation soon changed however as geophytes suffered less mortality than shrub/forb/succulent species in the first two years. Slow-growing and shade intolerant shrubby species *Felicia filifolia* declined quickly when fast growing forb *Scabiosa africana* and shrubby species *Dimorphotheca cuneata* in the same canopy group developed their shady canopies. In the low canopy forb/succulent group, shade in-tolerated species *Esterhuysenia alpina* was largely eliminated by dense evergreen *Gazania* canopies. Adult plants of ground layer forb species *Geranium incanum, Gazania krebsiana* and *Gazania leipoldtii* acted as ephemeral elements in the communities but simultaneously self-seeded to maintain the coverage in the next year. Tall evergreen geophyte *Aristea capitata* (major) survived better in the tall geophyte only community and communities when mixed with tall forbs where it had much more protection from neighboring plants within the community. Surprisingly, *Aristea capitata* (major) survived well in mixes with lower forbs, which may have protected it by reducing long wave radiation loss from the soil during nights in winters reducing damage to the meristems at ground level.

As losses of forbs and shrubs mounted, what initially had seemed to be the most successful were replaced by those communities composed of tall canopy layer geophytes and forbs/shrubs. The lowest growing layer proved to be problematic in the productive soils of the experiment, with many of the forbs being lost and the geophytes growing so slowly as to offer no competition to incoming weeds. The low geophytes only community was generally the weediest communities as the vegetation coverage was extremely sparse during the test period.

When low-medium forbs were mixed with tall geophytes, the communities were more balanced than in the tall geophytes communities only where there was more dominance by clump forming species such as *Kniphofia*. The general pattern of growth of tested species on site was that shrubs/forbs and tall geophytes rapidly increased in size in the first growing season. Some species were in the first two years “more successful” than others and these are shown in Table 7.3.

Table 7.3 Performance of the species in the first two growing season.

Species that flowered or were at flowering size	Species present but not flowering size
Dimorphotheca cuneata (orange) (year two)	*Babiana cuneata*
Dimorphotheca cuneata (white) (year one and year two)	*Bulbinella latifolia* var.*latifolia*
Dimorphotheca nudicaulis (year one and year two)	*Esterhuysenia alpina*
Gazania leipoldtii (year one and year two)	*Felicia filifolia*
Geranium incanum (year one and year two)	*Gladiolus cardinalis*
Gazania krebsiana (year one and year two)	*Hesperantha pauciflora*
Gazania rigida (year one and year two)	*Ixia thomasiae*
Hesperantha vaginata (year two)	
Ixia curvata (year two)	
Ixia rapunculoides (year two)	
Kniphofia sarmentosa (year one and year two)	
Romulea komsbergensis (year two)	
Scabiosa africana (year one and year two)	
Ursinia sericea (year one and year two)	
Watsonia borbonica (year two)	
Watsonia marlothii (year two)	
Watsonia schlechteri (year two)	
Watsonia 'Tresco Dwarf Pink' (year one and year two)	

Species that mostly died in the first two years	Species that failed to re-sprout after the first biomass harvest
Aristea major (sensitive to winter cold 2012-1, replaced in the second year)	*Dimorphotheca cuneata* (orange)
Berkheya herbacea (flowered but sensitive to winter cold 2012-13, replaced in the second year)	*Dimorphotheca cuneata* (white)
Gazania othonites (flowered, fungal disease after winter 2012-13, replaced in the second year)	*Lessertia frutescens*
Goniolimon speciosum (presumably damaged by wetness)	
Lessertia frutescsens (flowered but died after annual cutting)	

Ground coverage was mainly contributed by shrubs, forbs and tall geophytes in the first two years. Shrubs and forbs typically produced more biomass initially than geophytes, particularly low-medium geophytes in the first two years, and produce much bigger canopies. As time passes however, more medium height geophytes will form a closed canopy and have higher competition capacity to increase their coverage in the communities. Key species will be *Watsonia* 'Tresco Dwarf Pink', *Gladiolus cardinalis* and *Watsonia schlechteri*.

