

# **Postfire regeneration of mountain fynbos by resprouting: A comparison of species with different life history types**

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Science in Conservation Ecology*



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## Declaration

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## Summary

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The fire-prone mediterranean-type climate regions of the world are immensely biodiverse. Changes in fire frequency due to anthropogenic ignitions and climate change are one of the factors threatening the plant diversity of these regions. Many postfire regeneration studies have focused on seedling recruitment, whereas much can still be learned about regeneration through resprouting. This project focused on resprouters after a fire and assessed if there are differences between the obligate (OS) and facultative (FS) resprouting life history types. OS species have to resprout after fire, as their seeds are not fire resistant and seedling recruitment takes place in fire-free periods, whereas FS species have the ability to resprout and recruit seedlings after a fire.

My analyses found a significant difference in postfire resprout success between OS species and FS species, supporting the division of woody resprouting shrubs into these two life history types. OS species had minimal fire-related mortality and this was related to their ability to resprout early and vigorously after fire. OS species had no postfire mortality, which points to traits that enable them to endure the hot and dry summer months. The FS species varied in their response to fire and had greater fire induced mortality than the OS species. Postfire mortality (post-sprouting) was also greater compared to OS species, especially towards the end of the long dry summer suggesting a link to water stress.

A postfire seedling survey of target FS, OS and non-sprouters (NS), revealed that NS species had seedling/adult ratios that were orders of magnitude higher ranging between 40-200 seedlings per adult against less than 1-10 seedlings per adults for FS, with OS species recruiting no seedlings directly postfire, as is consistent with their life history type. Although the NS species do not sprout and the FS species had some mortality, the population was at or above replacement two-year postfire on account of seedling recruitment. OS species maintained their pre-fire population by successfully resprouting and by experiencing almost no postfire mortality. These results provide strong justification for grouping woody resprouters into OS and FS species in future studies seeking to understand the underlying differences in postfire recovery.

Postfire flowering phenology was also observed during the two year study period. Geophytes, mostly belonging to the Iridaceae and Orchidaceae were overrepresented within the first year postfire, many displaying fire-stimulated flowering. This suggests that some geophytes limit their reproductive cycle to the immediate postfire environment, when nutrients and light are abundant. Smaller resprouting shrubs generally flowered earlier than larger resprouting shrubs. Many non-sprouting shrubs did not reach maturity within the study period and those that did mostly belonged to the Fabaceae and Asteraceae families. This

study added 71 species to the existing Paarl Mountain species list, including eight new red listed species, highlighting the importance of early postfire field surveys.

## Opsomming

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Veldbrande is 'n natuurlike verskynsel in die meditereense klimaatstreke van die wereld. Hierdie areas is ook bekend vir hulle ryk biodiversiteit. Veranderinge in die vuur frekwensie as gevolg van klimaatsverandering en veldbrande wat deur mense veroorsaak word, bedreig die plantdiversiteit van hierdie streke. Vorige veldbrandstudies het meestal gefokus op saailinge en daar bestaan 'n groot leemte om regenerasie deur herspruiting beter te verstaan. Hierdie navorsingsprojek fokus op herspruiting van fynbos plante as 'n oorlewingstrategie na 'n veldbrand. Spesifiek word daar gekyk na verskille tussen verpligte (VH) en nie-verpligte (fakultatiewe) herspruiters (FH). VH spesies moet herspruit na vuur om hulle populasie stabiel te hou, aangesien hulle saad nie vuurbestand is nie. FH spesies het die vermoë om te herspruit sowel as saailinge te werf na 'n brand.

Die studie bevindinge dui op betekenisvolle verskille tussen hierdie twee lewensgeskiedenisstipes en regverdig die groepering van houtagtige herspruiter spesies as VH of FH. VH het minimale mortaliteit getoon na die veldbrand. Bykans alle plante het vinnig en kragtig herspruit. VH besit ook eienskappe wat hulle in staat stel om die warm, droeë somers te oorleef. Die oorlewing van FH was wisselvallig, met mortaliteit as gevolg van direkte vuurskade en verdere mortaliteit gedurende die lang somermaande, moonlik as gevolg van water stress.

'n Saailingstudie van VH, FH en ook nie-spruiters (NS) het getoon dat die saailing/volwasse verhoudings van NS ordes hoër is as die van FH. VH het geen saailinge direk na die vuur geproduseer nie. Twee jaar na die vuur was FH en NS saailing getalle steeds heelwat meer as die aantal volwasse plante wat dood is in die veldbrand. VH het hul populasie stabiliteit gehandhaaf deurdat alle volwasse plante suksesvol herspruit het. Hierdie bevindinge regverdig die verdeling van herspruitende fynbos spesies as VH of FH. Verdere studies is belangrik om die onderliggende ekofisiologiese verskille tussen die twee lewensgeskiedenisstipes beter te verstaan.

Die blompatrone van verskillende spesies is ook aangeteken tydens die tweejaar studieperiode. Bolplante, veral in die iris- (Iridaceae) en orgidee (Orchidaceae) families het oorheers gedurende die eerste jaar na die brand, aanduidend van 'n vuur-gestimuleerde blompatroon. Sommige bolplante mag hul voorplantingssiklus beperk tot die periode direk na 'n veldbrand, terwyl daar genoeg lig is en die grond verryk is met voedingsstowwe. Kleiner herspruitende struik het in die algemeen vroeër geblom as groter struik. Nie-herspruitende struik het meestal nie seksuele volwassenheid bereik binne twee jaar na die veldbrand nie, buiten sommige in die ertjie- (Fabaceae) en asterfamilies (Asteraceae). Die

studie het 71 nuwe spesies tot die bestaande Paarlberg spesielys gevoeg, waarvan agt rooidataspesies was, wat die waarde van plantopnames direk na 'n veldbrand beklemtoon.

## Dedication

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To the Friends of the Tygerberg CREW team

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## CHAPTER 1

### Introduction - The mediterranean-type climate regions of the world: towards a better understanding of how plants resprout after fire

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#### Mediterranean-type climate regions

There are five mediterranean-type climate (MTC) regions in the world (shown in Figure 1.1), where the climate is characterized by hot dry summers and cool wet winters (Cowling *et al.* 1996; Keeley *et al.* 2012). Collectively these regions occupy less than 5% of the earth's land surface, yet harbour almost 20% of the world's vascular plant species (Cowling *et al.* 1996). With many large metropolitan centres lying within these immensely biodiverse regions (Keeley *et al.* 2012), transformation of large tracts of the landscape has been inevitable. It is thus not surprising that all five MTC regions were included in Myers *et al.*'s (2000) list of global biodiversity hotspots that deserve special conservation priority (Cowling *et al.* 1996; Myers *et al.* 2000).



**Figure 1.1.** The dark coloured areas on the map represent the five regions that have a mediterranean-type climate characterized by hot dry summers and where more than 65% of the annual rain falls during the cool winters (Figure reproduced with permission from Cowling *et al.* 1996).

All MTC regions have mild to cool wet winters with rainfall levels that support plant growth during winter and spring (Rundel 2010). Another unifying factor is the dominance of evergreen sclerophyllous shrubs (Linder *et al.* 1992; Cowling *et al.* 1996), which dry out sufficiently in the hot and generally dry summers to create highly fire-prone landscapes with

a predictable wildfire season (Keeley & Bond 1997; Keeley et al. 2012). The similarities in evergreen sclerophyllous shrubs in these disjoint regions of the world were recognized in the nineteenth century (Grisebach 1872 and Schimper 1903, cited in Keeley et al. 2012). Since then, these similarities in vegetation structure and function at the community level, despite the unrelatedness of many taxa, have been cited as classic examples of evolutionary convergence (Cowling et al. 2005). One of the first major comparative studies of MTC regions was undertaken by Mooney & Dunn (1970), which opened the door to many collaborative studies across all five regions (Keeley et al. 2012). A recent example being a study by Jacobsen et al. (2009), that compared water stress tolerance of shrubs in fynbos and Nama karoo communities in South Africa to shrubs in Californian chaparral.

### **Fire, soil and climate**

Natural fires have occurred for millions of years and evidence suggests that fires date back to the origin of terrestrial plants (Pausas & Keeley 2009; Keeley et al. 2012). Fire has likely been a selective force through much of the evolution of land plants (Keeley et al. 2011; Keeley et al. 2012; but also see Axelrod 1989; Hopper 2009; Bradshaw et al. 2011), with historical variations in frequency and intensity according to the available atmospheric oxygen levels (Scott & Glasspool 2006). The longstanding belief that the origins of vegetation patterns in the world could be explained by climate and a soil alone has been challenged (Scott 2000; Bond et al. 2005; Pausas & Keeley 2009; Bond & Scott 2010; He et al. 2011). It is now postulated that at least in the MTC regions, it is not geology and climate alone, but rather the interactions between fire, geology and climate that have shaped the plant communities over millions of years (Keeley et al. 2012).

Plant species within MTC regions have traits that allow persistence after all or most above ground biomass has been consumed by a fire (Bond & van Wilgen 1996; Cowling et al. 1996; Bond & Keeley 2005). Resprouting is the most widespread plant trait that provides resilience in these fire-prone landscapes, but fire-dependant reproductive traits, like fire stimulated seed germination and flowering, are also common in plant communities in most MTC regions (Keeley et al. 2012). Chile is the only MTC region that lacks species with fire-dependent seedling recruitment (Cowling et al. 2005; Ojeda et al. 2010). One explanation is that the formation of the Andes cut off summer lightning storms to central Chile, which caused a lack of a natural source of ignitions and excluded fire for a few million years (Keeley et al. 2012). The degree of summer drought and winter precipitation varies amongst the regions (Rundel 2010; Keeley et al. 2012) and so does soil fertility (Cowling et al. 1996). These differences along with a natural source of ignition have had a profound influence on the fire regime and ultimately the vegetation structure of each MTC region (Keeley et al. 2012).

There are five parameters that define a fire regime (Keeley et al. 2009): 1) patterns of fuel consumption and spread (i.e. crown fire, ground fire or understory fire), 2) intensity and severity, 3) frequency, 4) size and distribution and 5) seasonality. The predominant fire behaviour in the MTC regions is crown fires that consume most of the above ground biomass, where the fires are usually of high intensity and occur during summer or early autumn. The fire frequency however differs greatly between the five MTC regions (Keeley et al. 2012).

The community composition and pre- and postfire diversity differs markedly between the five MTC regions (Cowling et al. 1996) and this is partially related to differences in soil fertility (Cowling et al. 1996; Pausas & Bradstock 2007; Keeley et al. 2012). The two northern hemisphere MTC regions and central Chile have moderately fertile soils, where in the absence of disturbance the dominant sclerophyllous species develop closed-canopy shrublands or woodlands with little understory diversity. Although Chile lacks natural fires, anthropogenic fires over the past few centuries, along with grazing and charcoal cutting, have opened up canopies of matorral vegetation, resulting in an increase in stand biodiversity (Armesto et al. 2010). In California and the Mediterranean Basin the community diversity increases greatly after a fire due to the abundance of fire-stimulated ephemeral flora in California and the abundance of annuals and moderate abundance of geophytes in both regions (Keeley et al. 2012). As central Chile lacks fire-dependant species, there is no increase in postfire diversity. Fynbos in South Africa and kwongan in Australia occur on nutrient poor soils with a patchy composition of different growth forms that seldom form closed canopies (Vlok & Yeaton 2000 for fynbos; Keeley et al. 2012). This supports high community diversity even in mature vegetation with only a moderate increase in diversity postfire (Keeley et al. 2012). All MTC regions have a different mix of resprouting and seeding species and recent studies have demonstrated that different fire regimes may have played a selective role in the mix of reproductive traits found in each region (Keeley et al. 2011; Keeley et al. 2012).

Of all MTC regions, The Mediterranean Basin has had the longest documented history of intensive human interaction, presumably including anthropogenic fires, which makes it difficult to establish its "natural" fire regime (Buhk et al. 2007; Keeley et al. 2012). The two southern hemisphere MTC regions burn more frequently than the shrublands or heathlands of the other three MTC regions (Cowling et al. 1996); however, in many areas fire frequency is increasing due to anthropogenic ignitions (Whelan 1995; Syphard et al. 2006; van Wilgen et al. 2010) and climate change (Westerling et al. 2006). An increase in fire intensity due to the additional fuel load provided by woody invasive alien species has also been recorded (van Wilgen & Richardson 1985; Gordon 2003; van Wilgen et al. 2010). Climate change

predictions for all MTC regions suggest increased summer droughts and decreased rainfall, especially during the winter months (Tyson et al. 2002, cited in Midgley et al. 2003; Keeley et al. 2012), which could also result in altered fire regimes.

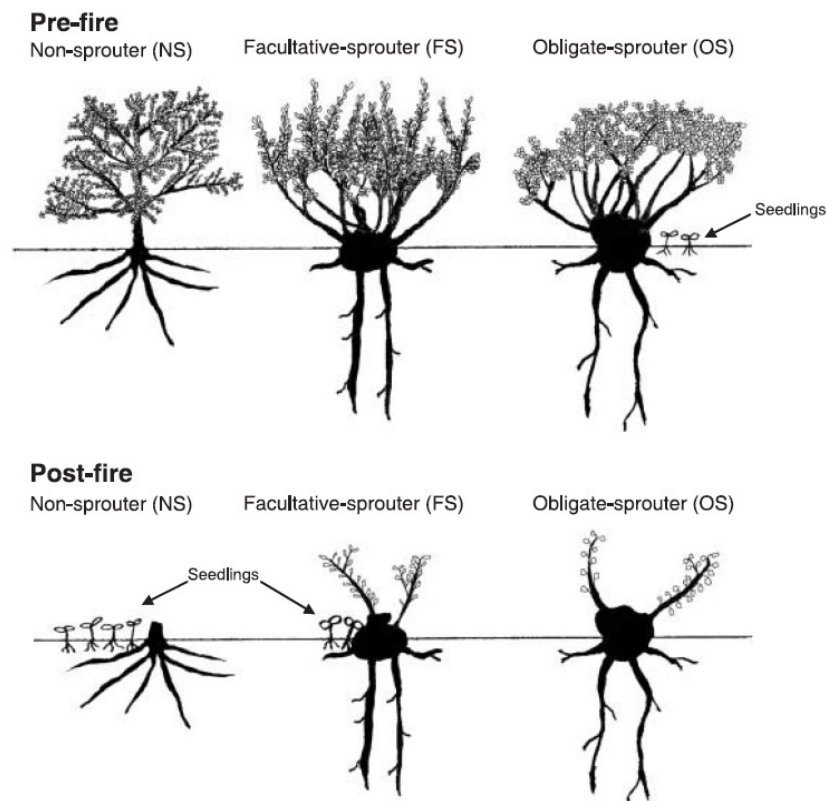
### **Postfire regeneration strategies in MTC regions**

Postfire regeneration is through resprouting and seedling recruitment, which is mostly fire dependant. Three main life history types can be recognized (see Figure 1.2). Obligate resprouters (OS) are species that can only persist through fires by vegetative resprouts. These species usually have short-lived fleshy seeds that are vertebrate dispersed and need mesic conditions under mature vegetation to germinate (Cowling et al. 1997; Keeley et al. 2006). Seedling recruitment is rare in these species and takes place during the fire-free intervals (van Wilgen & Forsyth 1992; Cowling et al. 1996, 1997; Keeley et al. 2006). Obligate resprouting in woody species is a highly conserved trait at the generic level (Keeley et al. 2012) and is mostly limited to a few genera. Geophytes make up a substantial part of the postfire flora in all MTC regions and also survive fires through resprouting (Keeley et al. 2012). As many of these species do not maintain dormant seedbanks, they can also be termed as obligate resprouters (Keeley & Bond 1997).

Facultative resprouters (FS), sometimes also called facultative seeders, are species that resprout, but also recruit seedlings postfire. Seedling recruitment in these species is fire-dependent and occurs as a single pulse in the postfire environment (Keeley & Bond 1997; Keeley et al. 2006). Obligate seeders or non-sprouters (NS) are killed by fire and have become dependant on fire for successful seedling recruitment, as either germination is linked to fire or seed release is synchronized to the immediate postfire environment (van Wilgen & Forsyth 1992; Keeley & Bond 1997; Keeley et al. 2006). These species have delayed reproduction to a single pulse of seedling recruitment in the first year postfire from dormant seedbanks, that are either soil-stored or canopy stored (serotiny). NS species are dependent on postfire seedling recruitment for persistence.

Non-sprouters that recruit seedlings after fire are common in the MTC regions of South Africa and Australia and with much diversity in genera. Although also abundant in California and the Mediterranean Basin (Keeley et al. 2012), these regions have less diversity in genera. Non-woody species that are essentially also non-sprouters include fire ephemerals that exhibit a degree of fire-stimulated germination (Bell et al. 1984; van Wilgen & Forsyth 1992; Keeley et al. 2006) and annuals.





**Figure 1.2.** Classification of different life history types, based on how plants regenerate after a fire, as used in the study. Non-sprouters (NS) are killed by fire and recruit new seedlings in open canopy gaps in the postfire environment. Facultative resprouters (FS) recruit new seedlings in open canopy gaps or in partial shade underneath resprouts and also sprout from a lignotuber following fire. Seeds of obligate resprouters (OS) are killed by fire, but burned adults survive by vegetative resprouting. Seedlings of OS species only recruit in between fire events in the shady understory of mature vegetation. (Figure reproduced with permission from Pratt *et al.* 2008).

### Functional trait and life history trait classification systems used in MTC regions

All MTC regions are under pressure from anthropogenic disturbances. This increases the sense of urgency to get a better understanding of ecosystem resilience to disturbances like altered fire regimes (Cowling *et al.* 1996; Lavorel *et al.* 1998). Grubb (1977) was the first to use the term “regeneration niche” to explain the co-existence of seemingly similar species that utilise different regeneration pathways within a plant community. As plant communities regenerate in many different ways after a fire, several classifications systems have been suggested that may have some predictive value at the species and community level.

One way of classifying plant species in a community is to group them into different types according to specific functional traits. An advantage of this approach is that it makes

predicting the behaviour and dynamics of plant communities under different fire regimes possible (Keeley et al. 2011). An important study to use this approach was that by Noble & Slatyer (1980) who introduced the concept of vital attributes (life history traits) to predict species and community response to a disturbance like fire. This sophisticated system requires detailed information for each species including the mechanism of persistence through fire, seed storage and longevity, competition and shade-tolerance, time to reproductive maturity and longevity. Bell et al. (1984) defined five categories of species response (or life history types) to fire. One study in South African mountain fynbos used this system, along with Noble & Slatyer's (1980) vital attributes to define regeneration strategies in fynbos plants and how this influences community stability in different plant communities (van Wilgen & Forsyth 1992). A limitation of the functional trait approach is that in regions of high plant biodiversity empirical data are often lacking, or only available for the most dominant species in a community (van Wilgen & Forsyth 1992).

A simple binary system classifying species as either resprouters or non-sprouters and the possible trade-offs for each regeneration mode has been widely applied (e.g. le Maitre & Midgley 1992; Bond & van Wilgen 1996; Midgley 1996; Pausas & Verdú 2005; Higgins et al. 2008; Paula & Pausas 2011). Such a simple distinction however fails to appreciate that resprouters represent a diverse group that can employ both resprouting and reseeding strategies to a variable degree (Bellingham & Sparrow 2000; Vesik & Westoby 2004). Although it accounts for differences between the two strategies, intraspecific variability is not captured (Moreira et al. 2012).

Another simplified classification system suggested by Bond & van Wilgen (1996) focused on two plant regeneration traits; postfire resprouting ability (resprouter/non-sprouter = R+/R-) and postfire seed germination (fire-dependant germination/ fire-independent germination = P+/P-), and the different combinations thereof. This system of grouping plants into regeneration functional groups or types has been applied to existing datasets from Australia, California and the Mediterranean Basin and facilitated generalized predictions at a local, but not at a global scale. This resulted from the fact that traits not captured by this classification (like e.g. seed dispersal), differed greatly between different geographical locations (Pausas et al. 2004). A recent extensive postfire demographic study by Keeley et al. (2006) supported the inclusion of life-form (e.g. shrub, subshrub, tree etc.) into regeneration functional groups, if early successional dynamics were to be captured at the community level. Herbaceous perennials make up the bulk of the immediate postfire diversity in most MTC regions and likely play an essential part in ecosystem functioning (Keeley et al. 2006). In most postfire succession studies the focus has been on the dominant woody species and herbaceous species have been ignored (Keeley et al. 2006).

From the above it is clear that several plant functional classification systems have been applied in studies within the MTC regions. These vary from a broad binary classification system to more specific classifications, based on a collection of functional traits or vital attributes to define a group. Lavorel et al. (1997) pointed to the *ad hoc* approaches in identifying functional groups in the past. Terminology is not always uniformly applied and standardized methodologies are required to facilitate study comparisons.

## Study rationale

Many studies focus on a single broad functional group, like non-sprouters. Studies on population persistence through seed dependant regeneration, where each new cohort of seedlings represent a new generation, are abundant (Grubb 1977; Keeley & Zedler 1978; Bond et al. 1984; Laurie & Cowling 1994; Keeley & Bond 1997; Heelemann et al. 2008). Studies on non-sprouter species include descriptions of fire related germination cues (Keeley & Bond 1997) and other fire-related traits like the increased flammability caused by dead floret retention (Lamont & Cowling 1984) and highly combustible leaves, along with dead leaf and branch retention (Schwilk & Ackerly 2001). There are research papers on the influence of pre-fire plant densities on postfire seedling recruitment (Bond et al. 1984) and studies on seed longevity and dispersal mechanisms (Enright et al. 1998; Holmes & Newton 2004), all of which contribute to the wealth of information on non-sprouters.

Resprouters were less well studied until Bond & Midgley (2001) introduced the term “persistence niche” to focus attention on traits that facilitate persistence of mature plants through disturbance as this has a profound influence on postfire succession and community composition. Previous studies did evaluate the competitive interactions between resprouters and reseeders (e.g. Vlok & Yeaton 2000), but studies focusing on differences in resprouting ability were lacking. Since then there has been an increased interest in resprouters and studies include fire interval effects on resprouters (Enright et al. 2011), how fire has influenced the evolution of resprouters (Lamont et al. 2011) and studies on carbon storage (e.g. Paula & Ojeda 2009). Studies focussing on the differences within resprouting species are in their infancy, with recent ecophysiological studies by Pratt et al. (2007, 2008, 2010, and 2012), starting to explore differences not only between resprouters and non-sprouters, but also between obligate resprouter and facultative resprouters, that might explain differential postfire resprout success.

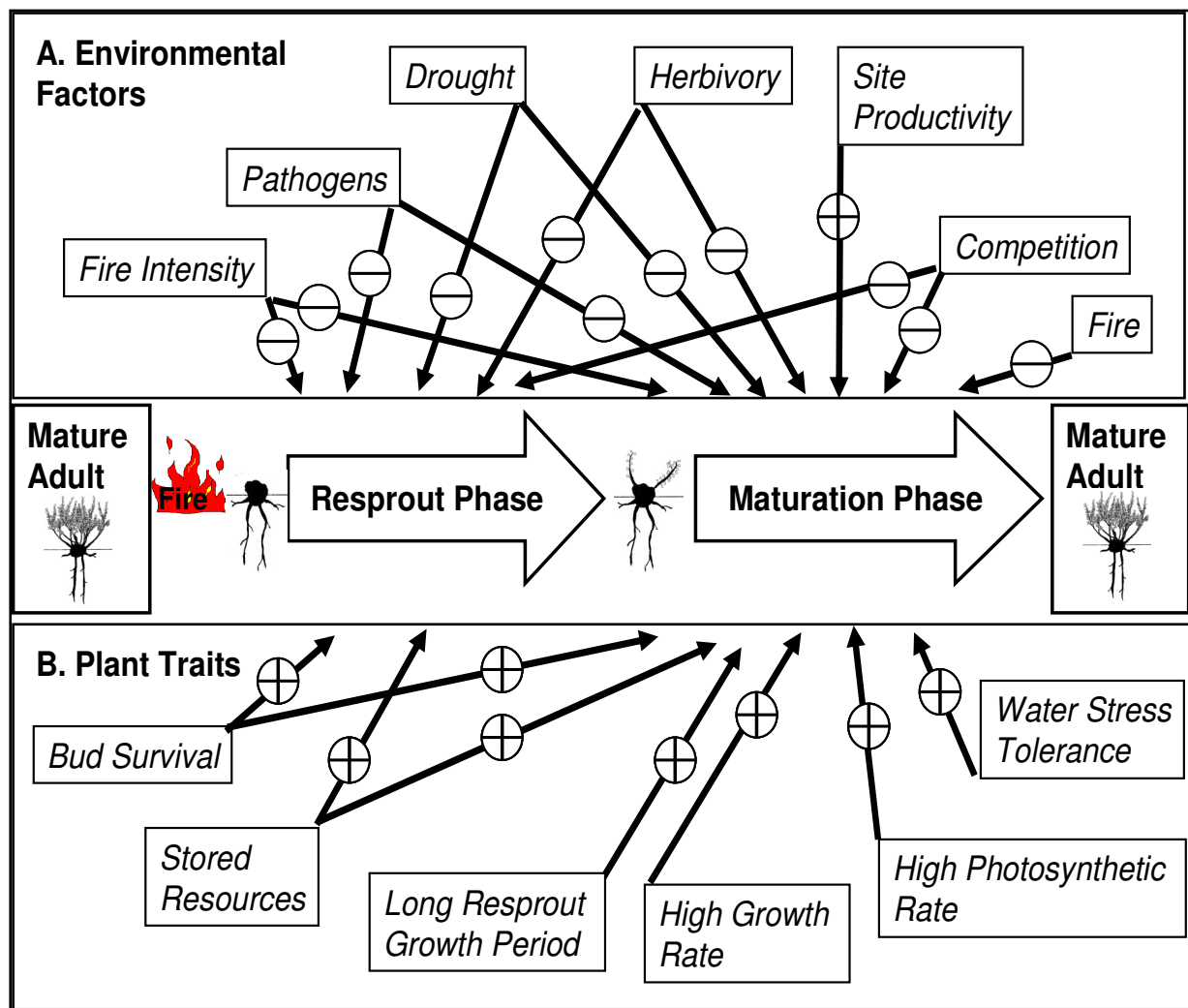
## **The Cape Floristic Region**

The Cape Floristic Region is dominated by fire-prone fynbos shrublands (Keeley et al. 2012) with an exceptional degree of biodiversity and niche adaptation (Cowling et al. 1996; Myers et al. 2000). Plants are stressed by long dry summers and nutrient poor soils, which makes these plant communities ideal for studies on postfire regeneration. To predict how ecosystems may respond to altered fire regimes requires an understanding of current vegetation dynamics in relation to fire (van Wilgen & Forsyth 1992). Plant life history type and the specific traits that enable postfire survival are essential to characterize, in order to understand evolutionary pathways and predict how plant communities will respond to altered fire regimes (van Wilgen & Forsyth 1992; Bond & van Wilgen 1996; Bond & Midgley 2001; Pausas et al. 2004; Buhk et al. 2007).

Fynbos has a relatively short fire return interval of between 10-20 years depending on the type of fynbos (van Wilgen 1982; Schutte et al. 1995; van Wilgen et al. 2010). Fire return intervals that are too short can obliterate certain NS species if new seedlings have not had sufficient time to mature and replenish their seed bank (Zedler et al. 1983; Le Maitre 1992; Syphard et al. 2006). Postfire regeneration studies in South Africa have mainly focused on the Proteaceae family, apart from the Swartboskloof study in Jonkershoek (van Wilgen & Forsyth 1992). The majority of Proteaceae are however NS species (Bond & Midgley 2001) and very little information exists on plants that persist through resprouting (FS and OS species), even though some fynbos communities harbour a large number of resprouter species (van Wilgen & Forsyth 1992). In a sample of 4418 fynbos species, Le Maitre & Midgley (1992) found that just over half of the species were resprouters, but this information is rarely captured in standard texts (Bond & Midgley 2001) and for fynbos species no central database houses the life history types of all species. Postfire resprout success is widely divergent between different species in fynbos (van Wilgen & Forsyth 1992), but the reasons that underlie these differences are still poorly understood (Bond & Midgley 2001). Understanding the contributory causes requires careful distinction between different resprout phases.

### **Postfire resprouting phases**

Resprouters need to have traits that protect them during a fire event. Having survived the fire, factors affecting resprout success can be divided into environmental (abiotic) factors and species specific (biotic) traits (see Figure 1.3).



**Figure 1.3.** Environmental factors (A) and plant traits (B) affecting postfire resprout success. Important phases to distinguish include the early resprout phase and the later maturation phase. Factors and traits are in boxes and solid arrows point to the phase in which they are expected to directly or indirectly influence resprout success. Circles with a + or – indicate whether a factor or trait is expected to have a positive or negative effect, respectively.

### *Resprouting phase*

Most FS and OS species resprout from buds contained within storage organs like lignotubers. If these buds are killed or damaged by a fire then resprouting will not take place (Canadell & López-Soria 1998; Veski & Westoby 2004). Bark thickness is an important trait for fire tolerance and bud protection (Whelan 1995), but this seems less important in chaparral and fynbos vegetation; possibly due to smaller shrub size and the high intensity fires characteristic of these regions (Hodgkinson 1998). One exception in mountain fynbos is *Protea nitida* that resprouts epicormically after a fire.

In the absence of photosynthesis postfire, the energy and carbon for resprouting is provided by stored reserves in the roots and/or storage organs like lignotubers. Plants actively regulate a balance between shoots (photosynthetic surface area) and roots (absorption area) (Bazzaz 1997). When the photosynthetic shoot is removed the root to shoot balance is disturbed. With no carbon uptake, resprouting cannot occur once carbon stores become depleted. The timing of the fire is thus crucially important, since it may affect the availability of stored carbohydrates. Natural fires in South African fynbos typically occur towards the end of the long dry summer, when stored reserves are at a peak. Other factors that may influence resprouting is pre-fire plant health (Le Maitre et al. 1992) and pre-fire plant size (Noble 1984; Stohlgren & Rundel 1986).