The tolerance of shade of the small geophytes from Fynbos and Renosterveld is rarely commented on in the ecological literature, but it was clear in the competition study that some species are relatively shade tolerant. The *Ixia, Gladiolus, Babiana* and *Hesperantha* species tested vary in their tolerance capacity of the shade cast by the canopies of tall shrubs and forbs. *Ixia* and *Hesperantha* species, *Romulea komsbergensis* seemed to be more shade tolerated as they largely survived in communities mixed with low dense *Gazania* forbs. The phenomenon may be related to their habitat structures or growth phenology. Most of them naturally occur amongst dwarf shrubs or grow in autumn and flower in early spring to escape some of the light competition within the communities.

In contrast to more traditional scientific research in horticultural in which the focus is only on relatively few species, this study concentrated on assessing a large number of species in response to winter cold and summer wetness in the field environment. Although for this reason the conclusions drawn are more general, the advantages of the more contextual approach taken in this study is that clear patterns began to emerge of how Western Cape species responded and how factors such provenance strongly influence this. This emerging big picture provides a strong basis for future, more detail research within species in relation to collection locations and ideal genera. The author proposed research is required in the following research directions:

- The lowest temperatures most species experienced in the experiment was -5^{o}C at the soil surface without protection. Some species survived from -8^{o}C without protection in outdoor condition. However, the maximum degree of winter cold tolerance of most species was still unknown. Laboratory experiments involving step-wise gradated minimum temperatures within chilling cabinets would be extremely useful in the next stage for confirming actual differences in minimum temperature tolerance within specific populations.

- To look at interactions between wetness, coldness, and ancillary factors such as age and pre-conditioning on these Mediterranean species.

- The effect of summer wetness on these species from winter-rainfall areas requires more steps by investigation than was possible in this study. The summer mortality figures were more or less affected by delayed winter damaged on plant tissues from previous winter period. Further research could focus on some typical species through controlled irrigation and non-irrigation comparisons to find out whether there would be marked difference in species between with or with supplementary irrigation, or their performance when the wetness increase. This work would also look at how soil characteristics, and in particular soil drainage and oxygen levels affect these responses.

- More evergreen geophyte and forb and shrub species as well as some succulents of cold regions need to be explored to enrich the plant palette of this type of Mediterranean planting communities.

- Various substrates could be used to compare the different response of these species over winters and summers.

- It is necessary to explore more cold hardy and aesthetically pleasing, and functionally useful species to enrich the design palette, which will address 3 distinctive groups of different life forms:

  i) Long-lived post fire re-sprouting shrubs and forbs for the emergent coppice shrub layer, *Corymbium* is a particularly promising genus within the Asteraceae.

  ii) evergreen geophytes (i.e. *Aristea,* very-long flowering *Dilatris* species, *Lanaria lanata*) for the emergent geophytes layer

iii) the long-lasting low-medium ground cover evergreen forbs or short-lived evergreen forbs with good “self-seeding” capacity which also have some degree of shade tolerance for the forb dominant ground layer.

In practice, mechanisms of long-term management are always essential to maintain established naturalistic planting communities. This requires species in the communities to be capable of withstanding the annual canopy removal either by cutting or cutting and burning necessary to maintain tidiness, suppress competitive dominance and to ensure the geophytes present are able to flower reliably every year. Regular cutting with flash burning also can effectively limit the weedy species from outside and ensure a good appearance of the planting community in the next growing season. Generally speaking, cutting is acceptable to all the geophyte species, but not post fire re-seeding shrubs. Therefore, evaluation of more post fire re-sprouting shrubs and forbs will be essential to determine the management approach.

Climate change will continuously offer more possibility for these species from Western Cape Region with Mediterranean climate to survive in Western Europe. Winters are expected to be warmer and summers drier. This suggests winter cold and summer wetness will become less problematic on South African Mediterranean species. Establishing Mediterranean plant communities such as those studied in this PhD will become increasing realistic to realise in Southern UK, such as London, indeed many of the species in this research are already much more robust in London than in Sheffield. This research has shown that it is theoretically possible to achieve four-season floral display as whilst many of these species grow in winter and even flower in winter, in more temperate climates this extends into spring and in some cases summer.

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8.1 Appendix 1 – ANOVA comparison of different geographical regions

Table 8.1 Univariate ANOVA pairwise comparisons between different geographical regions, table 7.1 only shows compared regions with significant difference in winter mortality 2011/2012.

Dependent Variable: 2011-2012 Winter mortality

Winter.cover.condition	(I) Region	(J) Region	Mean winter mortality difference (I-J)	Std. Error	Sig.d	Possible factors on significant difference	
						Difference in altitute	Difference in frost days
winter uncovered blocks	Cape Peninsula	Roggeveld (continental inland mountains)	30.636*	4.855	0.000	✔	✔
	Stellenbosch to Hermanus (coastal mountain to coast)	Namaqualand (coastal plain to inland mountains)	26.518*	5.925	0.000	✔	✔
		Roggeveld (continental inland mountains)	37.370*	4.369	0.000	✔	✔
	Swartland (lower altitude to inland mountains)	Namaqualand (coastal plain to inland mountains)	22.865*	5.446	0.001		
		Roggeveld (continental inland mountains)	33.717*	3.722	0.000		✔
	Cedarberg & Clanwilliam (inland mountains)	Namaqualand (coastal plain to inland mountains)	38.711*,c	7.096	0.000		
		Roggeveld (continental inland mountains)	49.564*,c	5.921	0.000		✔
	Namaqualand (coastal plain to inland mountains)	Stellenbosch to Hermanus (coastal mountain to coast)	-26.518*	5.925	0.000	✔	✔
		Swartland (lower altitude to inland mountains)	-22.865*	5.446	0.001		
		Cedarberg & Clanwilliam (inland mountains)	-38.711a,*	7.096	0.000		
		Southern valleys & mountains	-50.516a,*	10.401	0.000	✔	
	Roggeveld (continental inland mountains)	Cape Peninsula	-30.636*	4.855	0.000	✔	✔
		Stellenbosch to Hermanus (coastal mountain to coast)	-37.370*	4.369	0.000	✔	✔
		Swartland (lower altitude to inland mountains)	-33.717*	3.722	0.000		✔
		Cedarberg & Clanwilliam (inland mountains)	-49.564a,*	5.921	0.000		✔
		Southern valleys & mountains	-61.368a,*	9.628	0.000	✔	✔
	Southern valleys & mountains	Namaqualand (coastal plain to inland mountains)	50.516*,c	10.401	0.000	✔	
		Roggeveld (continental inland mountains)	61.368*,c	9.628	0.000	✔	✔
winter covered blocks	Cape Peninsula	Cedarberg & Clanwilliam (inland mountains)	-32.579a,*	7.424	0.001		✔
	Stellenbosch to Hermanus (coastal mountain to coast)	Cedarberg & Clanwilliam (inland mountains)	-32.081a,*	7.13	0.000		✔
	Swartland (lower altitude to inland mountains)	Cedarberg & Clanwilliam (inland mountains)	-29.265a,*	6.665	0.001		
	Cedarberg & Clanwilliam (inland mountains)	Cape Peninsula	32.579*,c	7.424	0.001		✔
		Stellenbosch to Hermanus (coastal mountain to coast)	32.081*,c	7.13	0.000		✔
		Swartland (lower altitude to inland mountains)	29.265*,c	6.665	0.001		
		Roggeveld (continental inland mountains)	22.944*,c	6.379	0.015		✔
		Eastern Cape	35.241a,*,c	10.586	0.039	✔	✔
	Roggeveld (continental inland mountains)	Cedarberg & Clanwilliam (inland mountains)	-22.944a,*	6.379	0.015		✔
	Eastern Cape	Cedarberg & Clanwilliam (inland mountains)	-35.241a,*,c	10.586	0.039	✔	✔

Based on estimated marginal means

* The mean difference is significant at the

a An estimate of the modified population marginal mean (J).

c An estimate of the modified population marginal mean (I).

d Adjustment for multiple comparisons: Sidak.

8.2 Appendix 2 – ANOVA comparison of different provenances

Table 8.2 Univariate ANOVA pairwise comparisons between different provenances in winter uncovered treatment, table 7.2 only shows compared provenances with significant difference in winter mortality 2011/2012.