### *Maturation phase*

The maturation phase is the time from resprouting to reaching maturity. A major challenge faced by resprouters during the maturation phase is to restore the balance between roots and shoots. If an imbalance persists for too long, carbon starvation may lead to poor plant health and mortality (McDowell et al. 2008). Plants that resprout rapidly after a fire should restore their root to shoot balance sooner and then be able to replenish their depleted carbon reserves. Thus traits that promote balancing of the root to shoot ratio or tolerance to the stress induced by an imbalance, should characterize more successful resprouters.

Rapid growth will also be beneficial in recapturing space in the competitive postfire environment (Griffin 1973). Traits that facilitate higher rates of photosynthesis (net carbon assimilation) are predicted to be important for longer term survival during the maturation phase. A final trait to consider is water stress tolerance. The long dry summers cause many seedlings to die (Frazer & Davis 1988; Pratt et al. 2008), but the extensive roots system of resprouters offer some protection against excessive water stress (Thomas & Davis 1989). However, recent resprouts demonstrate greater sensitivity to water deficits (Rowan & Davis 2007; Osborne 2007) and post resprout dieback may be linked to water stress.

### **Life history type and resprouting**

The possible link between life history type and postfire resprout success has not been carefully evaluated. The relevance of life history type is illustrated by observations that seedlings of NS and FS species are often abundant postfire. Many of these seedlings suffer mortality, and typically FS suffer greater mortality than NS (Frazer & Davis 1988; Thomas & Davis 1989). However, since NS species depend on a single strategy to maintain population stability, it is critical that NS seedlings become established postfire to replace the adult plants

killed by the fire. FS species employ a dual strategy of resprouting and recruiting seedlings. Adults that die in a fire can be replaced by seedling recruits and therefore the population may still be maintained. It has been documented that FS populations that have lower postfire resprout survival tend to have relatively high levels of seedling recruitment that compensates for the loss of the adults (Stohlgren et al. 1989). Thus, there appears to be a trade-off between seedling recruitment and postfire resprout survival. This is an important point, because it suggests that there are intrinsic species and even intraspecific factors that control resprouting and that the phenomenon is not entirely controlled by stochastic abiotic factors (Moreira et al. 2012).

The demography of the OS life history type is quite different, since seeds of OS species are heat sensitive and relatively short lived and do not survive a fire (Keeley 2000). In order to ensure greater lifetime fitness, the pre-fire adults need to resprout to allow for greater seedling recruitment opportunities. Seedling recruitment for OS species tends to be rare and occur in between fires (Keeley 1986; Cowling et al. 1997; Bond & Midgley 2001). Because of these tradeoffs and differences in life history type demography, OS species fitness is predicted to be more dependent on resprouting and longevity than FS species. In order to get a more comprehensive overview of population stability and the relative contribution of different strategies to long term species survival, documentation of both resprouting and reseedling success over a longer time period is required.



## My study on Paarl Mountain

The overarching hypothesis for this study is that resprout success can be linked to life history type and plant functional traits in biodiverse south-western Cape mountain fynbos. The life history classification system used in this study differentiates: non-sprouters (NS), facultative resprouters (FS) and obligate resprouters (OS) (Keeley et al. 2006) (see Figure 1.2).

I conducted a 2-year repeated observation study documenting postfire regeneration in mountain fynbos following a wildfire that occurred from 3-7 March 2009. The Paarl Mountain Nature Reserve (33°44' S, 18°55' E) is situated close to the town of Paarl, Western Cape, South Africa. The vegetation is variable around the intrusive granite boulders and is classified as Boland Granite Fynbos at higher altitudes and Swartland Granite Renosterveld on the lower slopes (Mucina & Rutherford 2006). The mean annual rainfall on the mountain plateau is 960 mm (van Wilgen 1974; Zucchini 1992 in Milton 2003), with most of the rainfall occurring from May to September. The summer months are generally hot and dry, consistent with a mediterranean-type climate. The study area has a north-east facing aspect, with fine textured soils derived from granite. The elevation is around 600 m. The site last burned between 18 and 25 years ago (L. de Roubaix personal communication). The vegetation cover in the study site before the burn was dominated by ericoid and proteoid shrubs (Milton 2003).

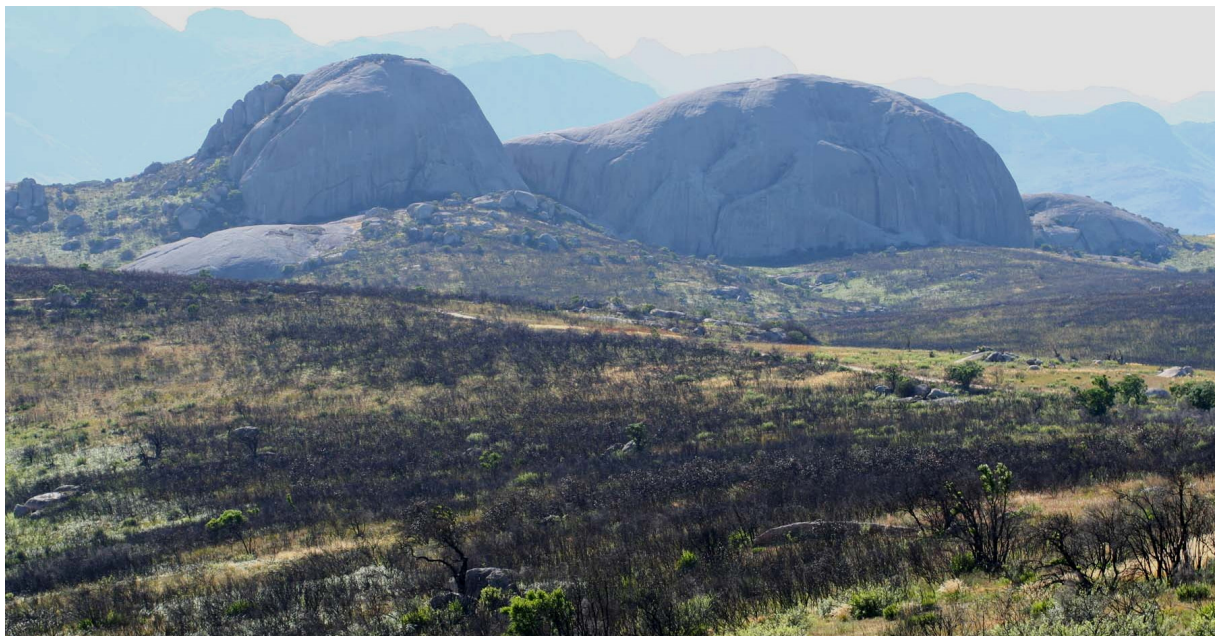


Figure 1.4 Granite outcrops on Paarl Mountain Nature reserve as seen from my study site, 7 months after the fire.



Paarl Mountain Nature Reserve (1910 ha) was established in 1970 and has been managed by the local municipality of Paarl and more recently the amalgamated Greater Drakenstein Municipality. The main roads in the reserve are accessible by vehicle and many maintenance tracks are open to mountain bikes. There are a variety of hiking tracks and the granite boulders attract rock climbers.

### **Main aims**

The main aims of the study were:

- 1) To compare the postfire resprout success of OS and FS species over a 2-year time period (Chapter 2).
- 2) To monitor seedling recruitment and compare the contribution of different regeneration strategies between OS, FS and NS species, one and two years postfire (Chapter 3).
- 3) To describe the postfire flowering phenology of species within the study site, by compiling a photographic library of species that flowered during each of the study visits (Chapter 4).

### **Methods**

Since this was a wildfire, I was unable to perform a pre-fire survey. In order to assess the pre-fire species composition I selected an adjacent unburned site with similar topographical features to establish the dominant woody species of the area. As I was interested in different resprouter species, I selected woody species that could be classified as either obligate resprouters (OS) or facultative resprouters (FS). In the seedling survey, the most dominant woody species for all three life history types (NS, FS and OS) present on the study site were selected. Details of the target species selected and the methods utilized to achieve each of the study aims are presented in the relevant chapters (Chapter 2, 3 and 4).

### **My personal contribution**

This master's project forms part of a bigger collaborative study between the California State University, Bakersfield and Stellenbosch University. I conceptualized the main study aims for the Paarl Mountain study. Site selection and target species selection was done in collaboration with the whole study team.

I personally conducted all the site visits and collected all the data (with the help of three volunteer field assistants) used in the analyses. One of the volunteer field assistants with a

particular interest in photography (Hedi Stummer) assisted with compiling the photographic library used for the flowering phenology chapter (Chapter 4). I constructed the database and did all the descriptive analyses. Prof Martin Kidd from the Centre for Statistical Consultation, Department of Statistics and Actuarial Sciences, University of Stellenbosch, assisted with the statistical analyses.

Figure 1.3 included in this chapter was reproduced from the original collaborative study protocol. All other written content and data analyses presented in this thesis represent my own research. I compiled the initial drafts and subsequent revisions of all chapters including the synthesis chapter, however I benefited greatly from the discussions and constructive input provided by my study supervisors Prof Karen Esler and Dr Shayne Jacobs from Stellenbosch University and Dr R. Brandon Pratt from California State University. Dr Anna Jacobsen from California State University also provided valuable input.

### **Thesis outline**

Chapter one (this chapter) serves as a general background to the study and outlines the study rationale.

The three data chapters (chapters two, three and four) are written in article format following the guidelines of the Journal of Ecology and some duplication within the article chapters is thus unavoidable.

The final chapter (chapter five) outlines the key findings of chapters' two to four and includes some management recommendations.

## References

- Armesto, J.J., Manuschevich, D., Mora, A., Smith-Ramirez, C., Rozzi, R., Abarzúa, A.M. & Marquet, P.A. (2010) From the Holocene to the Anthropocene: A historical framework for land cover change in southwestern South America in the past 15,000 years. *Land Use Policy*, **27**, 148-160.
- Axelrod, D.I. (1989) Age and origin of chaparral. *The California chaparral: paradigms reexamined*. (ed S.C. Keeley), Science series 34, pp. 7-19. Natural History Museum of Los Angeles County, Los Angeles, California.
- Bazzaz, F.A. (1997) Allocation of resources in plants: State of the science and critical questions. *Plant Resource Allocation* (eds. F.A. Bazzaz & J. Grace), pp. 303. Academic Press, San Diego.
- Bell, D.T., Hopkins, A.J.M. & Pate, J.S. (1984) Fire in the Kwongan. *Kwongan plant life of the sandplain: biology of a south-west Australian shrubland ecosystem*. (eds. J. S. Pate & J.S. Beard), pp. 178-204. University of Western Australia Press, Nedlands, western Australia.
- Bellingham, P.J. & Sparrow, A.D. (2000) Resprouting as a life history strategy in woody plant communities. *Oikos*, **89**, 409-416.
- Bond, W.J. & Keeley, J.E. (2005) Fire as a global 'herbivore': the ecology and evolution of flammable ecosystems. *Trends in Ecology and Evolution*, **20**, 387-394.
- Bond, W.J. & Midgley, J.J. (2001) Ecology of sprouting in woody plants: the persistence niche. *Trends in Ecology and Evolution*, **16**, 45-51.
- Bond, W.J. & Midgley, J.J. (2003) The evolutionary ecology of sprouting in woody plants. *International Journal of Plant Science*, **164**, S103-S114.
- Bond, W.J. & Scott, A.C. (2010) Fire and the spread of flowering plants in the Cretaceous. *New Phytologist*, **188**, 1137-1150.
- Bond, W.J. & van Wilgen, B.W. (1996) *Fire and Plants*, Chapman & Hall, London.
- Bond, W.J., Vlok, J. & Viviers, M. (1984) Variation in seedling recruitment of cape Proteaceae after fire. *Journal of Ecology*, **72**, 209-221.
- Bond, W.J., Woodward, F.I. & Midgley, G.F. (2005) The global distribution of ecosystems in a world without fire. *New Phytologist*, **165**, 525-538.
- Bradshaw, S.D., Dixon, K.W., Hopper, S.D, Lambers, H. & Turner, S.R. (2011). Little evidence for fire-adapted plant traits in Mediterranean climate regions. *Trends in Plant Science*, **16**, 69-75.
- Buhk, C., Meyn, A. & Jentsch, A. (2007) The challenge of plant regeneration after fire in the Mediterranean basin: scientific gaps in our knowledge on plant strategies and evolution of traits. *Plant Ecology*, **192**, 1-19.

- Canadell, J. & López-Soria, L. (1998) Lignotuber reserves support regrowth following clipping of two Mediterranean shrubs. *Functional Ecology*, **12**, 31-38.
- Cowling, R.M., Kirkwood, D., Midgley, J.J. & Pierce, S.M. (1997) Invasion and persistence of bird-dispersed, subtropical thicket and forest species in fire-prone coastal fynbos. *Journal of Vegetation Science* **8**, 475-488.
- Cowling, R.M., Ojeda, F., Lamont, B.B., Rundel, P.W. & Lechmere-Oertel, R. (2005) Rainfall reliability, a neglected factor in explaining convergence and divergence of plant traits in fire-prone Mediterranean-climate ecosystems. *Global Ecology and Biogeography*, **14**, 509-519.
- Cowling, R.M., Rundel, P.W., Lamont, B.B., Arroyo, M.K. & Arianoutsou, M. (1996) Plant diversity in mediterranean-climate regions. *Trends in Ecology and Evolution*, **11**, 362-366.
- Enright, N.J., Fontaine, J.B., Wetscott, V.C., Lade, J.C. & Miller, B.P. (2011) Fire interval effects on persistence of resprouter species in Mediterranean-type shrublands. *Plant Ecology*, **212**, 2071-2083.
- Enright, N.J., Marsula, R., Lamont, B.B., & Wissel, C. (1998) The ecological significance of canopy seed storage in fire-prone environments: a model for non-sprouting shrubs. *Journal of Ecology*, **86**, 946-959.
- Frazer, J.M. & Davis, S.D. (1988) Differential survival of chaparral seedlings during the first summer drought after wildfire. *Oecologia*, **76**, 215-221.
- Gordon A.J. 2003. Biology and host range of the stem-boring beetle *Aphanasium australe*, a promising agent for the biological control of *Hakea sericea* in South Africa. *Biocontrol*, **48**,113-122.
- Griffin, J.R. (1973) Xylem sap tensions in three woodland oaks of central California. *Ecology*, **54**, 152-159.
- Grisebach, A.H.R. (1872) *Die Vegetation der Erde nach ihrer klimatischen Anordnung*. W. Engelmann, Leipzig, Germany.
- Grubb, P.J. (1977) The maintenance of species-richness in plant communities: the importance of the regeneration niche. *Biological Review*, **52**, 107-145.
- He, T., Lamont, B.B. & Downes, K.S. (2011) Banksia born to burn. *New Phytologist*, **191**, 184-196.
- Heelemann, S., Proches, S., Rebelo, A.G., Van Wilgen, B.W., Porembski, S. & Cowling, R.M. (2008) Fire season effects on the recruitment of non-sprouting serotinous Proteaceae in eastern (bimodal rainfall) fynbos biome, South Africa. *Austral Ecology*, **33**, 119-127.
- Higgins, S.I., Flores, O. & Schurr, F. (2008) Costs of persistence and the spread of competing seeders and resprouters. *Journal of Ecology*, **96**, 679-686.

- Hodgkinson, K.C. (1998) Sprouting success of shrubs after fire: height-dependent relationships for different strategies. *Oecologia*, **115**, 64-72.
- Holmes, P.M. & Newton, R.J. (2004) Patterns of seed persistence in South African fynbos. *Plant Ecology*, **172**, 143-158.
- Hopper, S.D. (2009) OCBIL theory: towards an integrated understanding of the evolution, ecology and conservation of biodiversity on old, climatically buffered, infertile landscapes. *Plant and Soil*, **322**, 49-86.
- Jacobsen, A.L., Esler, K.J., Pratt, R.B. & Ewers, F.W. (2009) Water-stress tolerance of Mediterranean-type climate regions: Convergence of Fynbos and Succulent Karoo communities with California shrub communities. *American Journal of Botany* **96**, 1445–1453.
- Keeley, J.E. (1986) Resilience of mediterranean shrub communities to fires. Resilience in mediterranean-type ecosystems (eds. Dell, B., Hopkins, A.J.M. & Lamont, B.B.), pp.95-112. Junk, The Hague.
- Keeley, J.E. (2000) Chaparral. *North American Terrestrial Vegetation* (eds. M. G. Barbour & W. D. Billings), pp. 203-253. Cambridge, New York.
- Keeley, J.E., Aplet, G.H., Christensen, N.L., Conard, S.G., Johnson, E.A., Omi, P.N., Peterson D.L. & Swetnam, T.W. (2009) Ecological Foundations for Fire Management in North American Forest and Shrubland Ecosystems. General Technical Report PNW-GTR-779, pp.9-19. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon.
- Keeley, J.E. & Bond, W.J. (1997) Convergent seed germination in South African fynbos and Californian Chaparral. *Plant Ecology* **133**, 153-167.
- Keeley, J.E., Bond, W.J., Bradstock, R.A., Pausas, J.G. & Rundel, P.W. (2012) Fire in Mediterranean Ecosystems; ecology, evolution and management. Cambridge University Press, New York.
- Keeley, J.E., Fotheringham, C.J & Baer-Keeley, M. (2006) Demographic patterns of postfire regeneration in Mediterranean-climate shrublands of California. *Ecological Monographs* **76**, 235-255.
- Keeley, J.E., Pausas, J.G., Rundel, P.W., Bond, W.J. & Bradstock, R.A. (2011) Fire as an evolutionary pressure shaping plant traits. *Trends in Plant Science*, **16**, 406-411.
- Keeley, J.E. & Zedler, P.H. (1978) Reproduction of chaparral shrubs after fire: a comparison of sprouting and seeding strategies. *American Midland Naturalist*, **99**, 142-161.
- Lamont, B.B. & Cowling, R.M. (1984) Flammable infructescences in *Banksia*: a fruit-opening mechanism. *Australian Journal of Ecology*, **9**, 295-296.
- Lamont, B.B., Enright, N.J. & He, T. (2011) Fitness and evolution of resprouters in relation to fire. *Plant Ecology*, **212**, 1945-1957.

- Laurie, H. & Cowling, R.M. (1994) Lottery coexistence models extended to plants with disjoint generations. *Journal of Vegetation Science*, **5**, 161-168.
- Lavorel, S., Canadell, J., Rambal, S. & Terradas, J. (1998) Mediterranean terrestrial ecosystems: research priorities on global change effects. *Global Ecology and Biogeography*, **7**, 157-166.
- Lavorel, S., McIntyre, S., Landsberg, J. & Forbes, T.D.A. (1997) Plant functional classification: from general groups to specific groups based on response to disturbance. *Trends in Ecology and Evolution* **12**, 474-478.
- Le Maitre, D.C. (1992) The relative advantage of seeding and sprouting in fire-prone environments: a comparison of life histories of *Protea neriifolia* and *Protea nitida*. *Fire in South African Mountain Fynbos: Ecosystem, Community and Species Response at Swartboskloof* (eds B.W. Van Wilgen, D.M. Richardson, F.J. Kruger & H.J. van Hensbergen). pp 123-144. Springer-Verlag, New York.
- Le Maitre, D.C., Jones, C.A. & Forsyth, G.G. (1992) Survival of eight woody sprouting species following an autumn fire in Swartboskloof, Cape Province, South Africa. *South African Journal of Botany* **58**, 405-413.
- Le Maitre, D.C. & Midgley, J.J. (1992) Plant reproductive ecology. The ecology of fynbos. nutrients, fire and diversity (ed. R.M. Cowling), pp. 135-174, Oxford University Press, Cape Town.
- Linder, H.P., Meadows, M.E. & Cowling, R.M. (1992) History of the Cape flora. The Ecology of Fynbos, Nutrients, Fire and Diversity (ed. R.M. Cowling), pp. 113-134, Oxford University Press, Cape Town.
- McClellan, C.J., Lovett, J.C., Kuper, W., Hannah, L., Sommer, J.H., Barthlott, W., Termansen, M., Smith, G.F., Tokumine, S. & Taplin, J.R.D. (2005) African plant diversity and climate change. *Annals of the Missouri Botanical Garden*, **92**, 139-152.
- McDowell, N., Pockman, W.T., Allen, C.D., Breshears, D.D., Cobb, N., Kolb, T., Plaut, J., Sperry, J.S., West, A., Williams, D.G. & Yezzer, E.A. (2008) Mechanisms of plant survival and mortality during drought: why do some plants survive while others succumb to drought? *New Phytologist*, **178**, 719-739.
- Midgley G. F., L. Hannah, D. Millar, W. Thuiller, and A. Booth. 2003. Developing regional and species-level assessments of climate change impacts on biodiversity in the Cape Floristic Region. *Biological Conservation*, **112**, 87-97.
- Midgley, J.J. (1996) Why the world's vegetation is not totally dominated by resprouting plants: because resprouters are shorter than reseeders. *Ecography*, **19**, 92-95.
- Milton, S.J. (2003) Vegetation Survey. Paarl Mountain Nature Reserve. Conservation Ecology Department, University of Stellenbosch, 7701 Stellenbosch.

- Mooney, H.A. & Dunn, E.L. (1970) Convergent evolution of Mediterranean climate evergreen sclerophyll shrubs. *Evolution*, **24**, 292-303.
- Moreira, B., Tormo, J. & Pausas, J.G. (2012) To resprout or not to resprout: factors driving intraspecific variability in sprouting. *Oikos in press* (doi: 10.1111/j.1600-0706.2011.20258.x)
- Mucina, L. & Rutherford, M.C. (eds) (2006) The vegetation of South Africa, Lesotho and Swaziland. *Strelitzia* **19**. South African National Biodiversity Institute, Pretoria.
- Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., & Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature*, **403**, 853-858.
- Noble, I.R. (1984) Mortality of seedlings of *Eucalyptus* species after an intense fire in montane forest. *Australian Journal of Ecology*, **9**, 47-50.
- Noble, I.R. & Slatyer, R.O. (1980) The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbance. *Vegetatio* **43**, 5-21.
- Ojeda, F., Brun, F.G. & Vergara, J.J. (2005) Fire, rain and the selection of seeder and resprouter life-histories in fire-recruiting, woody plants. *New Phytologist*, **168**, 155-165.
- Ojeda, F., Pausas, J.G., & Verdú, M. (2010) Soil shapes community structure through fire. *Oecologia*, **163**, 729-735.
- Osborne, J.B. (2007) *Differences in the hydraulic properties of stem xylem between post-fire resprouts and pre-fire adults of Ceanothus spinosus*. Honors Thesis, Pepperdine University, Malibu, California.
- Paula, S. & Ojeda, F. (2009) Belowground starch consumption after recurrent severe disturbance in three resprouter species of the genus *Erica*. *Botany*, **87**, 253-259.
- Paula, S. & Pausas, J.G. (2011) Root traits explain different foraging strategies between resprouting life histories. *Oecologia* **165**, 321-331.
- Pausas, J.G., & Bradstock, R.A. (2007) Fire persistence traits of plants along a productivity and disturbance gradient in Mediterranean shrublands of SE Australia. *Global Ecology and Biogeography*, **16**, 330-340.
- Pausas J.G., Bradstock, R.A., Keith, D.A., Keeley, J.E., Hoffman, W., Kenny, B., Lloret, F. & Trabaud, L. (2004) Plant functional traits in relation to fire in crown-fire ecosystems. *Ecology*, **85**, 1085-1100.
- Pausas, J.G., & Keeley, J. (2009) A burning story: the role of fire in the history of life. *BioScience*, **59**, 593-601.
- Pausas, J.G. & Verdú, M. (2005) Plant persistence traits in fire-prone ecosystems of the Mediterranean basin: a phylogenetic approach. *Oikos*, **109**, 196-202.
- Pérez, B. & Moreno, J. (1998) Methods for quantifying fire severity in shrubland-fires. *Plant Ecology*, **139**, 91-101.



- Pratt, R.B., Jacobsen, A.L., Golgotiu, K.A., Sperry, J.S., Ewers, F.W. & Davis, S.D. (2007) Life history type and water stress tolerance in nine California chaparral species (Rhamnaceae). *Ecological Monographs*, **77**, 239-253.
- Pratt, R.B., Jacobsen, A.L., Jacobs, S.M. & Esler, K.J. (2012) Xylem transport safety and efficiency differ among fynbos shrub life history types and between two sites differing in mean rainfall. *International Journal of Plant Science* **173**, 474-483.
- Pratt, R.B., Jacobsen, A.L., Mohla, R., Ewers, F.W. & Davis, S.D. (2008) Linkage between water stress tolerance and life history type in seedlings of nine chaparral species (Rhamnaceae) *Journal of Ecology*, **96**, 1252-1265.
- Pratt, R.B., North, G.B., Jacobsen, A.L., Ewers, F.W. & Davis, S.D. (2010) Xylem root and shoot hydraulics is linked to life history type in chaparral seedlings. *Functional Ecology*, **24**, 70-81.
- Rowan, N.R. & Davis, S.D. (2007) Hydraulic transport properties of post-fire resprouts and pre-fire adults of holly-leaf redberry (*Rhamnus ilicifolia*) in the Santa Monica Mountains. *Ecological Society of America annual meeting*. San Jose, California, USA.
- Rundel, P.W. (2010) Convergence and divergence in mediterranean-climate ecosystems: what we can learn by comparing similar places. *The ecology of place* (eds. M. Price & I. Billick). pp. 93-108. University of Chicago Press, Chicago, Illinois.
- Schimper, A.F.W. (1903) *Plant geography upon a physiological basis*. Clarendon Press, Oxford, UK.
- Schutte, A.L., Vlok, J.H.J., & Van Wyk, B.E. (1995) Fire-survival strategy – a character of taxonomic, ecological and evolutionary importance in fynbos legumes. *Plant Systematics and Evolution* **195**: 243-259.
- Schwilk, D.W. & Ackerly, D.D. (2001) Flammability and serotiny as strategies: correlated evolution in pines. *Oikos*, **94**, 326-336.
- Scott, A.C. (2000) The Pre-Quaternary history of fire. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **164**, 297-345.
- Scott, A.C. & Glasspool, J.J. (2006) The diversification of Palaeozoic fire systems and fluctuations in atmospheric oxygen concentration. *Proceedings of the National Academy of Sciences*, **103**, 10861-10865.
- Seager, R., Ting, M., Held, I., Kushnir, Y., Lu, J., Vecchi, G., Huang, H.-P., Harnik, N., Leetmaa, A., Lau, N.-C., Li, C., Velez, J. & Naik, N. (2007) Model projections of an imminent transition to a more arid climate in southwestern North America. *Science*, **316**, 1181-1184.
- Stohlgren, T.J. & Rundel, P.W. (1986) A population model for a long-lived, resprouting chaparral shrub: *Adenostoma fasciculatum*. *Ecological Modelling*, **34**, 245-257.



- Syphard, A.D., Franklin, J. & Keeley, J. E. (2006) Simulating the effects of frequent fire on southern California coastal shrublands. *Ecological Applications*, **16**, 1744-1756.
- Thomas, C.M. & Davis, S.D. (1989) Recovery patterns of three chaparral shrub species after wildfire. *Oecologia*, **80**, 309-320.
- Tyson P., E. Odada, R. Schulze, C. Vogel. 2002. Regional-global change linkages: Southern Africa. *Global-Regional Linkages in the Earth System* (eds. P. Tyson, R. Fuchs, C. Fu, L. Lebel, A.P Mitra, E. Odada, J. Perry, W. Steffen, H. Virja), pp. 3-73. Springer-Verlag, Berlin.
- Van Wilgen, B. (1974) A management plan for the Paarl Mountain Nature Reserve, Nature Conservation Department (Conservation Ecology), University of Stellenbosch.
- Van Wilgen, B.W. (1982) Some effects of post-fire age on the above-ground plant biomass of fynbos (macchia) vegetation in South Africa. *Journal of Ecology* **70**, 217-225.
- Van Wilgen, B.W. & Forsyth, G.G. (1992) Regeneration Strategies in fynbos plants and their influence on the stability of community boundaries after fire. *Fire in South African Mountain Fynbos: Ecosystem, Community and Species Response at Swartboskloof* (eds B.W. Van Wilgen, D.M. Richardson, F.J. Kruger & H.J. van Hensbergen). pp 54-80. Springer-Verlag, New York.
- Van Wilgen, B.W., Forsyth, G.G., de Klerk, H., Das, S., Khuluse, S. & Schmitz, P. (2010) Fire management in Mediterranean-climate shrublands: a case study from the Cape fynbos, South Africa. *Journal of Applied Ecology* **47**, 631-638.
- Van Wilgen, B.W. & Richardson, D.M. (1985) The effect of alien shrub invasions on vegetation structure and fire behaviour in South African fynbos shrublands: a simulation study. *Journal of Applied Ecology*, **22**, 955-966.
- Vesk, P.A. & Westoby, M. (2004) Funding the bud bank: a review of the costs of buds. *Oikos*, **106**, 200-208.
- Vlok, J.H.J. & Yeaton, R.I. (2000) Competitive interactions between overstorey proteas and sprouting understorey species in South African mountain fynbos. *Diversity and Distributions*, **6**, 273-281.
- Westerling, A.L., Hidalgo, H.G., Cayan, D.R. & Swetnam, T.W. (2006) Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity *Science*, **313** 940-943.
- Whelan, R.J. (1995) *The Ecology of Fire*. Cambridge University Press, New York.
- Zedler, P.H., Gautier, C.R. & McMaster, G.S. (1983) Vegetation change in response to extreme events: the effect of a short interval between fires in California chaparral and coastal scrub. *Ecology*, **64**, 809-818.
- Zucchini, W. (1992) "Genrain" rainfall simulation programme for South Africa. Applied Statistics and Decision Sciences Unit. University of Cape Town, Rondebosch 7700.