Dependent Variable: 2011-2012 Winter mortality

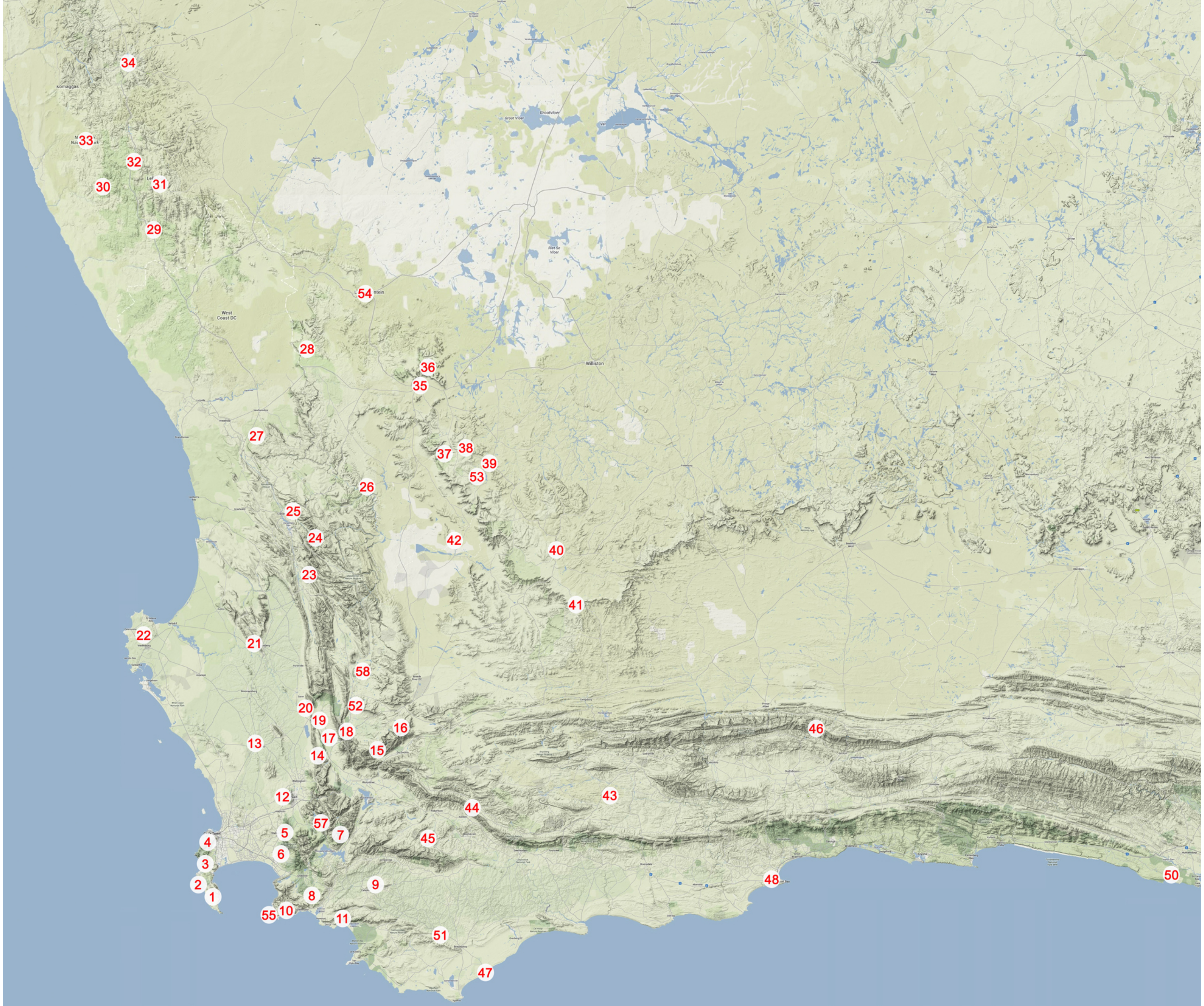
(I) Location	(J) Location	Mean Winter Mortality Difference (I-J)	Std. Error	Sig.d	Possible factors on significant difference	
					Difference in altitute	Difference in frost days
Cape Peninsula	Clanwilliam	-31.698*	6.859	0.004	✔	
Scarborough	Clanwilliam	-38.442*	8.657	0.010	✔	
	Springbok	-52.458*	12.465	0.027	✔	✔
	Little Karoo	-69.208*,b	16.281	0.022		✔
	loeriesfontein	-69.208*,b	16.281	0.022	✔	✔
Noordaoek	Clanwilliam	-35.608*	8.112	0.012		
	Springbok	-49.625*	12.093	0.042	✔	✔
	Little Karoo	-66.375*,b	15.997	0.034		✔
	loeriesfontein	-66.375*,b	15.997	0.034		✔
Table Mountain	Roggeveld	23.436*	5.757	0.048	✔	✔
	Sutherland	28.665*	6.437	0.009	✔	✔
Stellenbosch	Clanwilliam	-30.138*	6.22	0.001		
	Nieuwoudtville	15.851*	3.599	0.011	✔	✔
	Roggeveld	20.677*	4.93	0.028	✔	✔
	Sutherland	25.906*	5.709	0.006	✔	✔
Hermanus	Nieuwoudtville	27.068*	5.562	0.001	✔	✔
	Roggeveld	31.894*	6.503	0.001	✔	✔
	Sutherland	37.124*	7.112	0.000	✔	✔
	Mossel Bay	50.313*	11.709	0.018		✔
	Rooiwal	36.336*	8.777	0.036	✔	✔
Malmesbury	Clanwilliam	-29.307*	6.492	0.007		
	Nieuwoudtville	16.682*	4.052	0.039	✔	✔
	Roggeveld	21.508*	5.27	0.046	✔	✔
	Sutherland	26.738*	6.005	0.009	✔	✔
Bainskloof	Clanwilliam	-28.811*	6.526	0.011		✔
	Nieuwoudtville	17.178*	4.106	0.030		✔
	Roggeveld	22.004*	5.311	0.035		✔
	Sutherland	27.234*	6.041	0.007		✔
Tulbagh	Clanwilliam	-32.846*	6.799	0.001	✔	
	Springbok	-46.863*	11.254	0.032	✔	✔
	Little Karoo	-63.613*,b	15.373	0.036	✔	✔
	loeriesfontein	-63.613*,b	15.373	0.036	✔	✔
Gouda	Sutherland	32.019*	7.727	0.035	✔	✔
West coast	Nieuwoudtville	26.798*	6.33	0.024	✔	✔
	Roggeveld	31.623*	7.171	0.011	✔	✔
	Sutherland	36.853*	7.727	0.002	✔	✔
	Mossel Bay	50.042*	12.093	0.036		
Cedarberg	Nieuwoudtville	38.165*	5.814	0.000		
	Kamiesberg	34.530*	6.331	0.000		✔
	Roggeveld	42.991*	6.72	0.000		✔
	Sutherland	48.221*	7.311	0.000		✔
	Komsberg	33.373*	7.662	0.014	✔	✔
	Mossel Bay	61.410*	11.831	0.000	✔	✔
	Rooiwal	47.433*	8.939	0.000		✔
Clanwilliam	Cape Peninsula	31.698*	6.859	0.004	✔	
	Scarborough	38.442*	8.657	0.010	✔	
	Noordaoek	35.608*	8.112	0.012		
	Stellenbosch	30.138*	6.22	0.001		
	Malmesbury	29.307*	6.492	0.007		
	Bainskloof	28.811*	6.526	0.011		✔
	Tulbagh	32.846*	6.799	0.001	✔	
	Nieuwoudtville	45.989*	5.724	0.000	✔	✔
	Kamiesberg	42.354*	6.248	0.000	✔	✔
	Namaqualand	34.000*	7.96	0.020	✔	✔
	Roggeveld	50.815*	6.642	0.000	✔	✔
	Sutherland	56.044*	7.239	0.000	✔	✔
	Komsberg	41.197*	7.594	0.000	✔	✔
	Groot Swartberg	53.733*	11.787	0.006	✔	✔
	Mossel Bay	69.233*	11.787	0.000	✔	
	Rooiwal	55.257*	8.881	0.000	✔	✔
Nieuwoudtville	Stellenbosch	-15.851*	3.599	0.011	✔	✔
	Hermanus	-27.068*	5.562	0.001	✔	✔
	Malmesbury	-16.682*	4.052	0.039	✔	✔
	Bainskloof	-17.178*	4.106	0.030		✔
	West coast	-26.798*	6.33	0.024	✔	✔
	Cedarberg	-38.165*	5.814	0.000		
	Clanwilliam	-45.989*	5.724	0.000	✔	✔
	Garies	-50.339*	11.466	0.012	✔	
	Springbok	-60.006*	10.639	0.000	✔	✔
	Middelpos	-31.881*	6.33	0.001		✔
	Little Karoo	-76.756*,b	14.929	0.000	✔	✔
	loeriesfontein	-76.756*,b	14.929	0.000	✔	

(I) Location	(J) Location	Mean Winter Mortality Difference (I-J)	Std. Error	Sig.d	Possible factors on significant difference	
					Difference in altitute	Difference in frost days
Garies	Nieuwoudtville	50.339*	11.466	0.012	✔	
	Roggeveld	55.165*	11.951	0.004	✔	✔
	Sutherland	60.394*	12.293	0.001	✔	✔
	Mossel Bay	73.583*	15.415	0.002	✔	✔
	Rooiwal	59.607*	13.326	0.008	✔	✔
Kamiesberg	Cedarberg	-34.530*	6.331	0.000		✔
	Clanwilliam	-42.354*	6.248	0.000	✔	✔
	Springbok	-56.371*	10.93	0.000		✔
	Middelpos	-28.246*	6.808	0.034		✔
	Little Karoo	-73.121*,b	15.138	0.001	✔	
	loeriesfontein	-73.121*,b	15.138	0.001	✔	✔
Namaqualand	Clanwilliam	-34.000*	7.96	0.020	✔	✔
	Little Karoo	-64.767*,b	15.921	0.048	✔	✔
	loeriesfontein	-64.767*,b	15.921	0.048	✔	✔
Springbok	Scarborough	52.458*	12.465	0.027	✔	✔
	Noordaoek	49.625*	12.093	0.042	✔	✔
	Tulbagh	46.863*	11.254	0.032	✔	✔
	Kamiesberg	56.371*	10.93	0.000		✔
	Roggeveld	64.832*	11.16	0.000		✔
	Sutherland	70.061*	11.525	0.000		✔
	Komsberg	55.214*	11.751	0.003	✔	✔
	Groot Swartberg	67.750*	14.811	0.005	✔	✔
	Mossel Bay	83.250*	14.811	0.000	✔	✔
	Rooiwal	69.274*	12.621	0.000		✔
Roggeveld	Table Mountain	-23.436*	5.757	0.048	✔	✔
	Stellenbosch	-20.677*	4.93	0.028	✔	✔
	Hermanus	-31.894*	6.503	0.001	✔	✔
	Malmesbury	-21.508*	5.27	0.046	✔	✔
	Bainskloof	-22.004*	5.311	0.035		✔
	West coast	-31.623*	7.171	0.011	✔	✔
	Cedarberg	-42.991*	6.72	0.000		✔
	Clanwilliam	-50.815*	6.642	0.000	✔	✔
	Garies	-55.165*	11.951	0.004	✔	✔
	Springbok	-64.832*	11.16	0.000		✔
	Middelpos	-36.707*	7.171	0.000		✔
	Little Karoo	-81.582*,b	15.304	0.000	✔	✔
	loeriesfontein	-81.582*,b	15.304	0.000	✔	✔