## CHAPTER 2

### Postfire regeneration of mountain fynbos: A comparison of the obligate and facultative resprouting life history types

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#### Abstract

Fire is a natural occurrence in Mediterranean type climate regions and plant species that inhabit these regions have traits that facilitate their persistence under a given fire regime. Understanding how native vegetation responds to fire will become increasingly important to make predictions on how the vegetation might change under different fire regimes. The overarching hypothesis is that postfire resprout success in the south-western Cape is linked to life history type and plant functional traits. Obligate resprouters have to resprout to persist, as their seeds are killed by fire, facultative resprouters recruit seedlings and resprout after fire and non-sprouters are killed by fire and only recruit seedlings from a fire-stimulated seedbank. The aim of this study is to find predictors of resprout success and to see if there are significant differences between obligate and facultative resprouters. Results on mortality and survivorship from postfire fynbos data over a two year period show that there was a significant difference in postfire resprout success between obligate resprouters and facultative resprouters, with a near 100% resprout success of obligate resprouters, against 65% of facultative resprouters. Obligate resprouters all sprouted within the first four months postfire, while some facultative resprouters took up to a year to resprout after the fire. Obligate resprouters also had a greater relative growth rate than facultative resprouters, reaching half of their maximum growth over two years in only 184 days compared to 277 days for facultative resprouters. Variables influencing mortality due to fire were different from those influencing postfire mortality. Lignotuber exposure, number of pre-fire shoots as well as fire intensity played a significant role in mortality due to fire. Postfire mortality was significantly correlated to life history type, where facultative resprouter species had higher mortality rates and plants that had a longer lag period after the fire before they resprouted had higher postfire mortality rates. My results thus confirm that obligate resprouters are stronger resprouters than facultative resprouters.

## Introduction

The five Mediterranean-type ecosystems of the world have been identified as biodiversity hotspots of global conservation concern (Cowling et al. 1996; Myers et al. 2000). These ecosystems are prone to fire of a particular frequency; however, fire frequency has increased in many areas in these regions due to human activities and global climate change and this alteration in fire regime may destabilize these systems (Syphard et al. 2006; van Wilgen et al. 2010). To predict how these systems respond to altered fire regimes we need to better understand how plants respond to fire and what makes them resilient to this disturbance. To this end, numerous studies have been done in fire-prone Mediterranean type ecosystems all over the world to better understand vegetation recovery after a fire (Noble & Slatyer 1980; Bond 1984; le Maitre et al. 1992; Privett et al. 2001; Keeley et al. 2006). Common themes have emerged and have allowed researchers to classify plants into different categories based on how they respond to fire (Bond & van Wilgen 1996; Lavoirel et al. 1997; Allen 2008) or to disturbance more generally (Noble & Slatyer 1980; Noble & Gitay 1996; Lavoirel et al. 1997). Plants use different survival mechanisms to regenerate after fires and the binary classification system, classifying species as either resprouters or non-sprouters has been widely applied in mediterranean-type ecosystems (Bond & van Wilgen 1996; Bond & Midgley 2001, 2003; Vesk & Westoby 2004; Verdú et al. 2007). This simple dichotomy captures a lot of variation in important plant traits and life history parameters (Vesk & Westoby 2004); however it lacks a distinction between obligate and facultative resprouters.

South African fynbos vegetation is well adapted to intermittent crown fires and plant species generally regenerate rapidly after fire. Resprouters are well represented in the flora of the Cape Floristic region. In one study in Swartboskloof, Jonkershoek, close to the town of Stellenbosch, 210 species were recorded on a post-burn site, of which more than 70% were resprouters (van Wilgen & Forsyth 1992). Further, Le Maitre & Midgley (1992) reported just over 50 % of the 4418 Cape flora species they evaluated to be resprouters. Despite the prevalence of resprouters, the ecology of non-sprouters has been more widely studied (e.g. Bond et al. 1984; Laurie & Cowling 1994; Keeley et al. 2006; Heelemann et al. 2008). The focus on non-sprouters (often referred to as obligate seeders) has been justified as this is a diverse group, many of them endemic to the fynbos vegetation type. Additionally, for many taxa, resprouting is ancestral and thus non-sprouting is derived. This has provided an interesting puzzle as the seedling stage is such an obvious vulnerable stage in the life cycle of plants. Seedling recruitment for many species takes place in a single germination event triggered by fire (Schutte et al. 1995; Bond & van Wilgen 1996; le Maitre & Midgley 1992; Cowling et al. 1997; Keeley & Bond 1997; Ojeda et al. 2005) and failure to germinate or failure to advance to the adult stage could have devastating effects on those reseeders

populations (Ojeda et al. 2005). Thus it would seem that non-sprouters abandoned a safer resprouting life history type for a riskier non-sprouting one.

Wells (1969) noted the ubiquity of resprouting, yet the lack of information on resprouting behaviour in taxonomic monographs of plants (Bond & Midgley 2001) points to a gap in our knowledge on resprouters. Although we know that resprouting ability between different species differs widely (van Wilgen & Forsyth 1992; Bond & Midgley 2001; Moreira et al. 2012), the mechanisms underlying these differences are still poorly understood (le Maitre et al. 1992; van Wilgen & Forsyth 1992). Thus, it is not only regeneration through seedlings, but also resprouting behaviour that needs to be better understood in order to identify more accurate ways to model the effects of altered fire regimes, climate change and various other ecosystem disturbances on ecosystem structure and functioning (Bond 1997; Bond & Midgley 2001; Lavorel et al. 1997).

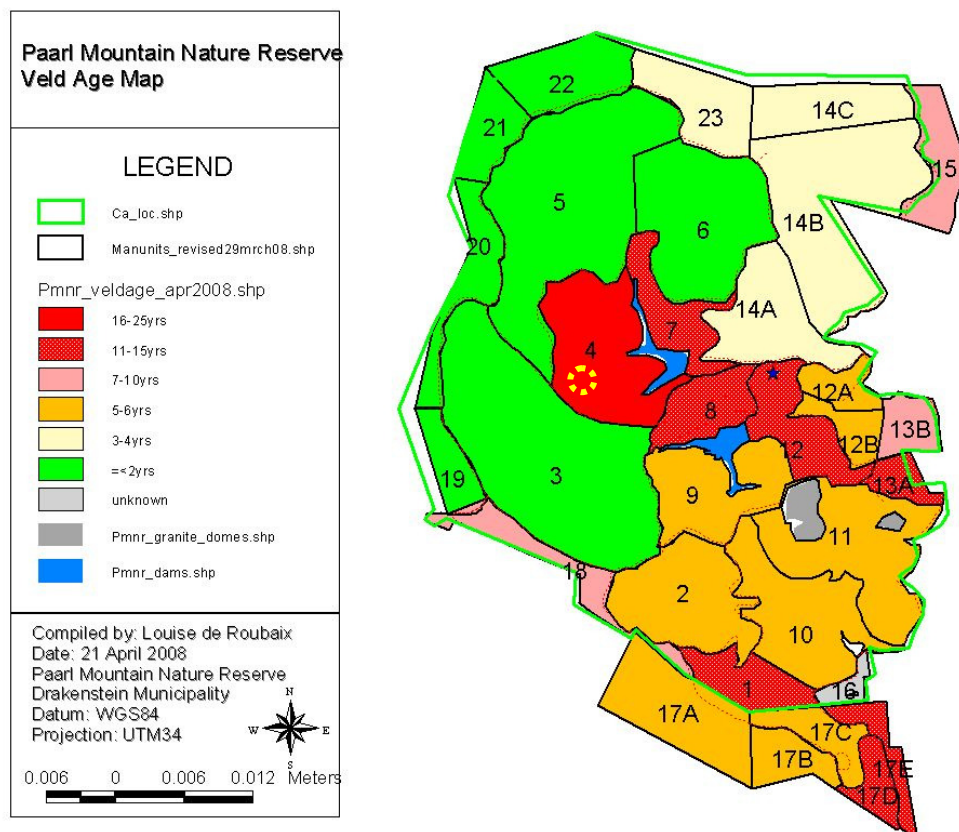
In this study I concentrated on resprouters in an effort to better understand the variability within this group. Vesk & Westoby (2004) classified resprouters as either weak resprouters or strong resprouters. I used another classification that has been used in resprouters, namely obligate resprouters (OS) and facultative resprouters (FS) (Keeley 1986; Keeley et al. 2006). Obligate resprouters regenerate postfire by resprouting only; seedling recruitment for these species is rare (Bond & Midgley 2001) and occurs mainly in the understory of mature vegetation during fire-free intervals (Keeley 1986; Midgley & Cowling 1993). Plants that have a dual strategy of resprouting and seeding are classified as facultative resprouters (FS). Species that die in the fire and only regenerate by seeds are classified as non-sprouters (NS). The seeds of FS and NS species in fire-prone fynbos vegetation germinate through cues related directly or indirectly to fire and seedling recruitment takes place almost exclusively during the first year post fire (Le Maitre & Midgley 1992; Schutte et al. 1995; Cowling et al. 1997; Keeley & Bond 1997).

Splitting the resprouters into obligate and facultative groups allows for more subtle characterization that may ultimately be more informative with respect to their biology. As obligate resprouting species rarely recruit seedlings (Bond & Midgley 2001) and do not recruit seedlings directly postfire as their seeds are generally not fire resistant (Keeley 1986), the fitness of individuals may be strongly tied to their ability to resprout and persist after fire to ensure seedling recruitment opportunities between fire cycles. Facultative resprouting species could also maximize their fitness by resprouting after fire; however, they do reliably recruit seedlings after fire. I hypothesized that OS species would exhibit greater resprout success than FS species.

I tested this hypothesis by recording the mortality of species due to fire and postfire and if this was related to their life history type. Moreover, I collected additional data that allowed me to assess why resprout success differed. This included growth, timing of resprouting, size and exposure of lignotuber, fire intensity, and the number of pre-fire shoots as an estimate of pre-fire health. I predicted that faster growth, earlier resprouting, larger and less exposed lignotubers, lower fire intensity, and greater number of pre-fire shoots would all be associated with greater resprout success.

## Methods

I conducted a 2-year repeated observation study, documenting postfire regeneration in mountain fynbos following a wildfire that occurred from 3-7 March 2009.



**Figure 2.1** Vegetation age map of Paarl Mountain Nature Reserve as mapped in April 2008. The yellow dotted circle is the area of the study site within compartment 4. The entire compartment 4 burned in the fire on Paarl Mountain between 3-7 March 2009. The map was obtained from L. de Roubaix, Paarl Mountain Nature Reserve, Drakenstein Municipality.



## Study Site

The Paarl Mountain Nature Reserve (33°44' S, 18°55' E) is situated close to the town of Paarl, Western Cape, South Africa. The vegetation is variable around the intrusive granite boulders and is classified as Boland Granite Fynbos at higher altitudes and Swartland Granite Renosterveld on the lower slopes (Mucina & Rutherford 2006). The mean annual rainfall on the mountain plateau is 960 mm (van Wilgen 1974; Zucchini 1992 in Milton 2003), with most of the rainfall occurring from May to September. The summer months are generally hot and dry, consistent with a mediterranean-type climate. The study area has a north-east facing aspect, with fine textured soils derived from granite. The elevation is around 600 m. The site last burned between 18 and 25 years ago (L. de Roubaix personal communication) (see Figure 2.1, compartment 4). The vegetation cover in the study site before the burn was dominated by ericoid and proteoid shrubs (Milton 2003).

## Species selection

Since this was a wildfire, I was unable to perform a pre-fire survey. In order to assess the pre-fire species composition I selected an adjacent unburned site with similar topographical features to establish the dominant species of the area. As I was interested in different resprouter species, I selected woody species that could either be classified as obligate resprouters (OS) or facultative resprouters (FS). See Table 2.1 for target species (see Appendix A for all species tagged). Nomenclature follows Goldblatt & Manning (2000) except for the *Searsia* spp, which follow Yi *et al.* (2004).



**Fig 2.2** Tagged *Diosma hirsuta* resprouting after the fire on Paarl Mountain in May 2009.

## Sampling methods

Field work started on 23 March 2009, 19 days postfire. A weather station was set-up to monitor rainfall (rain gauge) and temperature (HOBO pendant data logger, Onset Computer Corporation, Massachusetts, USA) at the study site. Individual burnt stumps were visually assessed and selected by walking transects across the study site. The selected stumps were tagged with numbered, fire-proof tags. I aimed to tag a minimum of 40 individuals per species, except for the dioecious species *Leucadendron salignum*, where I aimed to tag a minimum of 40 male and female plants each. The selection was done on the basis of recognizing possible resprouter species, through identifying burnt bark traits as well as scorched fallen leaves and fruit around the burnt stumps. The initial measurements included:

- (i) lignotuber circumference, as a measure for stored reserves, available bud bank and/or an estimate of plant age. (Moreno & Oechel 1991; le Maitre et al. 1992; Bell & Ojeda 1999; Paula & Ojeda 2006)
- (ii) number of pre-fire shoots, as a measure of pre-fire vigour (le Maitre et al. 1992).
- (iii) burnt branch diameter of terminal branches, as a measure of fire intensity (Moreno & Oechel 1993; Perez & Moreno 1998; Euston-Brown et al. 2004), the bigger the diameter of burnt branches, the more intense the fire.
- (iv) lignotuber height above soil (burl/lignotuber exposure) as well as slope, as a measure of erosion potential.

Follow-up data and measurements taken at each site visit included:

- (i) resprouted, yes/no,
- (ii) number of resprouted shoots,
- (iii) elongation of longest shoot (in cm),
- (iv) insect/mammal herbivory,
- (v) percentage alive.

When counting the resprouts ([ii] above), I limited the count to resprouts not more than 5cm away from the lignotuber. This was done to focus on a single main ramet, because without extensive excavation or genetic fingerprinting it was not feasible to study whole genets for root suckering species.

Field surveys were conducted at two weekly intervals for the first two months, then monthly for the rest of the first year postfire and then seasonally (winter, spring, summer and autumn)

for the second year. Table 2.1 reflects the final species count after species verification (post-sprout).

**Table 2.1** Sample size of target species after verification, including their life history type and growth form. Abbr. = abbreviation; LTH = life history type

Species	Family	Abbr.	LHT	Growth form	n
<i>Diospyros glabra</i> (L.) De Winter	Ebenaceae	Dsp	OS <sup>1,2</sup>	Dioecious shrub /small tree	45
<i>Searsia rosmarinifolia</i> (Vahl) F.A.Barkley	Anacardiaceae	Sr	OS <sup>2</sup>	Dioecious scrambling shrub	13
<i>Searsia tomentosa</i> (L.) F.A.Barkley	Anacardiaceae	St	OS <sup>2,3</sup>	Dioecious shrub / small tree	29
<i>Diosma hirsuta</i> L.	Rutaceae	Dma	FS <sup>2</sup>	Ericoid shrublet	37
<i>Cliffortia juniperina</i> L.f.	Rosaceae	Cj	FS <sup>4</sup>	Ericoid shrublet	34
<i>Cliffortia ruscifolia</i> L.	Rosaceae	Cr	FS <sup>2,3</sup>	Small leaved, spiny shrub	21
<i>Aspalathus bracteata</i> Thunb.	Fabaceae	Asp	FS <sup>5</sup>	Scrambling shrublet	51
<i>Leucadendron salignum</i> P.J.Bergius	Proteaceae		FS <sup>2</sup>	Small proteoid shrub	
<b>male</b>		Le M			44
<b>female</b>		Le F			43
<b>gender unknown</b>		Le U			7
<b>TOTAL</b>					<b>325</b>

<sup>1</sup> Cowling et al. 1997; <sup>2</sup> van Wilgen & Forsyth 1992; <sup>3</sup> Keeley & Bond 1997; <sup>4</sup> Whitehouse 2002; <sup>5</sup> C.H Stirton, personal communication

## Statistical analysis

Due to the difficulty of accurate postfire species assignment prior to resprouting, sample sizes were not uniform. Species sample sizes of less than ten were excluded from the species specific analyses. Percentage survival was compared between the two life history types (facultative vs. obligate) using cross tabulation and the Chi-square test. The non-parametric Mann-Whitney U test was used to compare days to 1<sup>st</sup> resprout between survivors and non-survivors at one year and two years postfire and also to compare the mean days to first resprout between the two life history types. Comparison of relative growth between species was done using a four parameter logistic equation (also called the sigmoid dose response curve). The following equation was used:

$$Y = \text{Bottom} + (\text{Top} - \text{Bottom}) / (1 + 10^{((\text{EC50} - X) * \text{HillSlope})})$$



Where the parameters have the following meaning:

Bottom: lower level where growth starts

Top: Upper level indicating maximum growth

EC50: Time taken to reach half the growth between bottom and top.

Hillslope: Measure of steepness of the growth.

However, because growth starts at zero, the bottom parameter was set to zero and not estimated. Thus, it was a three parameter equation that was fitted to the data.

Logistic regressions were used to analyse life history type differences in resprout mortality. Logistic regression was also used to assess the link between postfire mortality and pre-fire plant vigour, lignotuber circumference, fire intensity, lignotuber exposure, slope, life history type, as well as how soon after the fire plants resprouted. To analyse mortality due to the fire, plants that did not resprout after the fire were grouped and compared to all plants that did resprout after the fire. For mortality postfire, all plants that resprouted successfully and were still alive after two years were compared to those that resprouted initially but subsequently died. Each species was also analyzed separately; factors possibly associated with mortality were analysed using a one-way ANOVA (supported by a Mann-Whitney U-test, when data were not normally distributed), (see Appendix B). STATISTICA was used for all analyses (StatSoft, Inc.(2010). STATISTICA (data analysis software system), version 10. [www.statsoft.com](http://www.statsoft.com).)

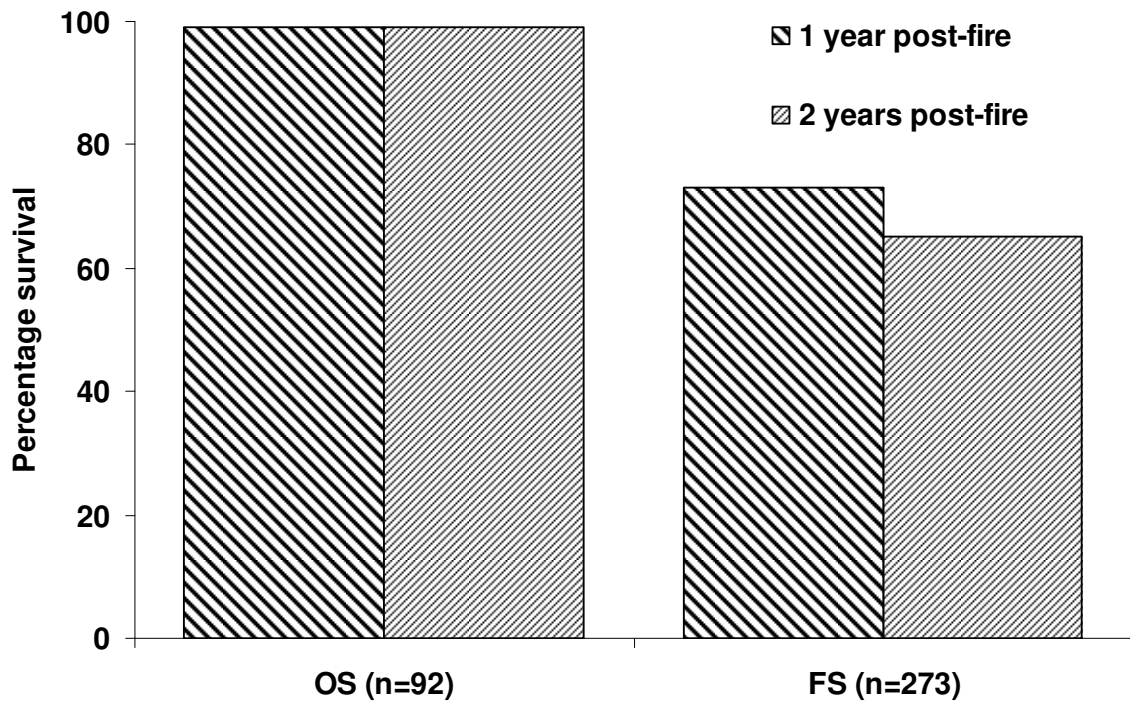
## Results

### Postfire survival

Two year postfire survival was significantly higher amongst the pooled OS species, which had an almost 100% survival rate, compared to 73% after the first summer ( $p < 0.0001$ ) and 65% after the second summer ( $p < 0.0001$ ) for the FS species (Figure 2.3). All the OS resprouted and only one (*Searsia tomentosa*) out of 92 tagged OS plants died subsequently.

Among the FS species that resprouted, mortality was generally greatest during the summer dry seasons suggesting that heat and water stress may have been causal factors in resprout mortality (Table 2.2 and Figure 2.4). However, for some species, e.g. *Aspalathus bracteata* and *Cliffortia ruscifolia* some mortality occurred during the wet winter season suggesting factors other than water stress as causing mortality. *Leucadendron salignum* male and female plants did not differ significantly in their resprout success ( $p = 0.218$ ). Some *L. salignum* plants resprouted well into the summer and some only resprouted in the second

year after the fire. No gender difference in the survival rate of late resprouting (resprouting after the first spring postfire) *L. salignum* plants were found (see Figure 2.4). , with two out of three late resprouting female *L. salignum* plants and four out of seven male *L. salignum* plants surviving two years postfire.



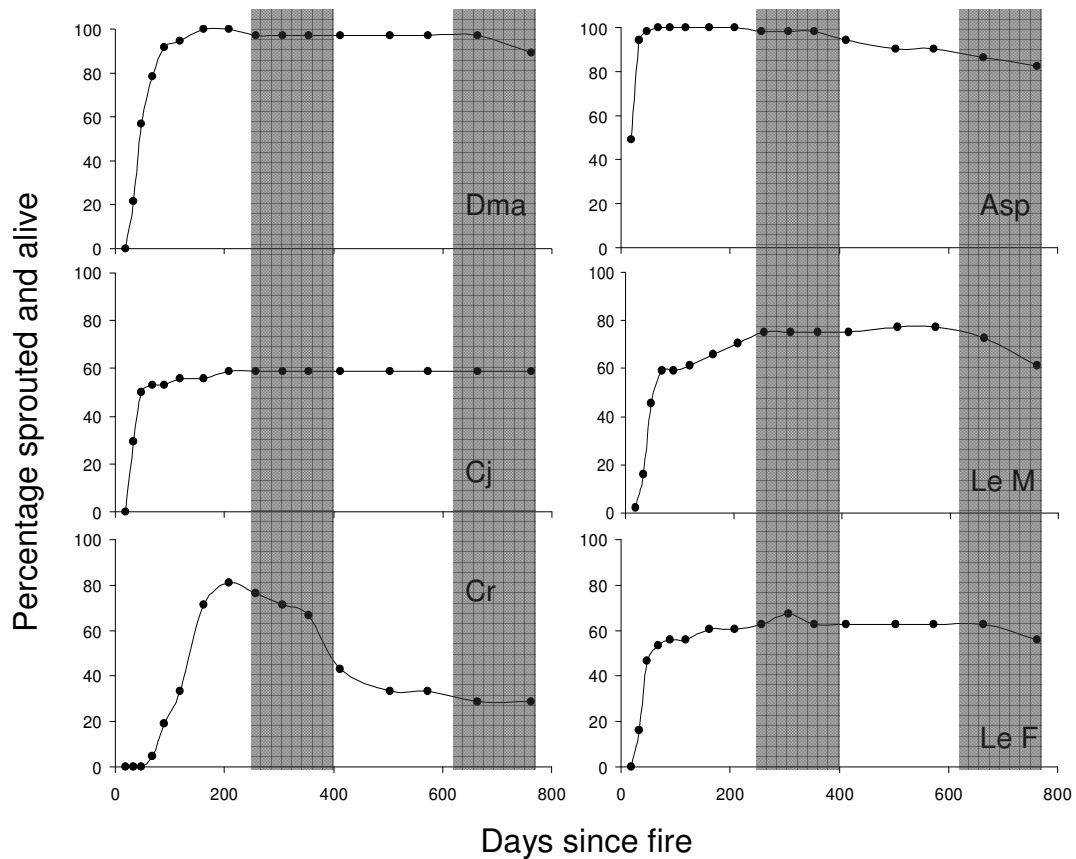
**Figure 2.3** Percentage survival of target species at **one** and **two** years postfire. Nearly all obligate resprouter (OS) species survived, whereas the facultative resprouter (FS) species had significant mortality ( $p < 0.0001$ ).

An analysis of all species combined indicated that plants that resprouted earlier had a better chance of surviving the first summer. The differences in time to first resprout comparing survivors to non-survivors was significant ( $p < 0.01$ ). The same analyses after two years was also significant ( $p < 0.01$ ), even when analyzing the FS species separately to exclude any confounding effects by the OS species ( $p < 0.01$ ) (Fig. 2.5).

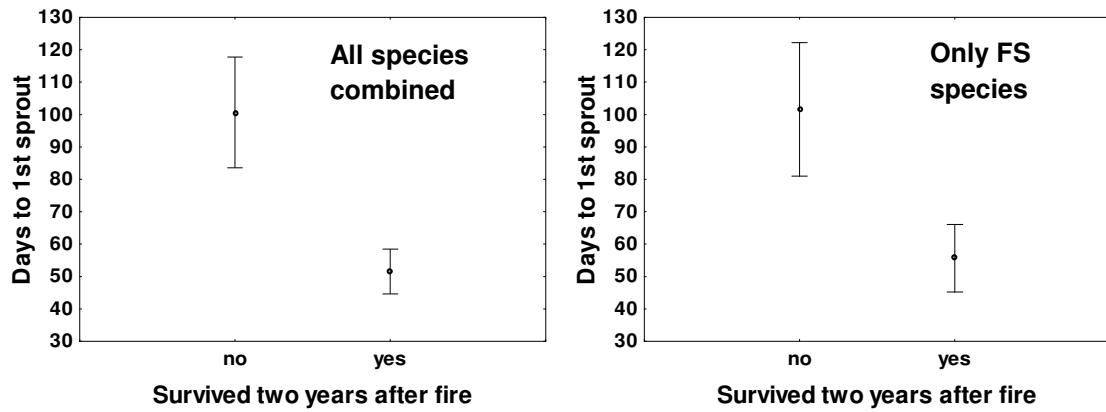
As a group, the OS species tended to resprout more rapidly, with a mean of 45 days compared to 65 days postfire for the FS species. Although not statistically significant ( $p = 0.71$ ), it does show a trend towards OS species resprouting earlier than FS species.

**Table 2.2** Percentage survival per species, after the fire.

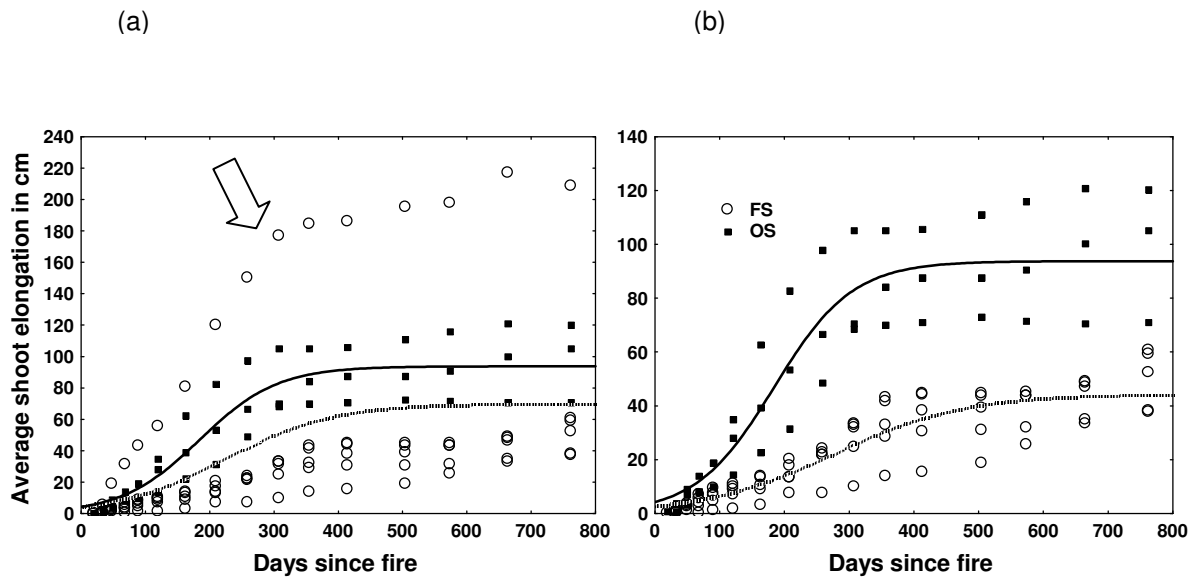
Species	Life history type	% survived fire	% resprouted individuals survived 1 <sup>st</sup> year postfire	% resprouted individuals survived 2 <sup>nd</sup> year postfire	% overall survival two years postfire
<i>Diospyros glabra</i>	OS	100	100	100	100
<i>Searsia rosmarinifolia</i>	OS	100	100	100	100
<i>Searsia tomentosa</i>	OS	100	97	97	97
<i>Diosma hirsuta</i>	FS	100	97	89	89
<i>Cliffortia juniperina</i>	FS	62	95	95	59
<i>Cliffortia ruscifolia</i>	FS	81	88	35	29
<i>Aspalathus bracteata</i>	FS	100	98	82	82
<i>Leucadendron salignum</i> M	FS	80	94	77	61
<i>L. salignum</i> F	FS	70	90	80	56



**Figure 2.4** A time scale of the percentage tagged facultative resprouter species that resprouted after the fire as well as the mortality that occurred during the two year sampling period. The shaded area depicts the dry summer months. Species abbreviations defined in Table 2.1



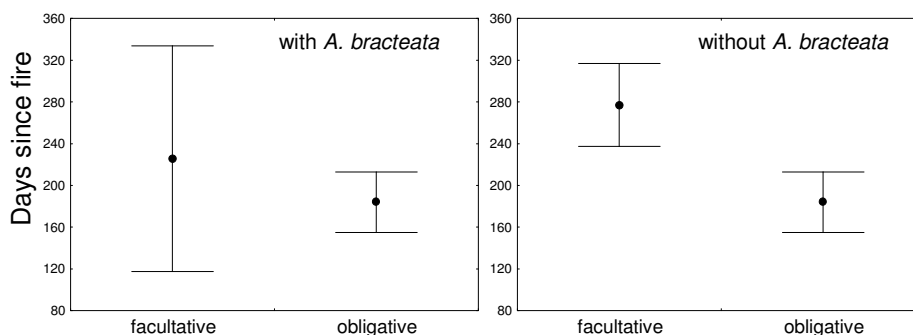
**Figure 2.5** Two year survival of target species that resprouted after the fire. Graph on **left** is for all species combined (Mann-Whitney U test,  $p < 0.01$ ). Graph on **right**, FS species analyzed separately (Mann-Whitney U test,  $p < 0.01$ ).