(I) Location	(J) Location	Mean Winter Mortality Difference (I-J)	Std. Error	Sig.d	Possible factors on significant difference	
					Difference in altitute	Difference in frost days
Middelpos	Nieuwoudtville	31.881*	6.33	0.001		✔
	Kamiesberg	28.246*	6.808	0.034		✔
	Roggeveld	36.707*	7.171	0.000		✔
	Sutherland	41.936*	7.727	0.000	✔	
	Mossel Bay	55.125*	12.093	0.006	✔	✔
	Rooiwal	41.149*	9.283	0.010		✔
Sutherland	Table Mountain	-28.665*	6.437	0.009	✔	✔
	Stellenbosch	-25.906*	5.709	0.006	✔	✔
	Hermanus	-37.124*	7.112	0.000	✔	✔
	Malmesbury	-26.738*	6.005	0.009	✔	✔
	Bainskloof	-27.234*	6.041	0.007		✔
	Gouda	-32.019*	7.727	0.035	✔	✔
	West coast	-36.853*	7.727	0.002	✔	✔
	Cedarberg	-48.221*	7.311	0.000		✔
	Clanwilliam	-56.044*	7.239	0.000	✔	✔
	Garies	-60.394*	12.293	0.001	✔	✔
	Springbok	-70.061*	11.525	0.000		✔
	Middelpos	-41.936*	7.727	0.000	✔	
	Little Karoo	-86.811*,b	15.573	0.000	✔	✔
	loeriesfontein	-86.811*,b	15.573	0.000	✔	✔
Komsberg	Cedarberg	-33.373*	7.662	0.014	✔	✔
	Clanwilliam	-41.197*	7.594	0.000	✔	✔
	Springbok	-55.214*	11.751	0.003	✔	✔
	Little Karoo	-71.964*,b	15.741	0.005	✔	✔
	loeriesfontein	-71.964*,b	15.741	0.005	✔	✔
Little Karoo	Scarborough	69.208*,c	16.281	0.022		✔
	Noordaoek	66.375*,c	15.997	0.034		✔
	Tulbagh	63.613*,c	15.373	0.036	✔	✔
	Nieuwoudtville	76.756*,c	14.929	0.000	✔	✔
	Kamiesberg	73.121*,c	15.138	0.001	✔	
	Namaqualand	64.767*,c	15.921	0.048	✔	✔
	Roggeveld	81.582*,c	15.304	0.000	✔	✔
	Sutherland	86.811*,c	15.573	0.000	✔	✔
	Komsberg	71.964*,c	15.741	0.005	✔	✔
	Groot Swartberg	84.500*,c	18.139	0.003	✔	✔
	Mossel Bay	100.000*,c	18.139	0.000	✔	✔
	Rooiwal	86.024*,c	16.4	0.000	✔	✔