**Figure 2.6** Growth curves (shoot elongation) of pooled OS species and FS species over the two year study period. The arrow in graph (a) identifies *A. bracteata* as an outlier within the FS group. In graph (b) *A. bracteata* has been excluded.

## Relative growth

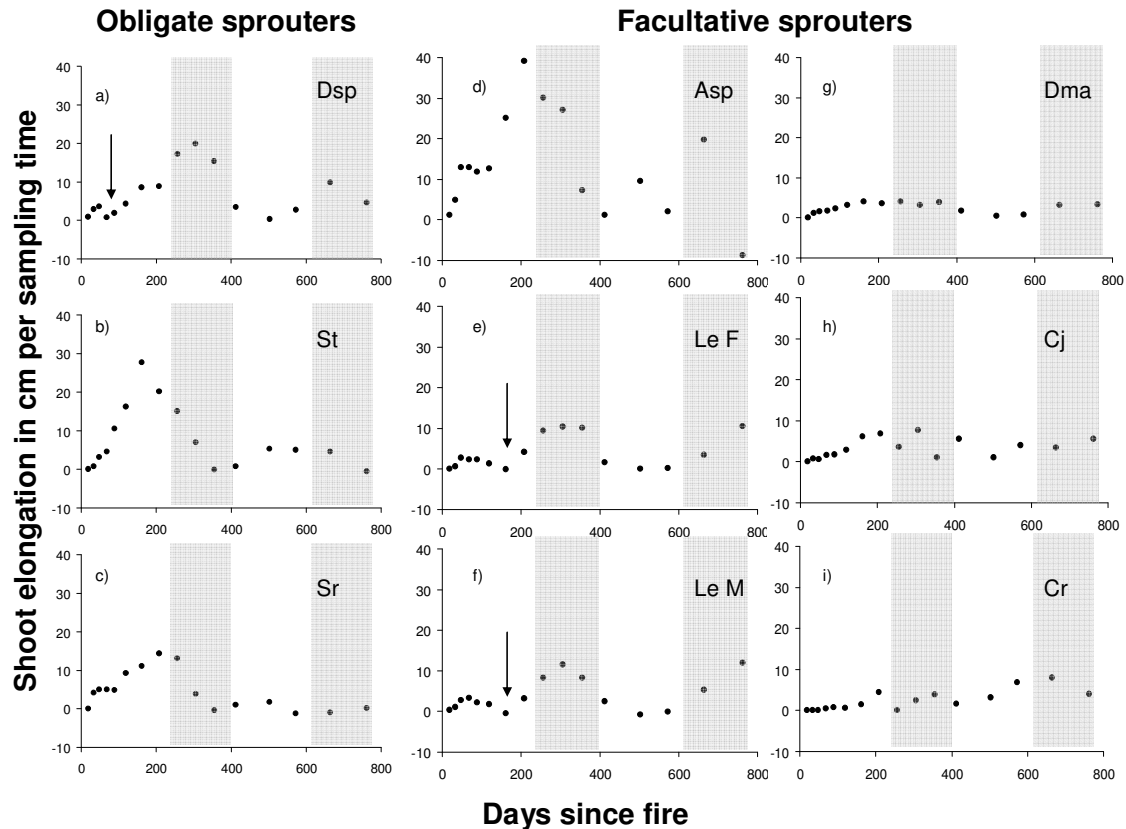
The OS species were generally taller and grew faster than the FS species and this difference was even more pronounced with the exclusion of *A. bracteata*, which was an outlier within the FS group (Figure 2.6). *A. bracteata* had a different growth form than all other shrubs, i.e. it was a scrambling shrublet with little biomechanical investment in stem tissues. Thus it is on these grounds that I also analyzed the data excluding *A. bracteata*. OS species reached the halfway mark of their total growth (EC50) over two years in a much shorter time than the FS species (184 days compared to 277 days; Figure 2.7).



**Figure 2.7** Average time taken to reach half of their estimated maximum growth (EC50) for facultative and obligate resprouter species. The bars indicate 95% confidence intervals.

## Absolute growth

The OS species generally had greater shoot elongation than the FS species with the exception of the FS *Aspalathus bracteata*, which was a sprawling shrub (Fig. 2.8). The height of plants can also be affected by herbivory. No mammal herbivory was observed within the first year and although some mammal herbivory was noted during the second summer postfire, it was minor. Insect herbivory was substantial early on in the postfire recovery phase and was species-specific (Figure 2.8), however plants resprouted again vigorously from below the damage.



**Figure 2.8** Mean stem elongation between sampling periods of resprouting stems of target species. Arrows indicate substantial insect herbivory. Shaded areas indicate the dry summer season. Growth rates peaked at different intervals; *Diospyros glabra* (Dsp), *Leucadendron salignum* (Le F & M) in summer, *Searsia tomentosa* (St) late autumn/ early winter, *S. rosmarinifolia* (Sr), *Aspalathus bracteata* (Asp) spring. *Diosma hirsuta*, *Cliffortia juniperina* (Cj) and *C. ruscifolia* (Cr) showed steady growth with a marginal peak in spring.

## Factors influencing postfire mortality

### Mortality due to fire

A number of factors predicted the mortality of plants in response to the fire. Pre-fire plant age and/or health, estimated as number of pre-fire shoots, was negatively and significantly correlated to mortality, i.e. more pre-fire shoots meant less mortality (Table 2.3). The height of the lignotuber exposed above the soil was significantly and positively correlated to mortality due to the fire (Table 2.3). Finally, fire intensity, estimated as the smallest terminal branch diameter, was negatively correlated to mortality, i.e. in areas of less intense burning the plants were more likely to die, which is opposite to what I expected (Table 2.3). None of the other variables (lignotuber circumference, slope and the lignotuber height/basal area) were correlated to mortality due to the fire.

**Table 2.3** Plants resprouted vs. plants not resprouted two years postfire. The variables that are highlighted were significant. The following arrow ( ↑ ) indicates an increase in odds to die and the arrow ( ↓ ) indicates a decrease in odds to die. The variables that are not highlighted were not significant.

N=329	Circumference (Circ.)	Branch diameter (mm)	Number of (#) pre-fire shoots	Slope	Lignotuber height (cm)	Lignotuber height/ basal area
t(322)	-0.90	<b>-2.23</b>	<b>-2.70</b>	0.27	<b>4.45</b>	1.59
p value	0.37	<b>0.03</b>	<b>&lt; 0.01</b>	0.79	<b>&lt; 0.001</b>	0.11
Odds ratio	0.99	<b>1.73 ↓</b>	<b>1.08 ↓</b>	1.01	<b>1.24 ↑</b>	10.42

### Mortality after the fire

Resprouter type and days to first resprout were significant predictors of mortality that occurred postfire. The odds were 23 times higher for a facultative resprouter to die postfire, than an obligate resprouter (Table 2.4). The odds to die increased by 1.01 for each day that resprouting was delayed, i.e. species resprouting earlier had a significantly better chance of surviving the two year postfire mark. None of the other variables were significantly correlated to postfire mortality.

**Table 2.4** Plants resprouted and alive compared to plants that had resprouted but had subsequently died within the two year study period. The highlighted variables were significant. The following arrow ( ↑ ) indicates an increase in odds to die and the arrow ( ↓ ) indicates a decrease in odds to die. The variables that are not highlighted were not significant.

N=283	Resprouted and alive OS vs. FS	Circ. (cm)	Branch diameter (mm)	# pre-fire shoots	Slope	Lignotuber height (cm)	Lignotuber height/ basal area	Days to first resprout
t(274)	<b>-2.30</b>	0.29	0.73	1.41	-0.62	0.63	-1.41	<b>-2.81</b>
p value	<b>0.02</b>	0.77	0.46	0.16	0.54	0.53	0.16	<b>&lt;0.01</b>
Odds ratio	<b>23 ↓</b>	1.00	1.20	1.04	0.97	1.04	0.01	<b>0.99 ↑</b>

### Mortality in general

Analyzing all data, thus not separating the mortality due to fire from mortality that took place after resprouting, resprouter life history type and number of pre-fire shoots were significant



mortality predictors (Table 2.5). The odds were 35 times smaller for an FS species to resprout and survive two years postfire, compared to an OS species. Plants with fewer pre-fire shoots had a significantly smaller chance of resprouting and surviving than plants with more pre-fire shoots (Table 2.5). This result however, is affected by autocorrelation with FS species being smaller than OS.

<b>Table 2.5</b> All plants alive vs. all plants dead two years postfire, not taking into account when the mortality occurred. The highlighted variables were significant. The following arrow (↓) indicates a decrease in odds to die. The variables that are not highlighted were not significant.								
N=329	<b>Resprouted and alive OS vs. FS</b>	Circ. (cm)	Branch diameter (mm)	<b># pre-fire shoots</b>	Slope	Lignotuber height (cm)	Lignotuber height/basal area	Days to first resprout
t(320)	<b>-2.60</b>	-0.47	0.88	<b>2.26</b>	-0.87	0.41	-1.63	1.44
p value	<b>0.01</b>	0.64	0.38	<b>0.02</b>	0.38	0.69	0.11	0.15
Odds ratio	<b>35 ↓</b>	1.00	1.22	<b>1.07 ↓</b>	0.87	1.03	0.01	1.00

## Discussion

### Life history type differences

The most striking observation is the difference in postfire mortality between obligate resprouters and facultative resprouters, with near 100% survival among the OS species. This supports the hypothesis that the OS life history type is associated with greater resprouting ability. Mortality amongst the OS was limited to one small *S. tomentosa* plant that died soon after resprouting and that appeared to be a juvenile plant, as indicated by its single and small circumference stem. This individual probably established itself during the last fire-free interval and was not yet robust enough to survive the most recent fire (Manders & Richardson 1992; Manders et al. 1992). The finding that OS are more successful resprouters than FS is consistent with a tradeoff between persistence and longevity, exemplified by the OS, and recruitment of seedlings and shorter life span, exemplified by the FS. Recruitment of seedlings in an open canopy postfire environment may lead to selection for greater water stress tolerance traits for FS than OS species that recruit in a shady fynbos understory (Midgley & Cowling 1993). This is consistent with a recent study that found FS to have greater drought-induced cavitation resistance of stems than OS species (Pratt et al.

2012). It is possible that there is a tradeoff between water stress tolerance and resprout ability among fynbos species.

In a recent study in Californian chaparral, Pratt et al. (unpublished data) found OS and FS species to be ecophysiologically divergent and this may be relevant to the resprouting success of the two life history types. FS species were more water stress resistant (measured as xylem cavitation resistance) than the OS species, but OS species had higher carbon assimilation rates than FS species. This suggests a possible trade-off between resprout success and drought tolerance. This is consistent with seedling recruitment patterns between OS and FS species, where OS species seedlings establish in shaded microsites in the understory of mature vegetation (Keeley 1992; Midgley & Cowling 1993) and thus are likely exposed to less water stress during the seedling stage, whereas FS species seedlings have to cope with higher light and water stress conditions.

There were some clear factors that were linked to the greater resprout success for the OS species that may be linked to resprout carbon balance. When a resprout is top-killed, the root system and adventitious buds are alive and require carbohydrates to remain alive. These carbohydrates initially come from stores in the lignotuber and roots, but these stores are finite and a new shoot must be quickly and rapidly deployed. Consistent with this, OS species grew faster than FS and this may have been important in re-establishing a balanced root to shoot ratio after a fire. Moreover, the OS generally had a shorter lag period before they resprouted than FS species. *A. bracteata* was an extreme outlier within the FS group and grew the fastest of all species. This species employed a different strategy from all the other target species with its very rapid horizontal growth. I suggest that being a sprawling shrublet, it does not have to invest in structural support, like the upright growing shrubs, which is supported by unpublished data from the study site by Pratt et al., which found that *A. bracteata* has lower xylem density than the other target species. Rapid horizontal growth allows maximum sunlight capture before being over-shadowed by taller plants.

One interesting consideration may be differences in the biogeographic origins of plants in these two life history types. Within fynbos most woody OS species are bird-dispersed (Manders et al. 1992; Midgley & Cowling 1993; Cowling et al. 1997). They are widespread species that co-occur in other vegetation types (often patches of sub-tropical thicket) (Cowling et al. 1997) and they have a common biogeographic origin, dating back to before the onset of a Mediterranean climate in the Western Cape (Linder et al. 1992; Cowling et al. 2005). However, dated molecular phylogeny data for OS species within fynbos that may support this hypothesis is still lacking.

## Causes of differential postfire mortality rates

Time to first resprouting was highly correlated with one-year and two-year postfire survival, irrespective of the life history type. Thus plants with a longer lag period before resprouting had higher mortality rates postfire. Moreno & Oechel (1993) made similar observations in a single Californian chaparral species, as did Le Maitre et al. (1992) in a study on eight woody fynbos resprouters.

The timing of postfire mortality coinciding with summer dry season suggests that the hot and dry summer months may have played a role in mortality amongst the FS species. A recent study conducted at my study site found that OS species were more vulnerable to water-stress-induced cavitation of stems than FS species (Pratt et al. 2012). This suggests that, at least for stem xylem, the FS are more resistant to water stress than the OS, which is opposite to what I would predict based on the mortality patterns. Moreover, another study near my study site found a pathogen was likely causing mortality among fynbos species during the summer dry season (Jacobsen et al. 2012). It is possible that greater rooting depth or greater pathogen resistance for the OS species is related to the absence of mortality during the dry summer months.

Some of the mortality caused by fire was linked to abiotic or plant-independent traits such as fire intensity (however see Mutch 1970; Bond & Midgley 1995; He et al. 2011 on fire-enhancing traits) and possibly erosion or animal activity leading to exposed lignotubers. Plants with more exposed lignotubers were less likely to resprout after the fire, which may be related to heat induced damage to the bud bank within the exposed lignotuber. Contrary to expectation, plants with wider branch diameters, which presumably experienced greater fire intensity, experienced less mortality in the analysis combining all species. With species specific analyses (see Appendix B) a similar trend was observed for most species, but only male *L. salignum* plants showed a significant correlation. These results differ from a previous study where burnt plants with wider branch diameters were less likely to survive (Moreno & Oechel 1993). However, Moreno & Oechel (1993) evaluated a single species, which complicates comparison, since our study included a mix of species with different growth forms and life history types (Euston-Brown et al. 2004).

The number of pre-fire stems was a significant predictor of mortality due to fire, where fewer stems were correlated to higher mortality. Le Maitre et al. (1992) and Vesk et al. (2004) also linked greater numbers of pre-fire shoots to postfire survival suggesting that the number of pre-fire shoots is a useful potential indicator of pre-fire vigour or health and postfire resprout success.

Previous studies on lignotuber size and resprout mortality has yielded mixed results. Paula & Ojeda (2006, 2009) found that plants with larger lignotubers have higher mortality rates after disturbance and this was assumed to be related to age, i.e. older plants with bigger lignotubers have been exposed to more disturbance events that may have depleted their bud banks. In contrast, a study on a single chaparral species found that plants with smaller lignotubers had higher postfire mortality (Moreno & Oechel 1991). The great variability in lignotuber size amongst different species in this study could well have confounded the results. Species specific analyses on those that suffered sufficient mortality to allow statistical analyses (see Appendix B) showed the relationship of lignotuber size and mortality to be significant in only one species, *C. juniperina*. This species showed a significant increase in mortality due to fire with decreased lignotuber size.

There was no significant difference in the male and female resprout success of *L. salignum*, although gender-related differences have been reported for late resprouting plants (resprouting after the first spring postfire) (le Maitre et al. 1992) as well as differences in cavitation resistance (Jacobsen et al. 2009). However, these differences might only become apparent if periods of extreme water stress occur during the postfire recovery period, which was not the case in this study.

### **Herbivory**

Mammal herbivory did not play an important role at the study site, but insect herbivory had an impact on the new growth of two species, namely *L. salignum* that was affected by weevils (family Apionidae) and leaf beetles (family Chrysomelidae)(Fig. 2.9) and *D. glabra* that was affected by the caterpillar *Tortrix capensana* (leaf-roller moth)(Fig. 2.10). Both species recovered from the insect herbivory by vigorously resprouting below the area damaged by the insects. Mammal herbivory was absent in the first year and mammal activity (mostly rodents) was only becoming apparent well into the second year postfire.



**Figure 2.9** Leaf beetle and weevil damage of *Leucadendron salignum* as seen on Paarl Mountain after a fire in 2009.



**Figure 2.10** Leaf-roller moth larvae damage on *Diospyros glabra* as seen on Paarl Mountain after a fire in 2009.

## Conclusion

Studies comparing non-sprouters and resprouters are abundant (e.g. Bell & Ojeda 1999; Bell & Pate 1996; Bell et al. 1996; Schwilk & Ackerly 2005; Paula & Pausas 2011), but few have compared OS and FS species. To my knowledge, no studies have compared OS and FS species in fynbos vegetation. My observations show that there is a significant difference in postfire resprout success between OS species and FS species, supporting the division of woody resprouting shrubs into these two life history types. The minimal fire-related mortality observed amongst OS species is related to their ability to resprout early and vigorously after fire and then being able to endure the hot dry summer months. In contrast, the FS species varied in their response to fire and they exhibited greater fire induced as well as postfire mortality. I hypothesize that there may be a tradeoff between resprout ability and water stress resistance. These results suggest that, although OS and FS species are both classes of resprouters, they differ in their postfire recovery justifying separating them as different resprouting types (Bond & Midgley 2003).



## References

- Allen, H.D. (2008) Fire: plant functional types and patch mosaic burning in fire-prone Ecosystems. *Progress in Physical Geography* **32**, 421–437.
- Bell, T.L. & Ojeda, F. (1999) Underground starch storage in *Erica* species of the Cape Floristic Region - differences between seeders and resprouters. *New Philologist* **144**, 143-152.
- Bell, T.L. & Pate, J.S. (1996) Growth and fire response of selected Epacridaceae of south-western Australia. *Australian Journal of Botany* **44**, 509 –526.
- Bell, T.L., Pate, J.S. & Dixon, K.W. (1996) Relationships between fire response, morphology, root anatomy and starch distribution in south-west Australian Epacridaceae. *Annals of Botany* **77**, 357-364.
- Bond, W. J. (1984) Fire survival of Cape *Proteaceae* - influence of fire season and seed predators. *Vegetatio* **56**, 65-74.
- Bond, W.J. (1997) Functional types for predicting changes in biodiversity: a case study in Cape Fynbos. Plant Functional Types: their relevance to ecosystem properties and global change (eds T.M. Smith, H.H. Shugart & F.I. Woodward), pp. 174-194. Cambridge University Press, Cambridge.
- Bond, W.J. & Midgley, J.J. (1995) Kill thy neighbour: an individualistic argument for the evolution of flammability. *Oikos* **73**, 79–85.
- Bond, W.J. & Midgley, J.J. (2001) Ecology of sprouting woody plants: the persistence niche. *Trends in Ecology & Evolution* **16**, 45-51.
- Bond, W.J. & Midgley, J.J. (2003) The evolutionary ecology of sprouting in woody plants. *International Journal of Plant Sciences* **164**, S103-S114.
- Bond, W.J. & van Wilgen, B.W. (1996) Fire and Plants, Chapman & Hall, London.
- Bond, W.J., Vlok, J. & Viviers, M. (1984) Variation in seedling recruitment of Cape Proteaceae after fire. *Journal of Ecology* **72**, 209-221.
- Cowling, R.M., Kirkwood, D., Midgley, J.J. & Pierce, S.M. (1997) Invasion and persistence of bird-dispersed, subtropical thicket and forest species in fire-prone coastal fynbos. *Journal of Vegetation Science* **8**, 475-488.
- Cowling, R.M., Procheş, Ş. & Vlok, J.H.J. (2005) On the origin of southern African subtropical thicket vegetation. *South African Journal of Botany* **71**, 1-23.
- Cowling, R.M., Rundel, P.W., Lamont, B.B., Arroyo, M.K. & Arianoutsou, M. (1996) Plant diversity in mediterranean-climate regions. *Trends in Ecology and Evolution*, **11**, 362-366.
- Euston-Brown, D., Botha, S. & Bond, W. (2004) Influence of fire severity on post-fire



- vegetation recovery on the Cape Peninsula. Draft final report for the Working for Water Programme.
- Goldblatt, P. & Manning, J.C. (2000) Cape Plants. A conspectus of the Cape flora of South Africa. *Strelitzia* 9, National Botanical Institute & Missouri Botanical Garden Press, Pretoria & St. Louis.
- He, T., Lamont, B.B. & Downes, K.S. (2011) Banksia born to burn. *New Phytologist*, **191**, 184-196.
- Heeleman, S., Proches, S., Rebelo, A.G., Van Wilgen, B.W., Porembski, S. & Cowling, R.M. (2008) Fire season effects on the recruitment of non-sprouting serotinous Proteaceae in eastern (bimodal rainfall) fynbos biome, South Africa. *Austral Ecology*, **33**, 119-127.
- Jacobsen, A.L., Esler, K.J., Pratt, R.B. & Ewers, F.W. (2009) Water-stress tolerance of Mediterranean-type climate regions: Convergence of Fynbos and Succulent Karoo communities with California shrub communities. *American Journal of Botany* **96**, 1445–1453.
- Jacobsen, A.L., Roets, F., Jacobs, S.M., Esler, K.J. & Pratt, R.B. (2012) Dieback and mortality of South African fynbos shrubs is likely driven by a novel pathogen and pathogen-induced hydraulic failure. *Austral Ecology* **37**, 227-235.
- Keeley, J.E. (1986) Resilience of mediterranean shrub communities to fires. Resilience in mediterranean-type ecosystems (eds. Dell, B., Hopkins, A.J.M. & Lamont, B.B.), pp.95-112. Junk, The Hague.
- Keeley, J.E. (1992) Recruitment of seedlings and vegetative sprouts in unburned chaparral. *Ecology* **73**, 1194-1208.
- Keeley, J.E. & Bond, W.J. (1997) Convergent seed germination in South African fynbos and Californian Chaparral. *Plant Ecology* **133**, 153-167.
- Keeley, J.E., Fotheringham, C.J & Baer-Keeley, M. (2006) Demographic patterns of postfire regeneration in Mediterranean-climate shrublands of California. *Ecological Monographs* **76**, 235-255.
- Laurie, H. & Cowling, R.M. (1994) Lottery coexistence models extended to plants with disjoint generations. *Journal of Vegetation Science*, **5**, 161-168.
- Lavorel, S., McIntyre, S., Landsberg, J. & Forbes, T.D.A. (1997) Plant functional classification: from general groups to specific groups based on response to disturbance. *Trends in Ecology and Evolution* **12**, 474-478.
- Le Maitre, D.C., Jones, C.A. & Forsyth, G.G. (1992) Survival of eight woody sprouting species following an autumn fire in Swartboskloof, Cape Province, South Africa. *South African Journal of Botany* **58**, 405-413.
- Le Maitre, D.C. & Midgley, J.J. (1992) Plant reproductive ecology. The ecology of fynbos.

- Nutrients, fire and diversity (ed. R.M. Cowling), pp. 135-174, Oxford University Press, Cape Town.
- Linder, H.P., Meadows, M.E., & Cowling, R.M. (1992) History of the Cape Flora. The ecology of fynbos. Nutrients, fire and diversity (ed. R.M. Cowling), pp. 113-134. Oxford University Press, Cape Town.
- Manders, P.T. & Richardson, D.M. (1992) Colonization of Cape fynbos by forest species. *Forest Ecology Management* **48**, 277-293.
- Manders, P.T., Richardson, D.M. & Masson, P.H. (1992) Is fynbos a stage in succession to forest? Analysis of perceived ecological distinction between two communities. Fire in South African Mountain Fynbos: Ecosystem, Community and Species Response at Swartboskloof (eds. B.W. van Wilgen, D.M. Richardson, F.J. Kruger & H.J. van Hensbergen), pp. 81-107. Springer-Verlag, New York.
- Midgley, J.J. & Cowling, R.M. (1993) Regeneration patterns of Cape subtropical thicket: where are all the seedlings? *South African Journal of Botany* **59**, 496-499.
- Milton, S.J. (2003) Vegetation Survey. Paarl Mountain Nature Reserve. Conservation Ecology Department, University of Stellenbosch, 7701 Stellenbosch.
- Moreno, J.M. & Oechel, W.C. (1991) Fire intensity and herbivory effects on post-fire resprouting of *Adenostoma fasciculatum* in southern California chaparral. *Oecologia* **85**, 429-433.
- Moreno, J.M. & Oechel, W.C. (1993) Demography of *Adenostoma fasciculatum* after fires of different intensities in southern California chaparral. *Oecologia* **96**, 95-101.
- Mucina, L. & Rutherford, M.C. (eds) (2006) The vegetation of South Africa, Lesotho and Swaziland. *Strelitzia* **19**. South African National Biodiversity Institute, Pretoria.
- Mutch, R. W. (1970) Wildland fires and ecosystems – a hypothesis. *Ecology* **51**, 1046–1051.
- Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., & Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature*, **403**, 853-858.
- Noble, I.R. & Gitay, H. (1996) A functional classification for predicting the dynamics of landscapes. *Journal of Vegetation Science* **7**, 329-336.
- Noble, I.R. & Slatyer, R .O. (1980) The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbance. *Vegetatio* **43**, 5-21.
- Ojeda, F., Brun, F.G. & Vergara J.J. (2005) Fire, rain and the selection of seeder and resprouter life-histories in fire-recruiting, woody plants. *New Phytologist* **168**, 155-165.
- Paula, S. & Ojeda, F. (2006) Resistance of three co-occurring resprouter *Erica* species to highly frequent disturbance. *Plant Ecology* **183**, 329–336.
- Paula, S. & Ojeda, F. (2009) Belowground starch consumption after recurrent severe disturbance in three resprouter species of the genus *Erica*. *Botany* **87**, 253-259.
- Paula, S. & Pausas, J.G. (2011) Root traits explain different foraging strategies between

- resprouting life histories. *Oecologia* **165**, 321-331.
- Pérez, B & Moreno, J.M. (1998) Methods for quantifying fire severity in shrubland fires. *Plant Ecology* **139**, 91-101
- Pratt, R.B., Jacobsen, A.L., Jacobs, S.M. & Esler, K.J. (2012) Xylem transport safety and efficiency differ among fynbos shrub life history types and between two sites differing in mean rainfall. *International Journal of Plant Science* **173**, 474-483.
- Pratt, R.B., Jacobsen, A.L., Mohla, R., Ewers, F.W. & Davis, D. (2008) Linkage between water stress tolerance and life history type in seedlings of nine chaparral species (Rhamnaceae). *Journal of Ecology* **96**, 1252-1265.
- Pratt, R.B., North, G.B., Jacobsen, A.L., Ewers, F.W. & Davis, S.D. (2010) Xylem root and shoot hydraulics is linked to life history type in chaparral seedlings. *Functional Ecology* **24**, 70–81.
- Privett, S.D.J, Cowling, R.M. & Taylor H.C. (2001) Thirty years of change in the fynbos vegetation of the Cape of Good Hope Nature Reserve, South Africa. *Bothalia* **31**, 99-115.
- Schutte, A.L., Vlok, J.H.J., & Van Wyk, B.E. (1995) Fire-survival strategy – a character of taxonomic, ecological and evolutionary importance in fynbos legumes. *Plant Systematics and Evolution* **195**: 243-259.
- Schwilk, D.W. & Ackerly, D.D. (2005) Is there a cost to resprouting? Seedling growth rate and drought tolerance in sprouting and nonsprouting *Ceanothus* (Rhamnaceae). *American Journal of Botany* **92**, 404-410.
- Syphard, A.D., Franklin, J. & Keeley, J. E. (2006) Simulating the effects of frequent fire on southern California coastal shrublands. *Ecological Applications*, **16**, 1744-1756.
- Thuiller, W., Slingsby, J.A., Privett, S.D.J & Cowling R.M. (2007) Stochastic Species Turnover and Stable Coexistence in a Species-Rich, Fire-Prone Plant Community. *PLOS One* **9**, e938.
- van Wilgen, B. (1974) A management plan for the Paarl Mountain Nature Reserve, Nature Conservation Department (Conservation Ecology), University of Stellenbosch.
- Van Wilgen, B.W. & Forsyth, G.G. (1992) Regeneration strategies in fynbos plants and their influence on the stability of community boundaries after fire. Fire in South African Mountain Fynbos: Ecosystem, Community and Species Response at Swartboskloof (eds. B.W. van Wilgen, D.M. Richardson, F.J. Kruger & H.J. van Hensbergen), pp. 54-80. Springer-Verlag, New York.
- Van Wilgen, B.W., Forsyth, G.G., de Klerk, H., Das, S., Khuluse, S. & Schmitz, P. (2010) Fire management in Mediterranean-climate shrublands: a case study from the Cape fynbos, South Africa. *Journal of Applied Ecology* **47**, 631-638.