(I) Location	(J) Location	Mean Winter Mortality Difference (I-J)	Std. Error	Sig.d	Possible factors on	
					Difference in altitute	Difference in frost days
Groot Swartberg	Clanwilliam	-53.733*	11.787	0.006	✔	✔
	Springbok	-67.750*	14.811	0.005	✔	✔
	Little Karoo	-84.500*,b	18.139	0.003	✔	✔
	loeriesfontein	-84.500*,b	18.139	0.003	✔	✔
Mossel Bay	Hermanus	-50.313*	11.709	0.018		✔
	West coast	-50.042*	12.093	0.036		
	Cedarberg	-61.410*	11.831	0.000	✔	✔
	Clanwilliam	-69.233*	11.787	0.000	✔	
	Garies	-73.583*	15.415	0.002	✔	✔
	Springbok	-83.250*	14.811	0.000	✔	✔
	Middelpos	-55.125*	12.093	0.006	✔	✔
	Little Karoo	-100.000*,b	18.139	0.000	✔	✔
	loeriesfontein	-100.000*,b	18.139	0.000	✔	✔
Rooiwal	Hermanus	-36.336*	8.777	0.036	✔	✔
	Cedarberg	-47.433*	8.939	0.000	✔	✔
	Clanwilliam	-55.257*	8.881	0.000	✔	✔
	Garies	-59.607*	13.326	0.008	✔	✔
	Springbok	-69.274*	12.621	0.000		✔
	Middelpos	-41.149*	9.283	0.010		✔
	Little Karoo	-86.024*,b	16.4	0.000	✔	✔
	loeriesfontein	-86.024*,b	16.4	0.000	✔	✔
loeriesfontein	Scarborough	69.208*,c	16.281	0.022	✔	✔
	Noordaoek	66.375*,c	15.997	0.034		✔
	Tulbagh	63.613*,c	15.373	0.036	✔	✔
	Nieuwoudtville	76.756*,c	14.929	0.000	✔	
	Kamiesberg	73.121*,c	15.138	0.001	✔	✔
	Namaqualand	64.767*,c	15.921	0.048	✔	✔
	Roggeveld	81.582*,c	15.304	0.000	✔	✔
	Sutherland	86.811*,c	15.573	0.000	✔	✔
	Komsberg	71.964*,c	15.741	0.005	✔	✔
	Groot Swartberg	84.500*,c	18.139	0.003	✔	✔
	Mossel Bay	100.000*,c	18.139	0.000	✔	✔
	Rooiwal	86.024*,c	16.4	0.000	✔	✔

Based on estimated marginal means
* The mean difference is significant at the
b An estimate of the modified population marginal mean (J).
c An estimate of the modified population marginal mean (I).
d Adjustment for multiple comparisons: Sidak.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