- Wells, P.V. (1969) The relation between mode of reproduction and extent of speciation in woody genera of the California chaparral. *Evolution*, **23**, 264-267.
- Whitehouse, C.M., (2002) Systematics of the genus *Cliffortia* L. [Rosaceae]. Unpublished PhD Thesis, Department of Botany, University of Cape Town, Rondebosch.
- Verdú, M., Pausas, J.G., Segarra-Moragues J.G & Ojeda, F. (2007) Burning phylogenies: fire, molecular evolutionary rates, and diversification. *Evolution* **61**, 2195-2204.
- Vesk, P.A., Warton, D.I. & Westoby, M. (2004) Sprouting by semi-arid plants: testing a dichotomy and predictive traits. *OIKOS* **107**, 72-89.
- Vesk, P.A. & Westoby, M. (2004) Sprouting ability across diverse disturbances and vegetation types worldwide. *Journal of Ecology* **92**, 310–320.
- Yi, T., Miller, A.J. & Wen, J. (2004) Phylogenetic and biogeographic diversification of *Rhus* (Anacardiaceae) in the Northern Hemisphere. *Molecular Phylogenetics and Evolution* **33**, 861-879.
- Zucchini, W. (1992) “Genrain” rainfall simulation programme for South Africa. Applied Statistics and Decision Sciences Unit. University of Cape Town, Rondebosch 7700.

## CHAPTER 3

### Postfire recruitment and regeneration in mountain fynbos: the role of life history type

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#### Abstract

Understanding how native plants respond to fire is important to predict vegetation change under different fire regimes. I hypothesized that postfire seedling recruitment would differ relative to resprouting ability amongst woody species in fynbos vegetation, according to their classification as obligate resprouter (OS), facultative resprouter (FS) or non-sprouter (NS) species. This hypothesis was evaluated following a fire on Paarl Mountain by monitoring seedling recruitment over a two year period. Obligate resprouters had significantly lower postfire resprout mortality than facultative resprouters (Chapter 2). The current study focussed on seedling recruitment and overall population stability. Non-sprouters recruited large numbers of seedlings (>200 seedlings/adult), but all adult plants were killed by the fire. Facultative resprouters adopted a dual strategy combining seedling recruitment and adult resprouting, which varied amongst species (from less than one to 30 seedlings/adult). The majority of seedling mortality occurred during the second summer, which was particularly hot and dry. Despite high seedling mortality, two year seedling survival still outnumbered adult mortality for NS and FS species. Obligate resprouters recruited no seedlings and relied on resprouting to maintain population stability. The clear patterns observed indicate the relevance of life history type when assessing species resilience to fire disturbance.

## Introduction

Fynbos is a shrubland with a mediterranean-type climate that experiences regular stand replacing crown fires (Bond & van Wilgen 1996). Plants within these mediterranean-type ecosystems possess different traits that allow them to persist through disturbance events like fire (Bond & van Wilgen 1996; Bond & Midgley 2001). Woody plants have often been classified according to how they regenerate after recurrent disturbances, like fire (Noble & Slatyer 1980; Bond & van Wilgen 1996; Pausas et al. 2004), in an attempt to predict community responses. One of the most commonly used classifications for woody plants in fire prone mediterranean-type climate regions is the dichotomous classification of resprouters and non-sprouters (Bond & van Wilgen 1996). Despite the complexities of vegetation recovery after fire (Cowling 1987), some general trends have been documented (Bond & Midgley 2001). Resprouters tend to recruit fewer seedlings than non-sprouters (Bond & van Wilgen 1996) and within the same genera, resprouter species are generally widespread, whereas local endemics are generally non-sprouters (Cowling et al. 1997; Bond & Midgley 2001). The pattern holds for *Banksia* in south-western Australia (Lamont & Markey 1995) and for the genus *Leucadendron* in the fynbos, when comparing life history types (Barker et al. 2004; Rebelo 1995) to their distributions (Rebelo 1995). Within fynbos resprouters tend to be more abundant on less productive sites (Midgley 1996; Ojeda 1998), however this is not the case in all mediterranean type vegetation for example south-east Australia (Pausas & Bradstock 2007) and southern California (Meentemeyer et al. 2001).

The average fire cycle for fynbos vegetation may differ according to the type of fynbos. Earlier estimates ranged between 12-20 years (van Wilgen 1982; Schutte et al. 1995), but more recent observations suggest an average fire interval of 10-13 years (van Wilgen et al. 2010) for most fynbos vegetation in the Western Cape. Resprouters and non-sprouters coexist in fynbos vegetation. From the 4418 Cape fynbos species assessed by Le Maitre & Midgley (1992), 52% were resprouters. However, many of the dominant canopy forming species in fynbos are non-sprouters (Bond et al. 1984; Heelemann et al. 2010). Thus, postfire regeneration of woody species in fynbos shrublands relies not only on resprouting of species present at the time of the fire but also on seedling recruitment from species with canopy stored (i.e. serotinous species) or soil stored seeds.

Keeley (1986) first used the term 'persisters' to describe resprouters. Subsequently Bond & Midgley (2001) invented the term "persistence niche", which focused attention on the resprouting behaviour of adult plants that survived a severe disturbance like fire. Pausas & Bradstock (2007) used the term 'persistence' in a different way, referring to resprouting as persistence at the individual level and seeds that survive fires as persistence at the

population level. In the previous chapter I explored persistence through resprouting, whereas in this chapter I focus on persistence through seedlings. For this purpose, I classified species into three life history types, namely non-sprouters, facultative resprouters and obligate resprouters. Non-sprouter (NS) species are those that succumb to the fire, and do not have the ability to resprout. They thus rely on a new cohort of seedlings to replace the adult population, which is why they can also be referred to as obligate seeders. Obligate resprouter (OS) species generally do not recruit seedlings directly postfire as their seeds are not fire resistant and in some species the seeds are only viable for a limited time (A. Hitchcock, personal communication). Seed germination of OS species generally takes place in the understorey of mature shrubs in fire free intervals (Keeley 1986; Midgley & Cowling 1993; Cowling et al. 1997). Facultative resprouter (FS) species have a dual strategy of resprouting and recruiting seedlings. They fill the spectrum between the two extremes of non-sprouters (obligate seeders) and obligate resprouters. The seeds of non-sprouters and facultative resprouters in fire prone fynbos are directly or indirectly fire stimulated and germination is restricted to the wet season in the first year post fire (Bond et al. 1984; Cowling & Lamont 1987; Laurie & Cowling 1994; Schutte et al. 1995).

The objectives of this study were to evaluate differences in species-specific seedling recruitment and to assess if these differences are linked to life history type. I predicted that the OS species do not recruit any seedlings directly postfire. I further predicted that both NS and FS species would recruit seedlings, but that the seedling to adult ratios for NS species would be higher than for the FS species. I thus hypothesized that there is a trade-off between postfire resprouting and postfire seedling recruitment (Bellingham & Sparrow 2000). I also predicted that the seedling recruitment for the FS species would offset adult mortality due to the fire as well as mortality postfire and that seedling recruitment for the NS species would offset the adult mortality due to the fire.

## **Methods**

### **Study Site**

This study was part of a larger study on postfire plant regeneration conducted after a wildfire in the Paarl Mountain Nature Reserve (33°44' S, 18°55' E). The reserve is close to the town of Paarl in the Western Cape, South Africa. The vegetation on the upper slopes where the study was undertaken is Boland Granite Fynbos (Mucina & Rutherford 2006). The mean annual rainfall on the mountain plateau is 960 mm, with a mean annual rainfall for the whole reserve of 858 mm (van Wilgen 1974, Zucchini 1992 cited in Milton 2003), and the highest rainfall occurring in winter, during the months of May to September. The summer months are



generally hot and dry, consistent with the Mediterranean type climate. The study area has a north-east facing aspect, with fine textured soils derived from granite. The elevation is around 600 m. The site last burned between 18 and 25 years ago (L. de Roubaix personal communication) and the vegetation cover on the study site before the burn was dominated by ericoid and proteoid shrubs (Milton 2003). The site represents a well-preserved fynbos habitat without woody invasive species and a minimum amount of herbaceous invasive species, adding little to the fuel load.

### Species selection

The most dominant woody resprouter and non-sprouter species were selected for study (Table 3.1). I grouped species into three life history types; non-sprouters, obligate resprouters and facultative resprouters, according to previous life history descriptions and my own field observations, since I wanted to compare the different resprouter types with each other as well as with non-sprouters.

**Table 3.1** Dominant species selected for the seedling study, with abbreviations used in text as well as life history types (LHT) and growth form. OS= obligate resprouter; FS= facultative resprouter; NS= non-sprouter. Abbr. = abbreviation

Species	Family	Abbr	LHT	Growth form
<i>Diospyros glabra</i> (L.) De Winter	Ebenaceae	Dsp	OS <sup>1,2</sup>	Dioecious large shrub
<i>Searsia angustifolia</i> (L.) F.A.Barkley	Anacardiaceae	Sa	OS <sup>3</sup>	Dioecious large shrub
<i>Searsia lucida</i> (L.) F.A.Barkley	Anacardiaceae	Sl	OS <sup>3</sup>	Dioecious large shrub
<i>Searsia rosmarinifolia</i> (Vahl) F.A.Bark.	Anacardiaceae	Sr	OS <sup>2</sup>	Dioecious scrambling shrub
<i>Searsia tomentosa</i> (L.) F.A.Barkley	Anacardiaceae	St	OS <sup>2,4</sup>	Dioecious large shrub
<i>Diosma hirsuta</i> (L.)	Rutaceae	Dma	FS <sup>2</sup>	Ericoid shrublet
<i>Cliffortia juniperina</i> L.f.	Rosaceae	Cj	FS <sup>5</sup>	Ericoid shrublet
<i>Cliffortia ruscifolia</i> L.	Rosaceae	Cr	FS <sup>2,4</sup>	Small leaved, spiny shrub
<i>Aspalathus bracteata</i> Thunb.	Fabaceae	Asp	FS <sup>6</sup>	Scrambling shrublet
<i>Leucadendron salignum</i> P.J.Bergius	Proteacea	Le s	FS <sup>2</sup>	Small proteoid shrub
<i>Leucadendron rubrum</i> Burm.f.	Proteacea	Le r	NS <sup>7</sup>	Large, erect proteoid shrub
<i>Leucospermum grandiflorum</i> (Salisb.) R.Br.	Proteacea	Ls g	NS <sup>7</sup>	Large, erect proteoid shrub
<i>Cliffortia erectisepala</i> Weim.	Rosaceae	Ce	NS <sup>5</sup>	Erect shrub

<sup>1</sup> Cowling et al. 1997; <sup>2</sup> van Wilgen & Forsyth 1992; <sup>3</sup> personal field observations; <sup>4</sup> Keeley & Bond 1997; <sup>5</sup> Whitehouse 2002; <sup>6</sup> C.H Stirton, personal communication; <sup>7</sup> Rebelo 1995.

## Sampling Methods

Two seedling counts were conducted in April after the first autumn rains, one year and two years after the fire. Twelve 100m<sup>2</sup> plots (10m x 10m) were randomly selected across the study site. A GPS reading was taken at the SW corner of each plot. Steel droppers were then planted at all four corners, as each 10m x10m plot was measured out. Pre-fire adult populations in each of the twelve 100m<sup>2</sup> plots were inferred from counting the skeletal remains as well as resprouted individuals during the first survey one year after the fire. Since many non-sprouter fynbos Proteaceae are relatively short lived (Rebello 1995), some may have died before the fire and their remains would have been consumed. Particular care was thus taken to look for stump remains of shrubs that may have burned to the ground. For the resprouting species, the vast majority had already resprouted by the time the seedling survey was done. They were easily identifiable from their young leaves and unique bark characteristics.

Seedlings may differ morphologically from the adult form (Whitehouse 2002; Rutherford et al. 2011) and all three *Cliffortia* species seedlings on the site differed significantly from their adult morphology, but could be positively identified through careful observations of leaf characteristics (Whitehouse 2002). Seedlings of the two *Leucadendron* species (*L. rubrum* and *L. salignum*) posed some difficulty in the first seedling count, but could be distinguished through careful observations of differing leaf shape and size and could be confirmed by the second count. Seedlings of the remainder of the species were easily identifiable. All seedlings (dead and alive recorded separately) for each species were recorded in a total of 48 1m x 1m plots. These were placed in each corner (NW, SW, and NE, SE) of the twelve 10m x 10m plots. For the 1m x 1m plots I used PVC piping and corners to clearly delineate each 1m x 1m square to simplify counting. Seedling mortality was assessed at one and two years postfire.

A rain gauge was set on 23 March 2009 and rain measures were documented about monthly or bi-monthly. The rainfall year is set from 1 April to 31 March of the following year. A HOBO pendant data logger (Onset Computer Corporation, Massachusetts, USA) was also installed that logged the temperature every two hours for the duration of the study.

## Statistical analysis

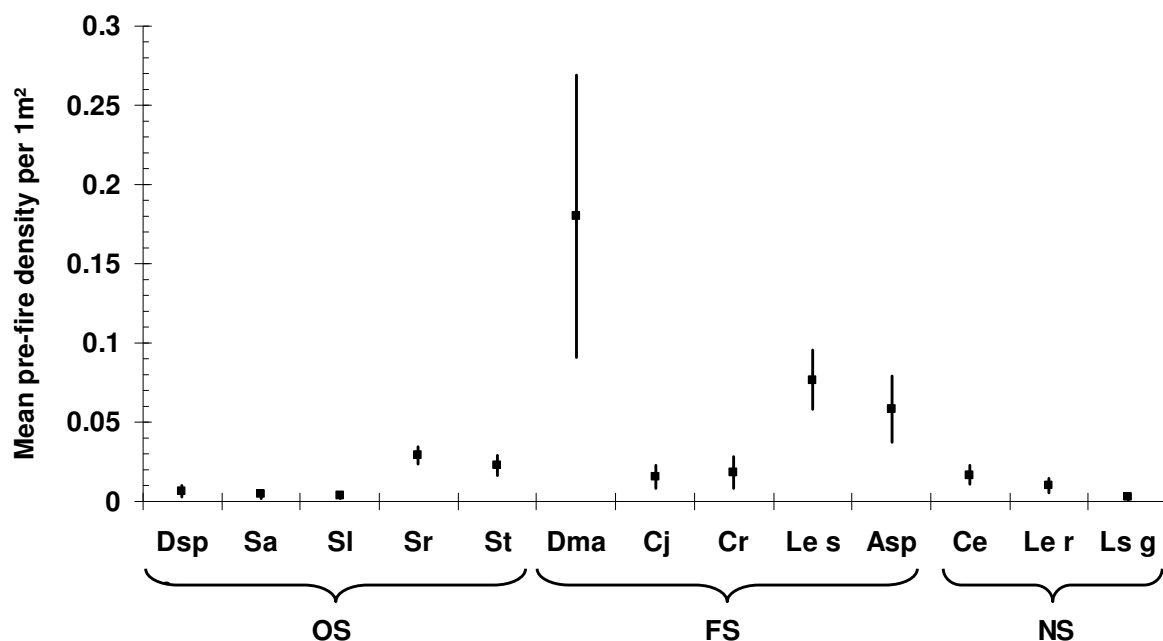
Different species and life history types were compared using STATISTICA (StatSoft, Inc.(2010). STATISTICA (data analysis software system), version 10. [www.statsoft.com](http://www.statsoft.com).) Pre-fire adult densities were calculated as mean densities per 1m<sup>2</sup>. Postfire seedling densities were also calculated as mean densities per 1m<sup>2</sup>. Total population densities two

years after the fire were calculated by adding the mean alive adults and seedlings per 1m<sup>2</sup>. Detailed statistical analyses comparing different life history types were not conducted, since the differences observed were evidently significant.

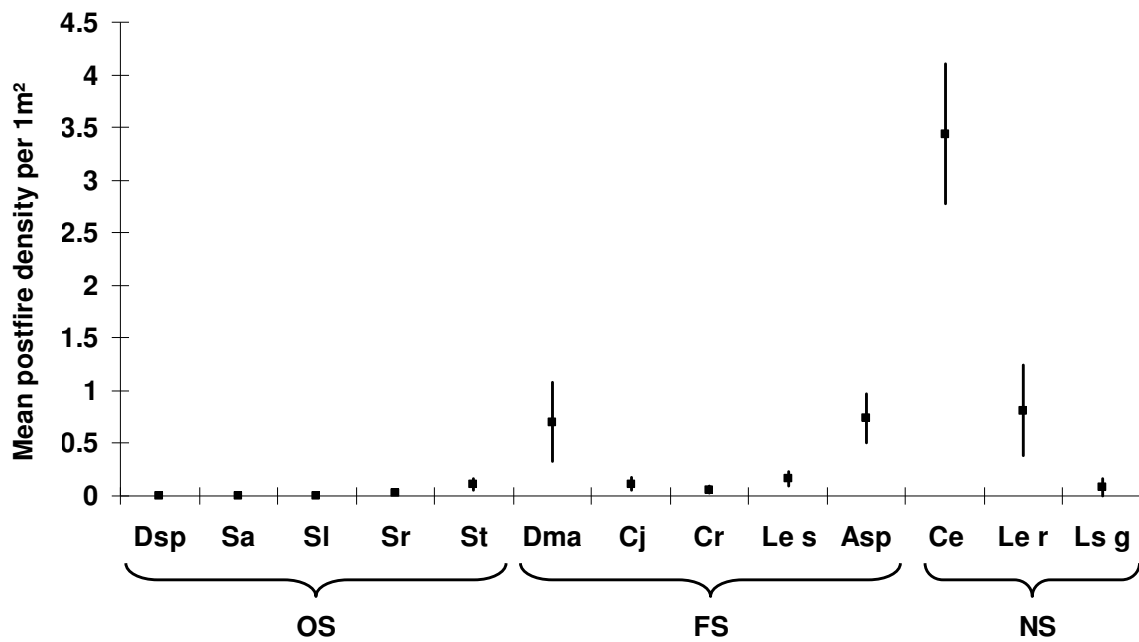
## Results

### Pre- and Postfire species density

The density of pre-fire adult plants (burnt skeletons and resprouted individuals) counted in all twelve plots varied between species, where the FS species as a group dominated the study site before the fire, with OS and NS species being less abundant (Fig 3.1). Two years postfire plant densities (all live adults and seedlings) differed greatly for FS and NS species, but not for OS species (Figure 3.2 and Table 3.2). Pronounced species-specific variability was observed among both FS species and NS species, although NS species generally had far greater increases in plant densities two years postfire compared to pre-fire (Figure 3.2). *Leucadendron salignum* (FS) barely doubled in density and *Aspalathus bracteata* (FS) increased its density by more than ten fold, while NS species varied from a 30 fold increase for *Leucospermum grandiflorum* to more than 200 fold for *Cliffortia erectisepala*.



**Figure 3.1** Mean pre-fire densities per 1m<sup>2</sup> with the standard error depicted by the line. Species are grouped into their life history type. See Table 3.1 for abbreviations of species and life history types.

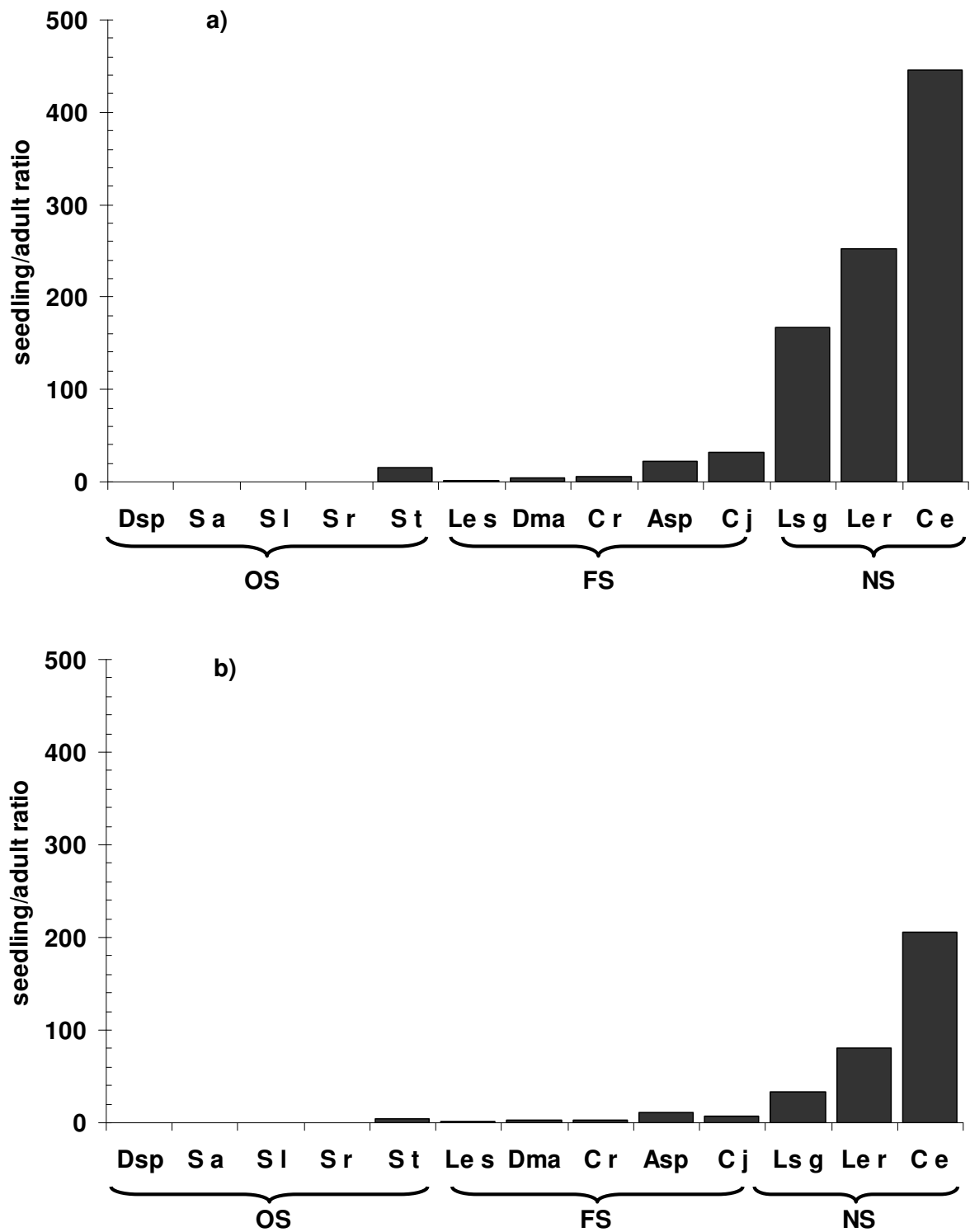


**Figure 3.2** Mean postfire densities per 1m<sup>2</sup>, two years after the fire. Fig. 3.1 and this figure are plotted at different scales as the pre-fire densities were so much lower. The standard error (SE) is shown by the line on either sides of the mean. Abbreviations are explained in Table 3.1

In the absence of new seedling recruitment or adult mortality, obligate resprouter densities remained unchanged, apart from *Searsia tomentosa*. A few seedlings of *S. tomentosa* were found at two locations on the study site, but the seeds were most likely deposited by birds after the fire. Both localities were beneath clumps of resprouted tall shrubs, including *Searsia* species that offered perfect perching sites for birds (Manders et al. 1992; Cowling et al. 1997). Germination studies of *S. tomentosa* seeds found that they only germinate when ripe, usually in the middle of summer, and in the same season as they are produced (A. Hitchcock - personal communication). None of the *Searsia* species on the study site, with the exception of *S. rosmarinifolia*, produced seeds the first year after the fire (personal observations, see next chapter on phenology) and thus the most likely explanation is bird dispersal from a nearby unburned site consistent with *S. tomentosa* being an obligate resprouter. Area recruitment measured as species presence per plot stayed unchanged for OS species but increased for FS and NS species.

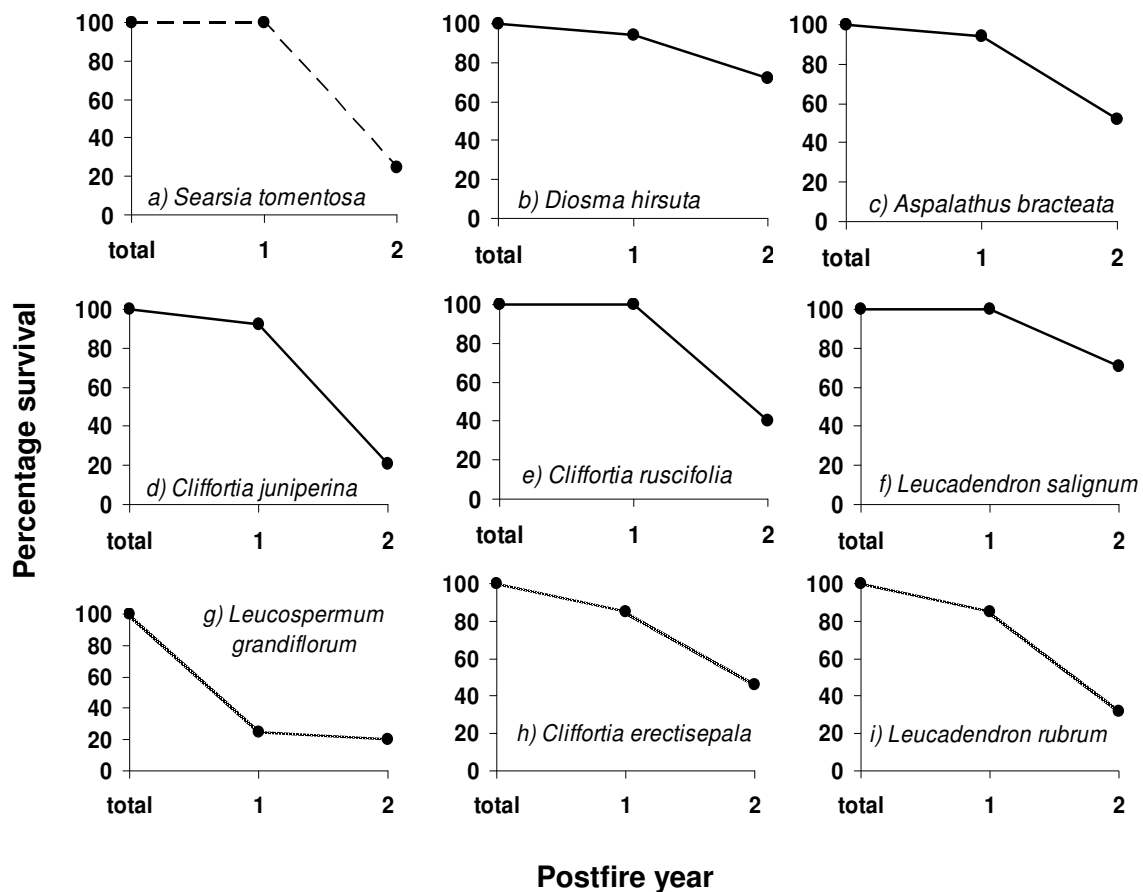
### Seedling to adult ratios

The non-sprouter species as a group produced far more seedlings than the other life history types, with a seedling/adult ratio being orders of magnitude higher than that of the facultative



**Figure 3.3** Seedling to adult ratios of selected species one year after the fire (a) including all seedlings (i.e. alive and dead) and two years after the fire (b) counting only the alive seedlings. Abbreviations explained in Table 3.1

resprouters (Fig 3.3). Although seedling recruitment was strongly associated with life history type, there was pronounced variability amongst individual species, especially within the group of facultative resprouters and non-sprouters. The seedling to adult ratio the second year postfire was lower due to some seedling mortality suffered by all species that produced seedlings, but the live seedlings still outnumbered the overall mortality (adults and seedlings) per species. Of the FS species, *L. salignum* had the lowest seedling/adult ratio two years postfire (1.4), while *A. bracteata* had the highest (11.9) (Fig. 3.3 and Table 3.2). The OS species did not recruit any seedlings apart from *S. tomentosa* (Fig. 3.3). (see paragraph above)



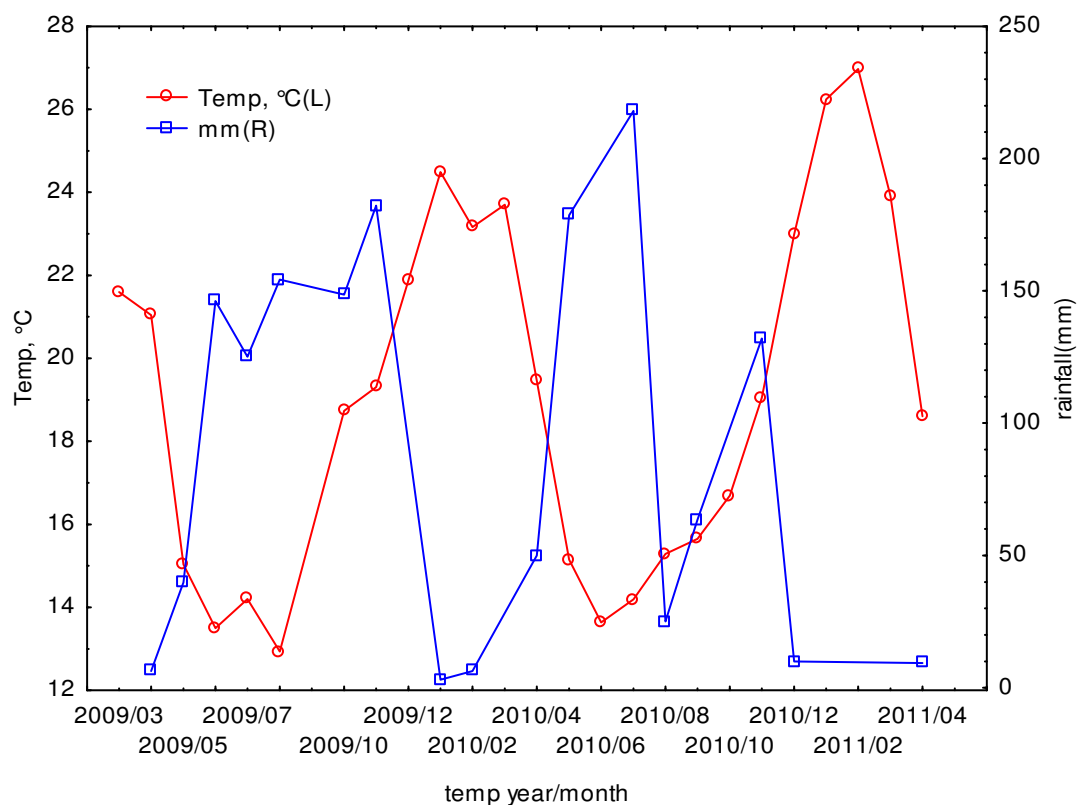
**Figure 3.4** Seedling survival over the two year observation period Graph a) with a dotted line being an obligate resprouter, (b-f) are facultative resprouter species and (g-i) non-sprouter species.

### Seedling survival

All seedlings showed marked mortality over the two year study period (Fig 3.4), with the greatest mortality recorded for the obligate resprouter *S. tomentosa* (75%). The greatest

variability in survival rate occurred amongst the FS species; from as low as 21% for *C. juniperina* to as high as 72% for *D. hirsuta*. Although NS species had the greatest number of seedlings, mortality was high with a survival rate of less than 50%. The timing of mortality was generally greatest in the second year after fire and independent of life history type. In contrast, *L. grandiflorum* showed high seedling mortality in the first year, and little thereafter.

The greater mortality observed in year two of the study may be related to a more stressful summer rainless season during year two. Rainfall during the first year postfire was a little above the annual average of 858mm at 946mm, but below average the second year at 750mm. Average temperatures were considerably higher during the second summer, with a longer period of no rainfall during summer (Figure 3.5).



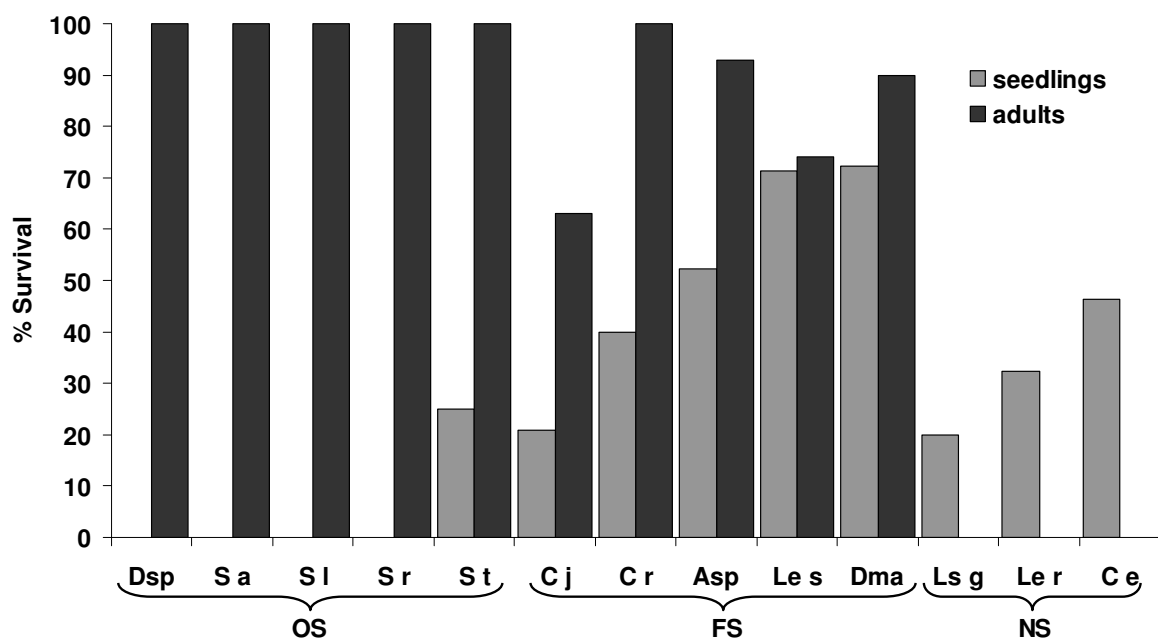
**Figure 3.5** Mean monthly temperature and total rainfall per sampling period measured over the two year study period.

### Seedling survival versus adult survival

Species that initially had a high seedling/adult ratio generally had greater seedling mortality rates, while species that had lower seedling/adult ratios had lower seedling mortality rates (Fig. 3.3 & 3.6). Strong associations were evident when comparing seedling and adult



survival two years after the fire, for species with different life history types (Fig 3.6). OS species demonstrated 100% resprout success, without any postfire seedling recruitment (apart from *S. tomentosa*); FS species adopted a dual strategy combining seedling recruitment and adult resprouting, which varied amongst species, but all were above replacement; NS species solely relied on seedling recruitment as all adults were killed by the fire. Although some NS species had low seedling survival rates, this was compensated for by the high seedlings/adult ratios (Fig. 3.3), thus seedlings were still above replacement values for dead adults.

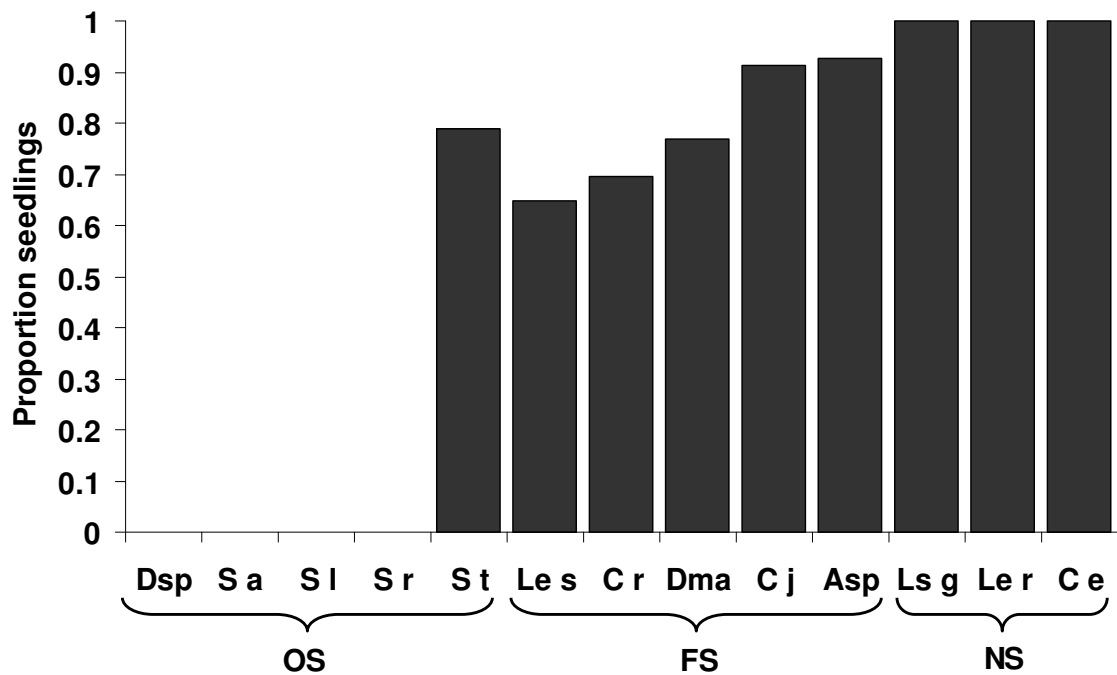


**Figure 3.6** Percentage seedling and adult survival two years after the fire. Seedling survival was calculated from total seedlings (alive and dead) counted in the first year (denominator) and live seedlings counted in the second year (numerator). Adult survival represents the percentage that had resprouted and remained alive after 2 years. The OS species generally did not produce seedlings and the NS species had no adults surviving the fire. The FS species show variability in resprouting and seedling survival.

### Seedlings as a proportion of all survivors

For all species that produced seedlings, the number of seedlings that survived after 2 years as a proportion of the whole live population was more than 0.5, indicating that there were more live seedlings than live adults two years postfire (Fig. 3.7). Again the different life

history types are highlighted, with the OS species not producing seedlings, the FS species resprouting and producing seedlings and NS species solely relying on seedling recruitment to replace the dead adults. Table 3.2 provides an overview that combines a short description of the relevant attributes of the thirteen species monitored with all the variables reflecting changes in postfire demography.



**Figure 3.7** Seedlings as a proportion of all live plants (per species) two years postfire, where 1 is equal to the whole population. Apart from *S. tomentosa*, OS species did not have any seedlings, the FS species had more seedlings than resprouted adults and the NS species only had seedlings.

**Table 3.2** Attributes and demography of thirteen species monitored for two years after a late summer season fire.

Species with abbreviation in brackets	Life history	Seed storage and dispersal	Prefire density (mean ±SE) indiv/1m <sup>2</sup>	Post fire density (mean ±SE) alive indiv/1m <sup>2</sup> after two years	Initial seedling / parent ratio	Seedling/ parent ratio after 2 years	Pre- and postfire plot presence	% seedling survival 2 years post fire	% resprout survival 2 years post fire (sample size in brackets)	Proportion live seedlings from live population two years post fire
<i>Diospyros glabra</i> (Dsp)	OS	Vertebrate dispersed	0.007 ± 0.004	0.007 ± 0.004	0	0	9/9	-	100 (8)	0
<i>Searsia angustifolia</i> (Sa)	OS	Vertebrate dispersed	0.004 ± 0.002	0.004 ± 0.002	0	0	4/4	-	100 (5)	0
<i>S. lucida</i> (Sl)	OS	Vertebrate dispersed	0.003 ± 0.001	0.003 ± 0.001	0	0	9/9	-	100 (4)	0
<i>S. rosmarinifolia</i> (Sr)	OS	Vertebrate dispersed	0.029 ± 0.006	0.029 ± 0.006	0	0	4/4	-	100 (35)	0
<i>S. tomentosa</i> (St)	OS	Vertebrate dispersed	0.023 ± 0.006	0.106 ± 0.056	14.8	3.7	4/4	25	100 (27)	0.78
<i>Diosma hirsuta</i> (Dma)	FS	Soil stored, myrmechochory	0.180 ± 0.090	0.703 ± 0.376	4.2	3.0	10/10	72	90 (216)	0.77
<i>Aspalathus bracteata</i> (Asp)	FS	Soil stored	0.058 ± 0.021	0.742 ± 0.233	22.5	11.8	8/11	52	93 (70)	0.92
<i>Cliffortia juniperina</i> (Cj)	FS	Soil stored, myrmechochory	0.016 ± 0.007	0.114 ± 0.060	31.6	6.6	4/5	21	63 (19)	0.91
<i>C. ruscifolia</i> (Cr)	FS	Soil stored, myrmechochory	0.018 ± 0.010	0.060 ± 0.032	5.7	2.3	4/4	40	100 (22)	0.62
<i>Leucadendron salignum</i> (Le s)	FS	Serotinous, winged, myrmechochory	0.077 ± 0.019	0.161 ± 0.066	1.9	1.4	9/10	71	74 (92)	0.65
<i>L. rubrum</i> (Le r)	NS	Serotinous, wind dispersed	0.010 ± 0.005	0.813 ± 0.433	252.1	81.3	4/10	32	-	1
<i>Leucospermum grandiflorum</i> (Ls g)	NS	Soil stored, myrmechochory	0.003 ± 0.002	0.083 ± 0.083	166.7	33.3	2/1	20	-	1
<i>C. erectisepala</i> (Ce)	NS	Soil stored, myrmechochory	0.017 ± 0.006	3.438 ± 0.664	446.3	206.3	7/12	46	-	1

## Discussion

### Diversity in life history type demography

Postfire seeding recruitment and regeneration dynamics are clearly different for different fynbos life history types. Obligate resprouters have no seedlings directly postfire with high adult resprout success, facultative resprouters have a broad range of seedling recruitment and adult resprout success, and non-sprouters rely solely on seedling recruitment, as all adults are killed by the fire leading to discrete generations (Laurie & Cowling 1994). These diverse life history types contribute to the high diversity found among woody shrubs in fynbos shrublands. Most studies have lumped life history types along a binary classification being non-sprouters and resprouters, but recent studies suggest that this may miss some important variation in the persistence stage between FS and OS (Pratt et al. 2012). This study suggests that there are important differences in the postfire demography between FS and OS and analysing them separately is important to fully understand the diversity of postfire responses of species in mediterranean-type shrublands. Moreover, FS and OS may respond differently to climate change and efforts to model such effects would benefit from considering FS and OS as separate types.

There appears to be a tradeoff between postfire resprout success and seedling recruitment that underlies the differences between resprout demography. At one extreme, the OS have near 100% resprout success and no postfire seedling recruitment. At the other extreme, NS have no 0% resprout success, but high seedling recruitment. In between these two extremes are FS that have variable resprout success (average of around 80% in this study) coupled with some seedling recruitment. These results are in contrast to findings in Californian chaparral shrublands where Keeley et al. (2006) reported little difference in seedling/adult ratios of NS and FS species. No other postfire seedling studies using the three-tiered life history classification were found. Thomas & Davies (1989) in a study of three chaparral shrub species (two FS and one NS) found that seedling survivorship was far more important than seedling/adult ratios, where the NS species had the highest seedling survivorship. My results broadly conform to the fecundity-life form hypothesis of Lamont & Wiens (2003) based primarily on studies performed in south-western Australian kwongan vegetation. Their literature review found that the majority of studies documented that non-sprouters produce more seedlings than resprouters, similar to trends reported by Bond & van Wilgen (1996) in other Mediterranean type ecosystems.

A trade-off between the number of seedlings recruited and drought tolerance (Richards & Lamont 1996) may exist among species that produce seedlings postfire. The hypothesis that species with a higher fecundity produce seedlings that are less tolerant to drought and species with a low fecundity produce seedlings that are more drought tolerant is supported by my observations. Species recruiting abundant seedlings had a generally lower seedling

survival compared to species recruiting only few seedlings (see Table 3.2). These results stand in contrast of a recent study that found no difference in water stress resistance of fynbos NS and FS at the adult stage of development (Pratt et al. 2012). It is possible that FS seedlings are more water stress resistant at the seedling stage and then plastically shift to being less tolerant once they establish deeper roots as an adult. However, it is not clear why the NS species would not employ a similar strategy to increase their seedling survival. The high seedling/adult ratios of the NS species also suggest a link between reproductive investment and plant longevity, with shorter lived non-sprouters allocating their resources to sexual reproduction, whereas longer lived resprouters allocate significant resources towards persistence (Bell & Ojeda 1999; Verdaguer & Ojeda 2002, 2005), while they recruit fewer seedlings (Bond & Midgley 2001; Schwilk & Ackerly 2005).

Seedling recruitment was very variable, especially amongst the FS species. Two years after the fire, the facultative resprouter *L. salignum* had the lowest seedling/adult ratio of all the species that recruited seedlings. The ratio of 1.35 is lower than the 2.47 that Le Maitre et al. (1992) found but much higher than the 0.001-0.1 ratio suggested by T. Rebelo (personal communication). A low seedling/adult ratio in *L. salignum* and high seedling/adult ratio in *L. rubrum* has been described by Williams (1972), who found that within the genus *Leucadendron*, seed-set was low for the resprouter species and high for the non-sprouter species.

*C. ruscifolia* also had a very low seedling /adult ratio, but none of the adult plants within the 10m x 10m study plots died within the two year monitoring period. This differs greatly from the low adult survival (only 29%) observed for *C. ruscifolia* shrubs tagged over the larger study site (see previous chapter). This difference is most likely due to different sampling techniques, since I used resprouts within a 5cm radius of the lignotuber to indicate adult survival in the larger site, while I regarded all resprouts from lignotubers or roots as a sign of survival in the subsequent seedling survey. An interesting observation was that resprouts close to the lignotuber often died, yet the root suckers thrived. These observations suggest that *C. ruscifolia*, at least at this site, might rely heavily on clonal spread from root suckers at the expense of resprouting from the lignotuber and postfire seedling recruitment. Clonal spread is common amongst *Cliffortia* species (Whitehouse 2002) and *C. ruscifolia* spreading clonally has been previously documented (Keeley et al. 2012). All FS species recruited sufficient numbers of seedlings to outnumber adult mortality and all resprouted adults flowered within the two year study period, except *C. ruscifolia*, which was also the only species to spread clonally.

*A. bracteata* had the highest seedling/adult ratio amongst the facultative resprouters. This was also the one species within the FS group that had an entirely different growth form, being a low, prostrate growing shrub that occupied maximum space early in the postfire

period, presumably making the best of the available light before being overshadowed by upright growing shrubs. This species might not be as long-lived as other FS species, being in the Fabaceae family that are typically more abundant in the early succession phase (Rundel 1989). This species was absent from the nearby unburned vegetation and only seen in open vegetation next to the road at other localities on Paarl Mountain (personal observations).

*L. grandiflorum* had fewer seedlings compared to the other two NS species in the study. This species tends to occur in clumps, having large (Holmes & Newton 2004), ant dispersed seeds (Rebello 1995) with a limited dispersal range. The clump of burned adult *L. grandiflorum* was on the edge of our study site and only a few seedlings and the remains of three burnt adult plants occurred within the sampled plots. None of the seedlings of NS species reached maturity within the two year study period. Resprouted OS species only started flowering during the second year after the fire with the exception of *S. rosmarinifolia* and *D. glabra* (see next chapter on phenology).

The rainfall and temperature data demonstrate a marked difference between the first and second year postfire, with below average rainfall and higher temperatures recorded during the second summer. Some seedlings may be more susceptible to drought than others (Moreno et al. 2011). This may explain why the majority of seedling mortality (see Fig. 3.4 & 3.5) occurred during the second summer. An exception to this observation was *L. grandiflorum* that experienced most seedling mortality during the first summer suggesting that factors other than water stress likely played a role. During the second year the resprouted plants have also grown into bigger plants, competing more ferociously for water and seedling access to resources may therefore be diminished

### **Resilience of fynbos populations to fire**

Comparisons of pre- and postfire species densities (adults and seedlings) showed a marked increase for all species that produced seedlings. Postfire densities were unchanged for the OS species, apart from *S. tomentosa*. As seedlings have to compete against each other and resprouting species for resources and light (Bond et al. 1984; le Maitre 1987; Laurie & Cowling 1994; Pausas & Bradstock 2007), further seedling mortality would be expected. However, populations were likely to remain stable, as the two-year densities were well above replacement values for NS and FS species and virtually unchanged for OS species. A shift in postfire community composition was noted at a local scale, which is in line with previous findings in fynbos vegetation (Privett et al. 2001; Thuiller et al. 2007). This does not necessarily imply a shift at the meta-community scale (Privett et al. 2001; Thuiller et al. 2007), which can only be detected in long-term studies.

## **Conclusion**

It is evident that woody fynbos species adopt different survival strategies to ensure postfire persistence. In contrast to NS species, OS species did not recruit seedlings directly postfire and depended exclusively on resprouting to maintain population stability. FS species demonstrated high variability using a combination of resprouting and reseeding strategies and in some cases clonal expansion. These results demonstrate that the simple distinction between resprouter and non-sprouter species fails to capture the diversity within resprouters, which justifies classifying them as obligate or facultative resprouters. The apparent tradeoff between postfire resprout success and seedling recruitment underpins the differences between resprout demography. Lastly, including life history type in standard species descriptions would be helpful, as this may be vitally important to assess species resilience to current and future disturbances.



## References

- Barker, N.P., Vanderpoorten, A., Morton, C.M. & Rourke J.P. (2004) Phylogeny, biogeography, and the evolution of life-history traits in *Leucadendron* (Proteaceae). *Molecular Phylogenetics and Evolution* **33**, 845-860.
- Bell, T.L. & Ojeda, F. (1999) Underground starch storage in *Erica* species of the Cape Floristic Region - differences between seeders and resprouters. *New Phytologist* **144**, 143-152.
- Bellingham, P.J. & Sparrow, A.D. (2000) Resprouting as a life history strategy in woody plant communities. *Oikos* **89**, 409-416.
- Bond, W.J. & Midgley, J.J. (2001) Ecology of sprouting woody plants: the persistence niche. *Trends in Ecology & Evolution* **16**, 45-51.
- Bond, W.J. & van Wilgen, B.W. (1996) *Fire and Plants*, Chapman & Hall, London.
- Bond, W.J., Vlok, J. & Viviers, M. (1984) Variation in seedling recruitment of Cape Proteaceae after fire. *Journal of Ecology* **72**, 209-221.
- Cowling, R.M. (1987) Fire and its role in coexistence and speciation in Gondwana shrublands. *South African Journal of Science* **83**, 106-112.
- Cowling, R.M., Kirkwood, D., Midgley, J.J. & Pierce, S.M. (1997) Invasion and persistence of bird-dispersed, subtropical thicket and forest species in fire-prone coastal fynbos. *Journal of Vegetation Science* **8**, 475-488.
- Cowling, R.M. & Lamont, B.B. (1987) Post-fire recruitment of four co-occurring *Banksia* species. *Journal of Applied Ecology* **24**, 645-658.
- Enright, N.J., Marsula, R., Lamont, B.B. & Wissel, C. (1998) The ecological significance of canopy seed storage in fire-prone environments: a model for non-sprouting shrubs. *Journal of Ecology* **86**, 946-959.
- Heelemann, S., Procheş, Ş., Porembski, S. & Cowling, R.M. (2010) Impact of graminoid cover on postfire growth of nonsprouting *Protea* seedlings in the eastern fynbos biome of South Africa. *African Journal of Ecology* **49**, 51-55.
- Holmes, P.M. & Newton, R.J. (2004) Patterns of seed persistence in South African fynbos. *Plant Ecology*, **172**, 143-158.
- Keeley, J.E. (1986) Resilience of Mediterranean shrub communities to fires. Resilience in Mediterranean-type ecosystems (eds. Dell, B., Hopkins, A.J.M. & Lamont, B.B.), pp.95-112. Junk, The Hague.
- Keeley, J.E. & Bond, W.J. (1997) Convergent seed germination in South African fynbos and Californian Chaparral. *Plant Ecology* **133**, 153-167.
- Keeley, J.E., Bond, W.J., Bradstock, R.A., Pausas, J.G. & Rundel, P.W. (2012) *Fire in Mediterranean Ecosystems: ecology, evolution and management*. Cambridge University Press, New York.

- Keeley, J.E., Fotheringham, C.J & Baer-Keeley, M. (2006) Demographic patterns of postfire regeneration in Mediterranean-climate shrublands of California. *Ecological Monographs* **76**, 235-255.
- Lamont, B.B. & Markey, A. (1995) Biogeography of fire-killed and resprouting *Banksia* species in South-western Australia. *Australian Journal of Botany* **43**, 283-303.
- Lamont, B.B. & Wiens D. (2003) Are seed set and speciation rates always low among species that resprout after fire, and why? *Evolutionary Ecology* **17**, 277–292.
- Laurie, H. & Cowling, R.M. (1994) Lottery coexistence models extended to plants with disjoint generations. *Journal of Vegetation Science* **5**, 161-168.
- Le Maitre, D.C. (1987) Effects of season of burn on species populations and compositions of fynbos in the Jonkershoek valley. *South African Journal of Botany* **53**, 284-292.
- Le Maitre, D.C. & Midgley J.J. (1992) Plant reproductive ecology. The Ecology of Fynbos – nutrients, fire and diversity (ed. Cowling, R.M.), pp. 135-174. Oxford University Press, Cape Town.
- Manders, P.T., Richardson, D.M. & Masson, P.H. (1992) Is fynbos a stage in succession to forest? Analysis of perceived ecological distinction between two communities. Fire in South African Mountain Fynbos: Ecosystem, Community and Species Response at Swartboskloof (eds. B.W. van Wilgen, D.M. Richardson, F.J. Kruger & H.J. van Hensbergen), pp. 81-107. Springer-Verlag, New York.
- Meentemeyer, R.K., Moody, A. & Franklin, J. (2001) Landscape-Scale Patterns of Shrub-Species Abundance in California Chaparral: The Role of Topographically Mediated Resource Gradients. *Plant Ecology* **156**, 19-41.
- Midgley, J.J. (1996) Why the world's vegetation is not totally dominated by resprouting plants; because resprouters are shorter than reseederers. *Ecography* **19**, 92-95.
- Midgley, J.J. & Cowling, R.M. (1993) Regeneration patterns of Cape subtropical thicket: Where are all the seedlings? *South African Journal of Botany* **59**, 496-499.
- Milton, S.J. (2003) Vegetation Survey. Paarl Mountain Nature Reserve. Conservation Ecology Department, University of Stellenbosch, 7701 Stellenbosch.
- Moreno, J.M., Zuazua, E., Pérez, B., Luna, B., Velasco, A. & Resco De Dios, V. (2011) Rainfall patterns after fire differentially affect the recruitment of three Mediterranean shrubs. *Biogeosciences Discussions* **8**, 5761-5786.
- Mucina, L. & Rutherford, M.C. (eds) (2006) The vegetation of South Africa, Lesotho and Swaziland. *Strelitzia* **19**. South African National Biodiversity Institute, Pretoria.
- Noble, I.R. & Slatyer, R.O. (1980) The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. *Vegetatio* **43**, 5-21.
- Ojeda, F. (1998) Biogeography of seeder and resprouter *Erica* species in the Cape floristic region – where are the resprouters? *Biological Journal of the Linnaean Society* **63**, 331-347.

- Pausas, J.G. & Bradstock, R.A. (2007) Fire persistence traits of plants along a productivity and disturbance gradient in Mediterranean shrublands of south-east Australia. *Global Ecology and Biogeography* **16**, 330-340.
- Pausas J.G., Bradstock, R.A., Keith, D.A., Keeley, J.E., Hoffman, W., Kenny, B., Lloret, F. & Trabaud, L. (2004) Plant functional traits in relation to fire in crown-fire ecosystems. *Ecology*, **85**, 1085-1100.
- Pratt, R.B., Jacobsen, A.L., Jacobs, S.M. & Esler, K.J. (2012) Xylem transport safety and efficiency differ among fynbos shrub life history types and between two sites differing in mean rainfall. *International Journal of Plant Science* **173**, 474-483.
- Privett, S.D.J, Cowling, R.M. & Taylor H.C. (2001) Thirty years of change in the fynbos vegetation of the Cape of Good Hope Nature Reserve, South Africa. *Bothalia* **31**, 99-115.
- Rebelo, T. (1995) Proteas. A field guide to the Proteas of Southern Africa. Fernwood Press, Vlaeberg.
- Richards, M.B, & Lamont, B.B. (1996) Post-fire mortality and water relations of three congeneric shrub species under extreme water stress - a trade-off with fecundity? *Oecologia* **107**, 53-60.
- Rundel, P.W., (1989) Ecological success in relation to plant form and function in the woody legumes. *Advances in Legume Biology* (eds. Stirton, C.H. & Zarucchi, J.L.), pp. 377-398. *Monographs of Systematic Botany* **29**. Missouri Botanical Garden.
- Rutherford, M.C., Powrie, L.W., Husted, L.B. & Turner R.C. (2011) Early post-fire plant succession in Peninsula Sandstone Fynbos: The first three years after disturbance. *South African Journal of Botany* **77**, 665-674.
- Schutte, A.L., Vlok, J.H.J., & Van Wyk, B.E. (1995) Fire-survival strategy – a character of taxonomic, ecological and evolutionary importance in fynbos legumes. *Plant Systematics and Evolution* **195**: 243-259.
- Schwilk, D.W. & Ackerly, D.D. (2005) Is there a cost to resprouting? Seedling growth rate and drought tolerance in sprouting and nonsprouting *Ceanothus* (Rhamnaceae). *American Journal of Botany* **92**, 404-410.
- Thomas, C.M. & Davis, S.D. (1989) Recovery patterns of three chaparral shrub species after wildfire. *Oecologia* **80**, 309-320.
- Thuiller, W., Slingsby, J.A., Privett, S.D.J & Cowling R.M. (2007) Stochastic species turnover and stable coexistence in a species-rich, fire-prone plant community. *PLOS One* **9**, e938.
- Van Wilgen, B. (1974) A management plan for the Paarl Mountain Nature Reserve, Nature Conservation Department (Conservation Ecology), University of Stellenbosch.
- Van Wilgen, B.W. (1982) Some effects of post-fire age on the above-ground plant

- biomass of fynbos (macchia) vegetation in South Africa. *Journal of Ecology* **70**, 217-225.
- Van Wilgen, B.W. & Forsyth, G.G. (1992) Regeneration strategies in fynbos plants and their influence on the stability of community boundaries after fire. Fire in South African Mountain Fynbos: Ecosystem, Community and Species Response at Swartboskloof (eds. B.W. van Wilgen, D.M. Richardson, F.J. Kruger & H.J. van Hensbergen), pp. 54-80. Springer-Verlag, New York.
- Van Wilgen, B.W., Forsyth, G.G., de Klerk, H., Das, S., Khuluse, S. & Schmitz, P. (2010) Fire management in Mediterranean-climate shrublands: a case study from the Cape fynbos, South Africa. *Journal of Applied Ecology* **47**, 631-638.
- Verdaguer, D. & Ojeda, F. (2002) Root starch storage and allocation patterns in seeders and resprouter seedlings of two Cape *Erica* (Ericaceae) species. *American Journal of Botany* **89**, 1189-1196.
- Verdaguer, D. & Ojeda, F. (2005) Evolutionary transition from resprouter to seeder life history in two *Erica* (Ericaceae) species: Insights from seedling axillary buds. *Annals of Botany* **95**, 593-599.
- Whelan, R. (1995) *The Ecology of Fire*. Cambridge University Press, Cambridge.
- Whitehouse, C.M., (2002) Systematics of the genus *Cliffortia* L. [Rosaceae]. Unpublished PhD Thesis, Department of Botany, University of Cape Town, Rondebosch.
- Williams, I.J.M. (1972) A revision of the genus *Leucadendron* (Proteaceae). *Contributions to the Bolus Herbarium* **3**, 1-425.
- Zucchini, W. (1992) "Genrain" rainfall simulation programme for South Africa. Applied Statistics and Decision Sciences Unit. University of Cape Town, 7700 Rondebosch.

## CHAPTER 4

### Postfire flowering phenology over a two year period on Paarl Mountain Nature Reserve

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#### Abstract

Postfire flowering phenology could be an important indicator of fire stimulated flowering in fire prone MTC regions of the world. I compiled a photographic record of as many flowering species as possible over a two year study period on Paarl Mountain Nature Reserve, recording their growth form as well as their life history type, wherever possible. Sixty-eight percent of all flowering species recorded were resprouters and more than half of those were geophytes. Within the woody growth forms, most of the smaller shrubs flowered within the first year after the fire, whereas the tall shrubs flowered later, with all shrubs over two meters flowering the first time only in the second year after the fire. Life history type (fire response) could not be established for all species as retrospective examination of the photographic record proved difficult. This information is most often not part of standard species descriptions, yet is vital in understanding species response to fire and ultimately how that influences vegetation composition. Fire has been an important driver in shaping plant traits, yet much is still to be learned about postfire flowering phenology and regeneration mechanisms of many fynbos species in relation to the fire regime they occur in.

## Introduction

Fynbos vegetation is fire-prone and occurs in the Mediterranean-type climate region of South Africa (Bond & van Wilgen 1996). Fire is an important driver of vegetation structure and composition in fynbos vegetation (Rutherford et al. 2011) and many fynbos species are dependent on fire for successful reproduction (Keeley et al. 2012). This association with fire, and more importantly the current fire regime, is now believed to stretch back much further in time than previously thought (Bytebier et al. 2011), where the current fynbos fire regime is defined by high intensity crown fires that occur in summer or autumn, when the vegetation has dried out sufficiently, at intervals of 10-30 years (Forsyth & van Wilgen 2008; Keeley et al. 2012). Mass flowering occurs after fires in most Mediterranean-type climate regions, yet up until now fire stimulated flowering has not received much attention in studies identifying plant traits that are associated with fire (Lamont & Downes 2011). There are many fynbos species (mostly annuals, fire ephemerals and geophytes) that complete their reproductive cycle in the immediate postfire environment (Le Maitre & Brown 1992; Van Wilgen & Forsyth 1992; Goldblatt & Manning 2000; Manning et al. 2002) and then either disappear or become dormant until the next fire. However, fire stimulated flowering also occurs in many shrubs (Keeley et al. 2012) and is not limited to herbaceous species.

For many species, specific postfire flowering cues are still poorly understood (Verboom *et al.* 2002; Bytebier et al. 2011). Goldblatt & Manning (1998) noted *Gladiolus phoenix* (Iridaceae) only flowered in the first season after a fire and cultivated plants could only be induced to flower if the 'effects of a fire' were simulated by burning plant material over the planted corms; however no mention is made of the possible trigger. Also, Lamont & Downes (2011) did not link any specific fire-related cues to the many geophytes and resprouters in Australia and South Africa that were identified as demonstrating fire-stimulated flowering. A few attempts have been made to identify specific cues, like the geophytic grass *Ehrharta capensis*, which grows in fynbos and flowers prolifically after fires, has been linked to postfire nutrient enrichment through ash deposition as well as the removal of vegetation cover (Verboom et al. 2002) and Keeley (1993) identified smoke as the cue for flowering in the fire-lily *Cyrtanthus ventricosus*.

Fire stimulated recruitment is not limited to flowering, but also by its effect on germination, through heat and smoke cues (Keeley & Bond 1997). Many fynbos species however have seed that lack dormancy (Keeley & Bond 1997) and it is not the fire *per se* that stimulates germination. As an example, many of the non-sprouting Proteaceae species are serotinous, thus retaining their seeds in the canopy until the adult plant dies. As these non-sprouting species die in a fire, their seeds are dispersed into the postfire environment as a single pulse (Lamont et al. 1991; Keeley et al. 2012), making use of the flush of nutrients, light and space for seedling recruitment. It is thus clear that fire-stimulated recruitment is an integral part of

fynbos ecology (Le Maitre & Midgley 1992; Cowling et al. 1997; Manning et al. 2002; Keeley et al. 2012) and the fire regime a key determinant of the species composition (Le Maitre 1992; Manders et al. 1992; Vlok & Yeaton 2000; Rutherford et al. 2011). Fire stimulated recruitment is not unique to fynbos and is also evident in other mediterranean-type climate regions for example in California (Keeley & Fotheringham 1998; Keeley et al. 2006) and Australia (Lamont et al. 1991; Lamont & Downes 2011).

The aim of this study was to compile a dataset of postfire flowering phenology of as many species as possible over a two year period after an autumn fire on Boland Granite Fynbos (Mucina & Rutherford 2006). A photographic record was established for only a proportion of the total species present, since time did not permit a more comprehensive survey. A further aim was to classify the plants according to their growth form and their life history type (fire response) as the latter information is often lacking in standard species descriptions (Bond & Midgley 2001) and both could be important variables that influences the immediate postfire flowering pattern (Keeley et al. 2006; Lamont & Downes 2011).

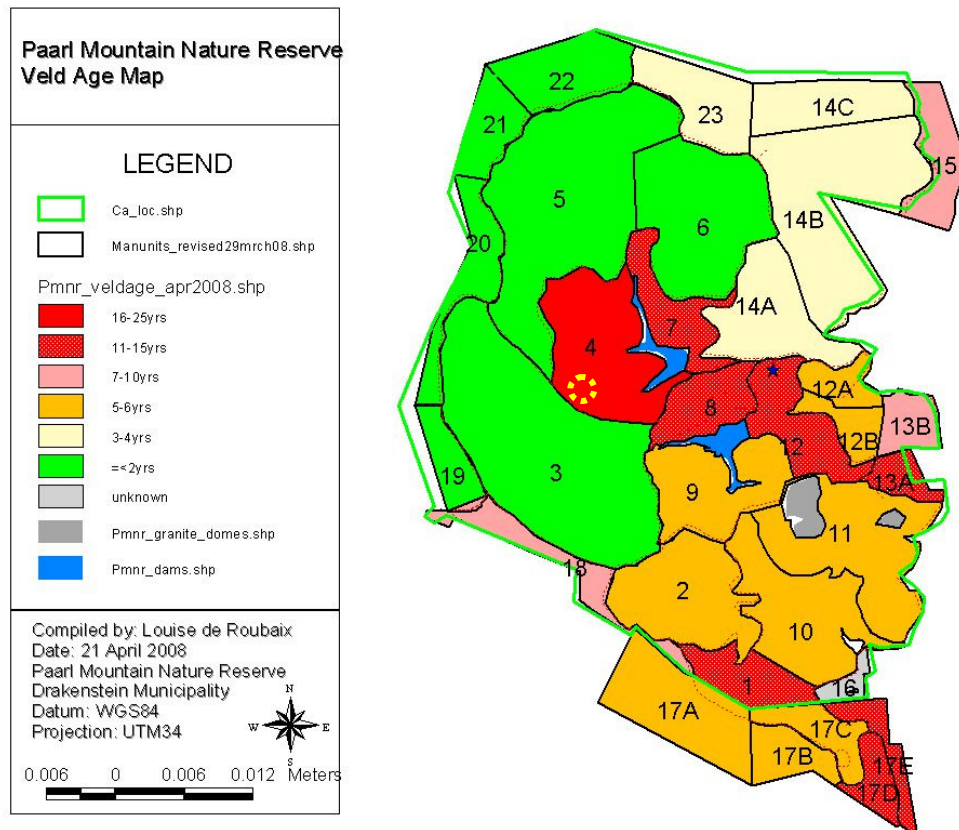
## **Methods**

The growth form classification was adapted from schemes used by Cowling *et al.* (1994), Goldblatt & Manning (2000) and Agenbag et al. (2008). The fire response was classified as either resprouter or non-sprouter (NS). If there was evidence of woody species having a dual strategy of resprouting as well as producing seedlings, they were further classified as facultative resprouters (FS). Where no seedlings were observed within the first year after the fire and where plants were previously labelled as obligate resprouters (OS), this classification was used.

## **Study site**

The current study site included, but was not confined to the study site previously described in chapters two and three of this thesis. I included some additional areas of the Paarl Mountain Nature Reserve that were burned during the same fire, namely compartments 4, 7 and 8 in Figure 4.1.





**Figure 4.1** Vegetation age map of Paarl Mountain Nature Reserve as mapped in April 2008. The yellow dotted circle in compartment 4 is the area of the study site in chapter 2 and 3. In this chapter compartments 4, 7 and 8 were included in the survey. All three compartments burned in the fire on Paarl Mountain between 3-7 March 2009. The map was obtained from L. de Roubaix, Paarl Mountain Nature Reserve, Drakenstein Municipality.

### Sampling methods

During a 2-year study period an extensive photo gallery of flowering species was compiled. These photos were taken during field trips collecting data on postfire plant regeneration, at two weekly intervals for the first two months, then monthly for the rest of the first year and seasonally (2-3 month intervals) through out the second year (see chapters two and three). Three additional field trips were undertaken in August, October and November of 2009, where the only aim was identifying species in flower and taking photos. The irregularity of these trips may well have biased the results, although spring to early summer is the peak flowering season on Paarl Mountain (Milton 2003). Plant identification was done mainly through using these photos. Paarl Mountain Nature Reserve has a recent species check-list, updated during a vegetation survey by Sue Milton (2003), as well as the local herbarium, housed in the reserve, which I used extensively to confirm identifications. New specimens were collected for the local herbarium if the species was a possible new record for the area and sent in to the Compton Herbarium at Kirstenbosch for identification. Data on rare and

endangered species were also shared with the Threatened Species Programme and the Custodians of Rare and Endangered Wildflowers (CREW) programme coordinated by the South African Biodiversity Institute (SANBI).

**Table 4.1** Growth form categories, adapted from Agenbag et al. (2008) and Cowling et al. (1994).

<b>GROUPS</b>	<b>CODE</b>	<b>DESCRIPTION</b>
herbs	AH	annual herb
	PH	perennial herb, including those with succulent leaves, parasites & climbers
dwarf shrubs (<0.25 m)	DS	dwarf shrubs, including succulent shrubs and parasites
low shrubs (0.25-1 m)	LS	low shrubs, including succulent shrubs, parasites and climbers
mid-high shrubs (1-2 m)	MS	mid-high shrubs
tall shrubs (>2 m)	TS	tall shrubs
geophytes	GEO	plants with underground storage organs and leaves that die back annually
graminoids	GRA	includes all grasses, sedges, restios

All species were assigned to a growth form (see Table 4.1 for growth form descriptions and coding), using plant descriptions by Goldblatt & Manning (2000) and verified by an online checklist, POSA (Plants of Southern Africa; <http://posa.sanbi.org/searchspp.php>). Wherever possible the life history type (fire response) was also documented. The fire response could not always be determined from retrospective photograph assessments. If there was doubt about the life history type and no reliable reference to fire response could be found in the literature for a particular species, then the fire response was not classified (indicated by a question mark). As growth forms and fire response of the same species may vary from site to site (Bond & van Wilgen 1996; van der Bank et al. 1999, Malgas et al. 2010) as well as a species overall phenology (Pierce 1984), the classification is most applicable to Boland Granite Fynbos (Mucina & Rutherford 2006) on Paarl Mountain Nature Reserve, and extrapolation beyond this region should be undertaken with caution.

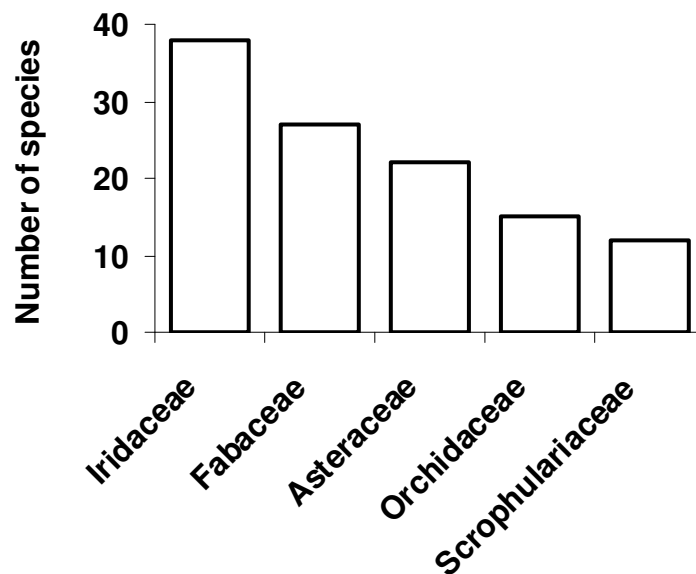
### **Statistical analysis**

Since the main aim was to utilize the information collected during informal observation to provide an overview of flowering phenology, no detailed comparative analysis was possible and only descriptive statistics were performed. The information gathered provides an overview of the flowering phenology at a community level after an autumn season fire in mountain fynbos.

## Results

### Plant species

A total of 227 flowering plants were recorded (Appendix C), comprising of 52 families and 125 genera. Five families (Figure 4.2) contributed 50.2 % of the species recorded (114 out of 227 species). Out of the 125 genera, 17 genera (Figure 4.3) had three or more species, contributing 39.6% of all recorded species; *Aspalathus* (16 species) had the most species, followed by *Moraea* and *Pelargonium* (eight species each). Four alien taxa, *Inula graveolens*, *Anagallis arvensis*, *Spergula arvensis* and *Plantago lanceolata* were recorded and these were included in the database.

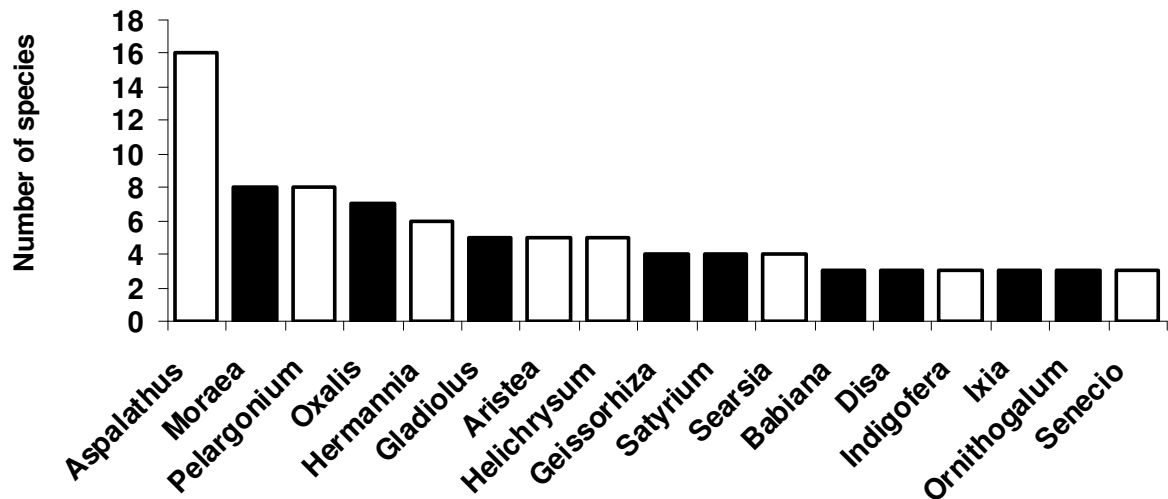


**Figure 4.2** The top five plant families with the most flowering species recorded on Paarl Mountain during a two year survey after an autumn season fire.

Of all the recorded species, 81% flowered within one year of the fire and only 52% flowered the 2<sup>nd</sup> year. Little less than a third of the species (32%) were observed to flower both years and 19% had their first flowering season in the second year after the fire.

### Growth forms

The growth forms that flowered most prolifically during the two years postfire were geophytes, followed by low shrubs, perennial herbs, dwarf shrubs and medium shrubs (see Table 4.1 for growth form descriptions and Figure 4.4 for results). Although the vast majority



**Figure 4.3** Top ranked genera with three or more species recorded in a two year survey after an autumn season fire on Paarl Mountain. Black boxes indicate monocotyledonous genera (except *Oxalis*), where all the species recorded in the current study were geophytes.

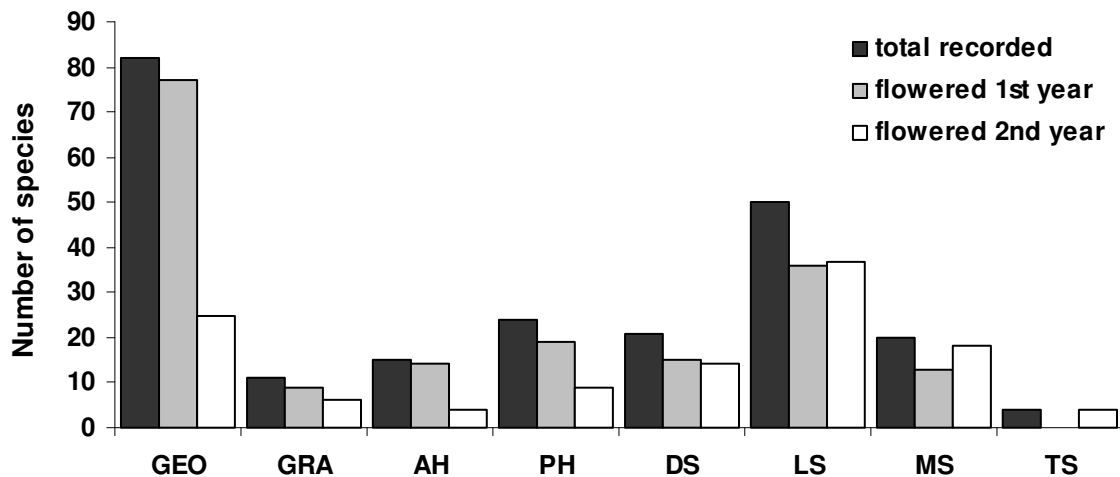
of species observed flowering during the study period flowered during the first year after the fire, none of the tall shrubs and just over half of the medium shrubs flowered the first year. A reduction in flowering was documented among the smaller stature growth forms during the second year, the sharpest reduction occurred amongst the geophytes and annuals, followed by perennials and graminoids. Low shrubs and medium shrubs showed an increase and tall shrubs flowered for the first time during the second year postfire (Figure 4.4). The percentage of flowering per growth form in total and during the first and second year, was greatest for geophytes overall (36%) and during the first year (42%). Low shrubs dominated the second year (32%), followed by geophytes (21%) with an overall decrease in representation by the lower growing, more herbaceous growth forms as well as the dwarf shrubs and an increase in all the other shrubs, especially the taller growth forms (Figure 4.5).

The average time taken for species to start flowering after the fire, if arranged according to growth form, was shortest for geophytes at around 6 months ( $n=79$ ), followed by annuals around 7 months ( $n=15$ ) and longest for medium shrubs at just under 12 months ( $n=15$ ) and tall shrubs at around 16 months ( $n=4$ ) (Figure 4.6). Nearly all the geophyte species flowered during the first spring postfire as indicated by their low standard error (Figure 4.6).

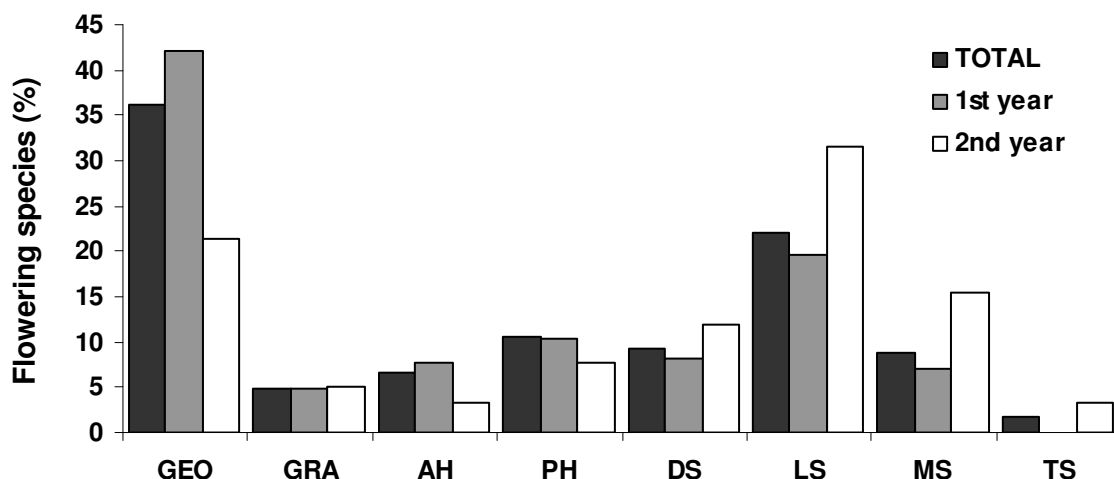
#### Life history type (fire response)

Sixty eight percent of all flowering species recorded were resprouters, 21% were non-sprouters and for 11% of the species the fire response could not be determined with certainty

(Figure 4.7). Out of the woody resprouters, eight were further classified as facultative resprouters and six as obligate resprouters (Appendix C). Further classification into facultative or obligate resprouters proved difficult, since the presence of seedlings was rarely captured in the photographs. However two seedling surveys were undertaken within the study site (see chapter 3) and seedling data from these surveys were incorporated (seedlings seen in seedling survey were also used to confirm if a species had a dual strategy

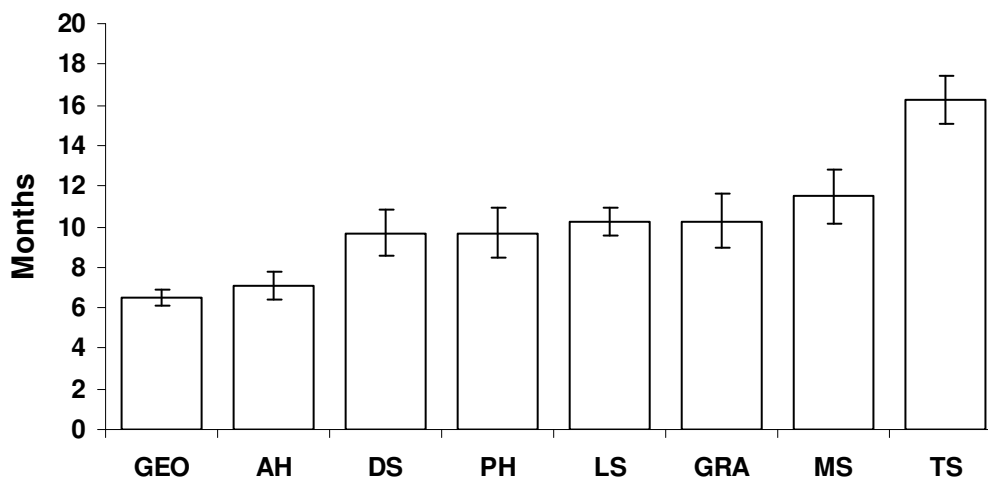


**Figure 4.4** Total number of species that flowered according to growth form over two years (black), as well as for the first year (grey) and second year (white). Codes for the growth forms are described in Table 4.1



**Figure 4.5** Percentage representation of the total recorded flowering species (black) according to growth form, as well as for the first year (grey) and second year (white). Codes for the growth forms are described in Table 4.1

and could thus be classified as a facultative resprouter). All the facultative resprouters flowered and produced seeds by the end of the first summer after the fire. The obligate resprouters tended to start flowering later, although three out of the six did flower within the first year.

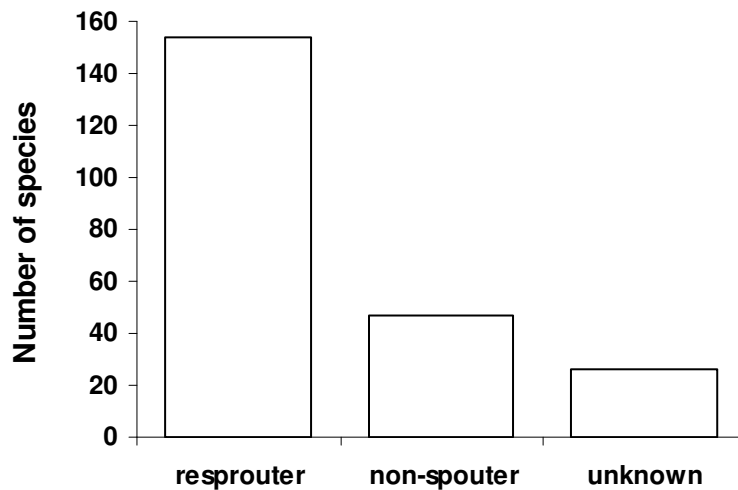


**Figure 4.6** Average ( $\pm 1$  SE) time taken (in months) to first flowering recorded per growth form (see Table 4.1 for codes).

More than half of the resprouters were geophytes (53%). Two geophytic graminoids, *Ehrharta capensis* and *E. ottonis*, were included in this group. Low shrubs contributed 13% and perennial herbs 10%. The rest was made up of graminoids, dwarf, medium and tall shrubs. The non-sprouters were dominated by low shrubs (43%), annuals (32%) and medium shrubs (17%) and the rest was made up of tall shrubs and dwarf shrubs. The species where the life history (fire response) was uncertain were scattered amongst the shrubs and also a few perennial herbs.

### Lineage in relation to life history and growth form

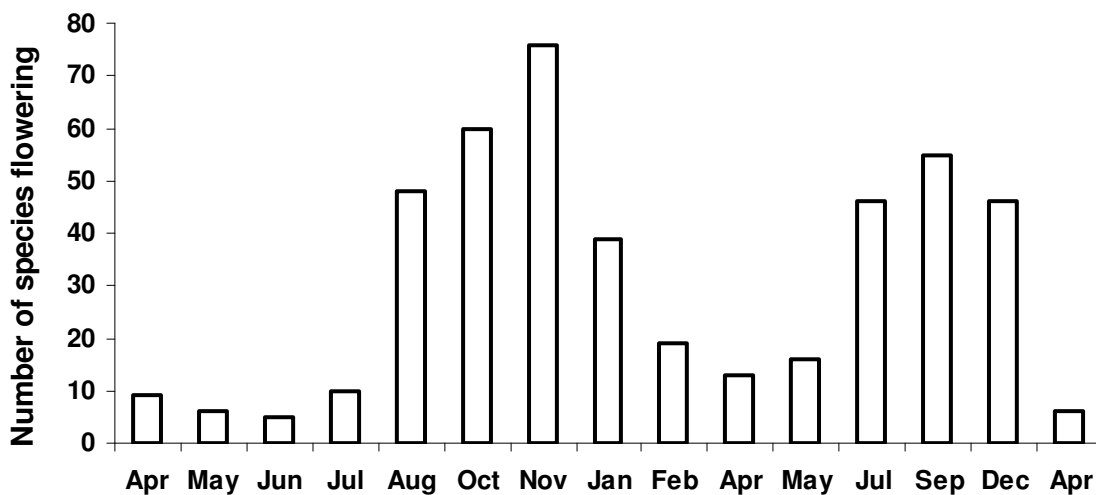
All the geophytes resprouted and species mainly belonged to monocotyledonous families, with the exception of a few geophytic species in the dicotyledonous families Geraniaceae, Oxalidaceae and Asteraceae. Woody resprouters belonged to a wide range of dicotyledonous families. Sixteen families were represented in the non-sprouters, but Asteraceae and Fabaceae dominated, with ten species each, followed by Scrophulariaceae with six species. All non-sprouters belonged to dicotyledonous families. Asteraceae was the most diverse family in relation to life history types and growth forms and *Pelargonium* the most diverse genus, with geophytes, annuals, perennial herbs and shrubs.



**Figure 4.7** Fire response of all documented species that flowered during the two year survey.

### Timing of flowering

The peak flowering season in the first and second year was spring, but with many species flowering in late winter and also early summer. The peak flowering month in the first year was November. In the second year, peak flowering occurred earlier and the greatest number of flowering species were recorded during September (Figure 4.8)



**Figure 4.8** Flowering phenology per month for all the months records were taken, during the two year postfire (n=227).



## Paarl Mountain Species check list and Herbarium

During the survey, 71 new species were added to the Paarl Mountain species check list. Specimens of 42 species were collected (48 records), of which 26 were new. Several records (7) were retained at Compton herbarium and 41 newly mounted herbarium sheets were added to the local herbarium housed at the Paarl Mountain Nature Reserve. Seventeen of the new herbarium records were geophytes and eight were red data species (see Appendix D for comprehensive Paarl Mountain Nature Reserve species list, Table 4.2 and Figure 4.9 for red data species). A current species list for Paarl Mountain Nature Reserve was compiled by combining all species that were collected or observed during this study as well as Sue Milton's study (2003), with a few records dating back to 30 years. The IUCN red list status for all current 556 species was also updated. (Appendix D).

**Table 4.2** Current Red data species of Paarl Mountain Nature Reserve according to the IUCN categories and criteria, Version 3.1 (IUCN 2001). Species in bold were added during the current study.

<u>Species</u>	<u>Current IUCN Status</u>
<i>Agathosma hispida</i> (Thunb.) Bartl. & H.L.Wendl.	Near Threatened (NT)
<i>Antimima aristulata</i>	Vulnerable (VU)
<b><i>Argyrolobium angustissimum</i></b>	Endangered (EN)
<i>Aspalathus araneosa</i> L.	VU
<b><i>Aspalathus stricticlada</i></b>	EN
<b><i>Babiana angustifolia</i> Sweet</b>	NT
<i>Babiana fragrans</i> (Jacq.) Steud. (= <i>Babiana disticha</i> Ker Gawl.)	NT
<i>Babiana villosula</i> (J.F.Gmel.) Ker Gawl. ex Steud.	EN
<i>Cliffortia ericifolia</i> L.f.	EN
<b><i>Disa longipetala</i> (Lindl.) Bolus (= <i>Schizodium longipetalum</i> Lindl.)</b>	Critically Endangered (CR)
<b><i>Disa physodes</i> Sw. (= <i>Monadenia physodes</i> (Sw.) Rchb.f.)</b>	CR
<b><i>Echiostachys spicatus</i> (Burm.f.) Levyns</b>	EN
<b><i>Erepsia patula</i> (Haw.) Schwantes</b>	VU
<i>Erepsia ramosa</i> L.Bolus	VU
<i>Ficinia distans</i> C.B.Cl.	VU
<i>Gladiolus recurvus</i> L	VU
<b><i>Gladiolus watsonius</i> Thunb.</b>	NT
<i>Hermannia rugosa</i> Adamson	VU
<i>Hesperantha spicata</i> (Burm.f.) N.E.Br. subsp. <i>spicata</i>	VU
<b><i>Lachenalia reflexa</i> Thunb.</b>	VU
<i>Lampranthus aduncus</i> (Haw) NEBr	Data deficient taxa (DDT)
<i>Leucadendron argenteum</i> (L.) R.Br.	EN
<i>Leucadendron lanigerum</i> H.Buek ex Meisn. var. <i>lanigerum</i>	EN
<i>Leucospermum grandiflorum</i> (Salisb.) R.Br.	EN

**Table 4.2** continued

<i>Lotononis prostrata</i> (L.) Benth.	NT
<b><i>Monsonia speciosa</i> L.</b>	EN
<b><i>Moraea versicolor</i> (Salisb. ex Klatt) Goldblatt</b>	VU
<i>Muraltia decipiens</i> Schltr.	EN
<i>Nemesia lucida</i> Benth.	DDT
<i>Oxalis pardalis</i> Sond.	DDT
<i>Pauridia minuta</i> (L.f.) T.Durand & Schinz	NT
<i>Podalyria sericea</i> (Andr.) R.Br.	NT
<i>Protea burchellii</i> Stapf	VU
<i>Protea scabra</i> R.Br.	NT
<i>Ruschia rubricaulis</i> (Haw.) L.Bolus	VU
<i>Xiphotheca lanceolata</i> (E.Mey.) Eckl. & Zeyh.	EN





**Figure 4.9** Red data species added to the Paarl Mountain Nature Reserve species list. From top to bottom , left to right: *Argyrobium angustissimum*, *Moraea versicolor*, *Monsonia speciosa*, *Disa longipetala* and *Disa physodes*. *Babiana angustifolia* and *Aspalathus stricticlada* were also added, but are not illustrated here.

## Discussion

### Flowering phenology according to plant families

Paarl Mountain has been well botanized and Milton (2003), in a survey of mostly mature fynbos (between 2 – 20 years post fire, with the majority being 8 years and older) added 310 plant specimens, pushing the number of recorded plant species that were collected within the boundaries of the Paarl Mountain Nature Reserve over the last 200 years to 710, including 45 alien taxa and 8 red data species. A comparison of the top 20 ranked indigenous families found in the current study and the Milton study (2003) show some interesting differences (Table 4.2 and Table 4.3), although the Milton study covered a much larger area. In both studies the top three ranked families correspond with the most species rich families in the Cape Floristic Region, but the order differs. In the Cape Floristic Region, the most species rich family is Asteraceae, followed by Fabaceae and then Iridaceae (Goldblatt & Manning 2000). In the current study, Iridaceae topped the list, followed by Fabaceae and then Asteraceae. There are 13 families in common in the two studies, but apart from the first three and Scrophulareaceae at number five, their rankings differ considerably (Table 4.2 and Table 4.3).

Many species in the Cape mountain fynbos flower profusely within the first year or two after a fire, when for a short period, the usually nutrient poor soil is enriched and the vegetation has been cleared, creating space for herbaceous and bulbous species to grow and reproduce (Manning *et al.* 2002). Iridaceae and Orchidaceae have many species that demonstrate obligate fire stimulated flowering (Manning 2007; Bytebier *et al.* 2011; Lamont & Downes 2011) and some where flowering is enhanced after fire (Manning 2007). This is especially true for the genus *Gladiolus* (Goldblatt & Manning 1998) and *Moraea* (Manning *et al.* 2002) in the Iridaceae and the genus *Disa* (Bytebier *et al.* 2011) in the Orchidaceae, but is not limited to these genera. This phenomenon may well explain why Iridaceae tops the list and Orchidaceae is ranked so much higher in the current study.

Proteaceae, Ericaceae and Restionaceae are amongst the top ten most species-rich families in the Cape Floristic Region and were also prominent in the Milton (2003) study, but very few were flowering in the current study. This is not surprising as the Proteaceae make up the majority of the overstorey species in mature mountain fynbos (>12 years postfire) (Bond *et al.* 1984) and many of these large shrubs and small trees are killed by fire and re-establish through a single pulse of postfire seedling recruitment (Bond *et al.* 1984; Keeley *et al.* 2012). These non-sprouters or obligate reseederers generally take several years to reach sexual maturity (Rebello 2001). It is thus expected that in the first few years after a fire very few Proteaceae flower and those that do are generally resprouters. Only two flowering



**Table 4.3** Top 20 most speciose indigenous plant families on Paarl Mountain during a two year survey after a late summer fire that consumed most of the vegetation on the mountain, compared with the 20 largest families in the Cape Flora (Goldblatt & Manning 2000). Numbers in brackets for both tables are for families that are not under the top 20 in the Cape flora. Families in common in both studies are in bold.

Family	Paarl species	Paarl rank	Cape Flora species	Cape Flora rank
<b>Iridaceae</b>	38	1	661	3
<b>Fabaceae</b>	27	2	760	2
<b>Asteraceae</b>	22	3	1036	1
<b>Orchidaceae</b>	15	4	227	10
<b>Scrophulariaceae</b>	12	5	418	6
<b>Geraniaceae</b>	9	6	155	16
<b>Poaceae</b>	9	7	207	11
<b>Malvaceae</b>	7	8	(91)	
<b>Oxalidaceae</b>	7	9	(118)	
<b>Aizoaceae</b>	5	10	660	4
<b>Hyacinthaceae</b>	5	11	192	13
Anacardiaceae	4	12	(28)	
Campanulaceae	4	13	184	14
Asphodelaceae	3	14	158	15
Boraginaceae	3	15	(44)	
Brassicaceae	3	16	(63)	
Colchicaceae	3	17	(33)	
<b>Polygalaceae</b>	3	18	141	17
		19		
		20		
TOTAL	180			12 out of 20

**Table 4.4** Top 20 most speciose indigenous plant families on Paarl Mountain during a study done by Sue Milton (2003), when the majority of the vegetation was mature, compared to the 20 largest families in the Cape Flora (Goldblatt & Manning 2000). (Table adapted from Milton 2003). (\* Selaginaceae in the Milton document has been subsumed into Scrophulariaceae.)

Family	Paarl species	Paarl rank	Cape Flora species	Cape Flora rank
<b>Asteraceae</b>	105	1	1036	1
<b>Iridaceae</b>	58	2	661	3
<b>Fabaceae</b>	50	3	760	2
<b>Poaceae</b>	44	4	207	11
<b>Scrophulariaceae</b>	33	5	330	6
Proteaceae	29	6	418	7
Restionaceae	18	7	318	8
Ericaceae	18	8	658	5
<b>Oxalidaceae</b>	17	9	(118)	
Cyperaceae	17	10	206	12
<b>Geraniaceae</b>	15	11	155	16
<b>Polygalaceae</b>	15	12	141	17
<b>Orchidaceae</b>	14	13	227	10
<b>Malvaceae</b>	14	14	(91)	
<b>Aizoaceae</b>	12	15	660	4
Rosaceae	12	16	(119)	
Crassulaceae	12	17	123	20
<b>Hyacinthaceae</b>	10	18	192	13
Apiaceae	10	19	(120)	
		20		
TOTAL	503			15 out of 20

Proteaceae species were observed in this survey and both *Leucadendron salignum* and *Protea acaulis* are resprouters. This does however not imply that no other Proteaceae were present. Four other proteoids were identified, however none of them flowered within two years of the fire, even though one, *Protea nitida* is an epicormic resprouter. The others were *Protea repens*, *Leucadendron rubrum* and *Leucospermum grandiflorum*, all tall growing non-sprouters.

Many *Erica* species are non-sprouters (obligate reseeder) and recruit seedlings after a fire (Schumann et al. 1992). *Ericas* are also known for delayed germination and establishment after a fire (Kruger & Bigalke 1984; Manders & Cunliffe 1987 cited in Rutherford et al. 2011). This would explain the lack of flowering Ericaceae species recorded in the immediate postfire environment, apart from a few resprouter species. *Erica cerinthoides* is a resprouter and known to flower profusely after fire (Manning 2007). The other *Erica* species recorded flowering was also a resprouter, but identification from the photo was difficult, as the flowers were still in bud.

It is also interesting to note that apart from some taller growing species in the Asteraceae and Fabaceae families, species within the remaining 11 families that were in common in both surveys are mainly low growing species, that would be expected to make maximal use of the extra space and light available in the immediate postfire environment (Keeley et al. 2006).

The total number of species recorded flowering declined in the second year. These figures only give a crude indication, as many flowering species may well have been missed during the two year study. However the decrease was sharpest amongst the geophytes and annuals and this could indicate that many of the geophytes recorded here may display fire stimulated flowering and the annuals may just have been outcompeted or shaded by taller species (Kruger 1979 in Rutherford et al. 2011).

An effort was also made to follow up on some of the red data species, to get a better understanding of their postfire flowering patterns. The orchids *Disa longipetala* and *Disa physodes*, both listed as critically endangered (CR), only flowered the first year after the fire and no flowering specimens could be found the second year. They can thus be said to demonstrate obligate fire stimulated flowering, as described by Lamont & Downes (2011). Out of the 15 species of orchids recorded, 11 were new records for Paarl Mountain, which may well indicate that some of these also display fire stimulated flowering. The only two orchids recorded in the second year were *Satyrium bicornis*, which was also the only orchid recorded as flowering both years and *Pterygodium cafferum*, which flowered for the first time in the second year. A specimen was sent in to Compton Herbarium and they were believed to be immature plants (personal communication W.R. Liltved).

The other red data species worth mentioning is *Argyrolobium angustissimum*, a dwarf resprouting shrublet in the Fabaceae. It had only once before been collected in 1827 by Johann Frantz Drège, apparently after a fire on Paarl Mountain and all specimens taken to herbaria in Europe. This species was listed as critically endangered, presumed extinct in the recent assessment of the red data plant species of South Africa (Raimondo et al. 2009) as no further records existed. In November 2009 this species was recorded at several sites in compartment 4, 7 and 8 on Paarl Mountain (Figure 4.1). It was again recorded in November 2010, but flowering was reduced. Annual demographic monitoring was initiated in 2010 and is undertaken by the Tygerberg CREW group (CREW = Custodians of Endangered Wildflowers) to establish a better understanding of this species life cycle in relation to fire. Since its rediscovery, this species has been re-evaluated and is now listed as endangered.

### Flowering phenology according to growth form

**Table 4.5** Percentage representation per growth form in the Cape Floristic Region as reported in Goldblatt & Manning (2000) compared to percentage representation per growth form of postfire flowering species on Paarl Mountain Nature Reserve during a survey in 2009-2011.

Growth form	Cape Floristic Region	Paarl Mountain survey
Annuals	6.8 %	6.6 %
Perennial herbs	11.4 %	11.0 %
Geophytes	17.2 %	35.7 %
Graminoids	8.8 %	4.8 %
Shrubs	53.3 %	41.9 %
Trees	2.4 %	0.0 %

It is clear that flowering phenology in mountain fynbos is influenced by the most recent fire disturbance and thus the timing of the survey relative to the fire cycle will influence which species would most likely be recorded. The percentage representation per growth form for the whole Cape Floristic Region (Goldblatt & Manning 2000) is by far dominated by shrubs (Table 4.5). In the current study (see Table 4.5), although shrubs still dominated, geophytes were overrepresented, annuals and perennial herbs were as can be expected for fynbos and graminoids, shrubs and trees underrepresented. Although only flowering species were recorded, the percentage representation per growth form was on par for annuals and perennial herbs and may indicate that they are more visible after a fire, some may display fire stimulated flowering and some may be fire ephemerals, like *Itasina filifolia* and

*Pseudoselago spuria* (Rutherford et al. 2011). The overrepresentation by geophytes may indicate that they are either just more visible after fire or many may display fire stimulated flowering (Bond & van Wilgen 1996; Manning et al. 2002). The number of new species added to the Paarl species list and herbarium and the fact that seven of the new records were red data species point to the importance of postfire surveys in capturing especially rare species and species with possible obligate postfire flowering, which may otherwise well be missed.

From the above results, it seems that growth form could be a good indicator of how soon after a fire flowering could be expected. Generally, the smaller growth forms flowered early and the taller growth forms, later. The life history (fire response) however plays as big a role and resprouters generally flower earlier than non-sprouters, with the exception of annuals. An exception worth mentioning is *Cliffortia ruscifolia*, a medium sized resprouting shrub that did not flower within the two years postfire. It does however spread clonally (Keeley et al. 2012), as was observed in this study and the clonal reproduction may be at the cost of reduced sexual reproduction. The percentage non-sprouters in this study seem very low, but this is due to many non-sprouters not reaching maturity within two years of the fire.

## **Conclusion**

Despite the limitations of this non-randomly sampled study, observed patterns provide important context for future studies and conservation efforts. Fire stimulated flowering was observed in several species and the postfire life history characteristics documented for many more. This information is often not part of standard species descriptions, yet is vital in understanding species response to fire and ultimately how that influences vegetation composition. Fire has been an important driver in shaping plant traits (Keeley et al. 2011, 2012), yet much is still to be learned about postfire flowering phenology and regeneration mechanism of many fynbos species in relation to the fire regime they occur in.



## References

- Agenbag, L., Esler, K.J., Midgley, G.F. & Boucher, C. (2008) Diversity and species turnover on an altitudinal gradient in Western Cape, South Africa: baseline data for monitoring range shifts in response to climate change. *Bothalia*, **38**, 161-191.
- Bond, W.J. & Midgley, J.J. (2001) Ecology of sprouting woody plants: the persistence niche. *Trends in Ecology & Evolution* **16**, 45-51.
- Bond, W.J. & van Wilgen, B.W. (1996) Fire and Plants, Chapman & Hall, London.
- Bond, W.J., Vlok, J. & Viviers, M. (1984) Variation in seedling recruitment of Cape Proteaceae after fire. *Journal of Ecology* **72**, 209-221.
- Bytebier, B., Antonelli, A., Bellstedt, D.U. & Linder, H.P. (2011) Estimating the age of fire in the Cape flora of South Africa from an orchid phylogeny. *Proceedings of the Royal Society of Biological Sciences*, **278**, 188-195.
- Cowling, R.M., Esler, K.J., Midgley, G.F. & Honig, M.A. (1994) Plant functional diversity, species diversity and climate in arid and semi-arid southern Africa. *Journal of Arid Environments*, **27**, 141-158.
- Cowling, R.M., Richardson, D.M. & Mustard, P.J. (1997) Fynbos. Vegetation of Southern Africa (eds R.M. Cowling, D.M. Richardson & S.M. Pierce), pp. 99-130. Cambridge University Press, Cambridge, UK.
- Forsyth, G.G. & van Wilgen, B.W. (2008) The recent fire history of the Table Mountain National Park and implications for fire management. *Koedoe*, **50**, 3-9.
- Goldblatt, P. & Manning, J. (1998) *Gladiolus* in Southern Africa. Fernwood Press, Vlaeberg, South Africa.
- Goldblatt, P. & Manning, J.C. (2000) Cape Plants. A conspectus of the Cape flora of South Africa. *Strelitzia* **9**, National Botanical Institute & Missouri Botanical Garden Press, Pretoria & St. Louis.
- IUCN. (2001). *IUCN Red List Categories and Criteria: Version 3.1*. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK. ii + 30 pp.
- Keeley, J.E. (1993) Smoke-induced flowering in the fire-lily *Cyrtanthus ventricosus*. *South African Journal of Botany*, **59**, 638.
- Keeley, J.E. & Bond, W.J. (1997) Convergent seed germination in South African fynbos and Californian chaparral. *Plant Ecology*, **133**, 153-167.
- Keeley, J.E., Bond, W.J., Bradstock, R.A., Pausas, J.G. & Rundel, P.W. (2012) Fire in Mediterranean Ecosystems: ecology, evolution and management. Cambridge University Press, New York.
- Keeley, J.E. & Fotheringham, C.J. (1998) Smoke-induced seed germination in California chaparral. *Ecology*, **79**, 2320-2326.
- Keeley, J.E., Fotheringham, C.J. & Baer-Keeley, M. (2006) Demographic patterns of postfire

- regeneration in Mediterranean-climate shrublands of California. *Ecological Monographs* **76**, 235-255.
- Keeley, J.E., Pausas, J.G., Rundel, P.W., Bond, W.J., Bradstock, R.A. (2011) Fire as an evolutionary pressure shaping plant traits. *Trends in Plant Science*, **16**, 406-411.
- Kruger, F.J. (1979) South African Heathlands. Heathlands and related shrublands – descriptive studies. *Ecosystems of the World* (ed. R.L. Specht), pp 19-80. Elsevier, Amsterdam.
- Kruger, F.J. & Bigalke, R.C. (1984) Fire in fynbos. *Ecological Effects of Fire in South African Ecosystems*. (eds. P. de V. Booysen & N.M Tainton), pp 67-114. Springer-Verlag, Berlin.
- Kubiak, P.J. (2009) Fire responses of bushland plants after the January 1994 wildfires in northern Sydney. *Cunninghamia*, **11**, 131–165
- Lamont, B.B. & Downes, K.S. (2011) Fire stimulated flowering among resprouters and geophytes in Australia and South Africa. *Plant Ecology*, **212**, 2111-2125.
- Lamont, B.B., Le Maitre, D.C., Cowling, R.M. & Enright, N.J. (1991) Canopy Seed Storage in Woody Plants. *Botanical Review*, **57**, 277-317.
- Le Maitre, D.C. (1992) The relative advantage of seeding and sprouting in fire-prone environments: a comparison of life histories of *Protea neriifolia* and *Protea nitida*. *Fire in South African mountain fynbos : Ecosystem, community and species response at Swartboskloof* (eds. B.W. van Wilgen, D.M. Richardson, F.J. Kruger & H.J. van Hensbergen), pp. 145–160. Springer-Verlag, Berlin.
- Le Maitre, D. C. & Brown, P. J. (1992) Life cycles and fire-stimulated flowering in geophytes. *Fire in South African mountain fynbos : Ecosystem, community and species response at Swartboskloof* (eds. B.W. van Wilgen, D.M. Richardson, F.J. Kruger & H.J. van Hensbergen), pp. 145–160. Springer-Verlag, Berlin.
- Le Maitre, D.C. & Midgley, J.J. (1992) Plant reproductive ecology. *The ecology of fynbos: nutrients, fire and diversity* (ed. R.M. Cowling), pp. 135-174. Oxford University Press, Oxford, UK.
- Malgas, R.R., Potts, A.J., Oetlé, N.M., Koelle, B., Todd, S.W., Verboom, G.A. & Hoffman, M.T. (2010) Distribution, quantitative morphological variation and preliminary molecular analysis of different growth forms of wild rooibos (*Aspalathus linearis*) in the northern Cederberg and on the Bokkeveld Plateau. *South African Journal of Botany*, **76**, 72-81.
- Manders, P.T. & Cunliffe, R.N. (1987) Fynbos plant life histories, population dynamics and species interactions in relation to fire: an overview. *South African National Scientific Programmes Report*, **135**, 15-23.
- Manders, P.T., Richardson, D.M. & Masson, P.H. (1992) Is fynbos a stage in succession to

- forest? Analysis of perceived ecological distinction between two communities. Fire in South African Mountain Fynbos: Ecosystem, Community and Species Response at Swartboskloof (eds. B.W. van Wilgen, D.M. Richardson, F.J. Kruger & H.J. van Hensbergen), pp. 81-107. Springer-Verlag, New York.
- Manning, J. (2007) Field guide to the fynbos. Struik Publishing, Cape Town, South Africa.
- Manning, J., Goldblatt, P., & Snijman, D. (2002) The Color Encyclopedia of Cape Bulbs. Timber Press, Portland, Oregon, USA.
- Milton, S.J. (2003) Vegetation Survey. Paarl Mountain Nature Reserve. Conservation Ecology Department, University of Stellenbosch, 7701 Stellenbosch.
- Mucina, L. & Rutherford, M.C. (eds) (2006) The vegetation of South Africa, Lesotho and Swaziland. *Strelitzia* **19**. South African National Biodiversity Institute, Pretoria.
- Pierce, S.M. (1984) A synthesis of plant phenology in the Fynbos Biome. *South African National Scientific Programmes Report* **88**. CSIR, Pretoria, South Africa.
- Raimondo, D., von Staden, L., Foden, W., Victor, J.E., Helme, N.A., Turner, R.C., Kamundi, D.A. & Manyama, P.A. (2009) Red List of South African Plants 2009. *Strelitzia*, **25**. South African National Biodiversity Institute, Pretoria.
- Rebelo, T. (2001) A field guide to the Proteas of Southern Africa. 2<sup>nd</sup> edn. Fernwood Press, Vlaeberg, South Africa.
- Rutherford, M.C., Powrie, L.W., Husted, L.B. & Turner R.C. (2011) Early post-fire plant succession in Peninsula Sandstone Fynbos: The first three years after disturbance. *South African Journal of Botany*, **77**, 665-674.
- Schumann, D., Kirsten, G. & Oliver, E.G.H. (1992) Ericas of South Africa. Fernwood Press, Cape Town.
- Van der Bank, M., van der Bank, F.H. & van Wyk, B.-E. (1999) Evolution of sprouting versus seeding in *Aspalathus linearis*. *Plant Systematics and Evolution*, **219**, 27-38.
- Van Wilgen, B.W. & Forsyth, G.G. (1992) Regeneration strategies in fynbos plants and their influence on the stability of community boundaries after fire. Fire in South African Mountain Fynbos: Ecosystem, Community and Species Response at Swartboskloof (eds. B.W. van Wilgen, D.M. Richardson, F.J. Kruger & H.J. van Hensbergen), pp. 54-80. Springer-Verlag, Berlin.
- Verboom, G.A., Stock, W.D. & Linder, H.P. (2002) Determinants of postfire flowering in the geophytic grass *Ehrharta capensis*. *Functional Ecology*, **16**, 705-713.
- Vlok, J.H.J. & Yeaton, R.I. (2000) Competitive interactions between overstorey proteas and sprouting understorey species in South African mountain fynbos. *Diversity and Distributions*, **6**, 273–281

## Chapter 5

### Synthesis

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The ability to resprout after a fire is highly variable amongst fynbos species. Grouping plants into functional types has been promoted as a tool in studies on plant community structure and function in fire-prone MTC regions of the world. It has been predicted that the MTC region in the Western Cape of South Africa, will become more arid with less reliable winter rains and more intense summer droughts. This may lead to more frequent fires.

Few studies have explored the relevance of the variability in resprout ability amongst species in MTC regions. My first study aim was to document postfire regeneration patterns, with a specific focus on obligate (OS) and facultative resprouters (FS) within mountain fynbos. My key findings (chapter 2) were:

- **Life history type** had a significant effect on resprouting ability and survival. OS were more successful resprouters than FS which is consistent with a tradeoff between persistence and longevity, exemplified by the OS, and recruitment of seedlings and shorter life span, exemplified by the FS.
- The ability to resprout **early** (shorter lag period) and re-establish a canopy (**grow fast**) after a fire had a significant effect on the two year postfire survival rate, irrespective of life history type.
- Mortality due to fire was linked to increased lignotuber exposure; fewer pre-fire shoots (pre-fire plant vigour and/or health) and fire intensity. The inverse relationship between fire intensity (measured as smallest terminal branch diameter) and mortality was unexpected.

It would be interesting if future studies could shed more light on the mechanistic differences between OS and FS species which may explain why OS species have greater resprout success. Life history type is often linked to lineage, as in *Searsia*, where obligate resprouting is a conserved generic trait (Keeley et al. 2012). On the other hand, there seems to be a remarkable amount of plasticity in some fynbos lineages, with multiple switches between resprouting and reseeding strategies over time (Bond & Midgley 2003). More accurate molecular phylogenies will certainly improve our understanding of plant evolution in fire-prone MTC regions.

Postfire regeneration is complex and can be influenced by multiple factors (biotic and abiotic) over time. Novel ways to examine complex systems (like structural equation modelling) are available, which may further our understanding of different postfire regeneration strategies, both at the life history type and species level.

A further aim was to establish if seedling recruitment was significantly different between OS, FS and non-sprouters (NS, obligate seeders). Key findings (chapter 3) were:

- An apparent tradeoff between postfire resprout success and seedling recruitment underpins the differences between OS and FS resprouter types. At one extreme, the OS have near 100% resprout success and no postfire seedling recruitment. At the other extreme, NS have no 0% resprout success, but high seedling recruitment. In between these two extremes are FS that have variable resprout success coupled with some seedling recruitment.
- NS seedling / adult ratios were orders of magnitude higher than those for FS, with species specific variability. None of the OS species demonstrated postfire seedling recruitment (as expected/ per definition). Some *Searsia tomentosa* (an OS species) seeds were dispersed into the burn site and germinated as early as the second year after the fire. The long-term fate of these seedlings is unknown, although the high mortality rate observed suggests that very few, if any, would grow into mature plants.
- Seedling recruitment and 2-year survival offset adult mortality for all NS and FS species.

In the flowering phenology chapter (chapter 4), it was difficult to classify species into life history types, beyond resprouters and non-sprouters, but some important observations were made:

- Herbaceous resprouters and more specifically geophytes made up the bulk of species that flowered within the first year after the fire. For some species this may indicate obligate fire stimulated flowering. This is especially true for the orchid family, as most species were only seen the first year after the fire, and the majority had not been recorded on Paarl Mountain before.
- Many species were added to the existing Paarl Mountain species list, including several new red data species, which highlights the importance of early postfire field surveys.

Despite the limitations of the observational aspect of the flowering phenology study, it highlighted the importance of fire stimulated flowering, which is clearly an important trait to include in future studies that focus on fire adaptations within fynbos.

### **Management recommendations**

Paarl Mountain Nature Reserve has a patch mosaic burning policy and it is recommended that this is continued. Early postfire surveys and monitoring are recommended for all red data species, especially those in the orchid family and the Paarl Mountain endemic *Argyrolobium angustissimum*, to ensure stable populations. Future postfire surveys may also reveal more species not yet captured and collected in the Paarl Mountain Herbarium and the Paarl Mountain species list. It is further recommended that a volunteer group is established to assist with this task. Volunteers could also assist with the maintenance of the Paarl Mountain Herbarium and future collections for the herbarium. The Tygerberg CREW group has been fulfilling this position on an *ad hoc* basis for the past three years and could assist with training new volunteers.

### **Conclusion**

From an evolutionary perspective there appears to be a tradeoff between postfire resprout success (persistence) and seedling recruitment, as exemplified by OS and FS species. Fire response or life history type are rarely included in standard reference works (Bond & Midgley 2001), despite being an important species characteristic in fire prone vegetation (Schutte et al. 1995). Life history type is an important indicator of resilience to fire and likely an adaptation to a certain fire regime. Life history type and fire dependant regeneration strategies like serotiny, heat or smoke stimulated germination and fire stimulated flowering should be part of standard species descriptions to enable a better understanding of plants in fire-dependent ecosystems. Furthermore, Keeley et al. (2006) pointed to the importance of not only life history type, but also life form in postfire demographic studies. Future demographic studies should thus include life history type, and life form. A sound knowledge of the fire response of plants will be essential in conservation planning and wise management, in the light of predicted changes in the climate and fire regimes.

## References

- Bond, W.J. & Midgley, J.J. (2001) Ecology of sprouting in woody plants: the persistence niche. *Trends in Ecology and Evolution*, **16**, 45-51.
- Bond, W.J. & Midgley, J.J. (2003) The evolutionary ecology of sprouting in woody plants. *International Journal of Plant Science*, **164**, S103-S114.
- Keeley, J.E., Bond, W.J., Bradstock, R.A., Pausas, J.G. & Rundel, P.W. (2012) Fire in Mediterranean Ecosystems; ecology, evolution and management. Cambridge University Press, New York.
- Keeley, J.E., Fotheringham, C.J & Baer-Keeley, M. (2006) Demographic patterns of post-fire regeneration in Mediterranean-climate shrublands of California. *Ecological Monographs* **76**, 235-255.
- Schutte, A.L., Vlok, J.H.J., & Van Wyk, B.E. (1995) Fire-survival strategy – a character of taxonomic, ecological and evolutionary importance in fynbos legumes. *Plant Systematics and Evolution* **195**: 243-259.

## APPENDICES

### Appendix A

**Table A.1** Sample size of different species after verification, including their life history type for regeneration and growth form. Numbers in brackets are combined *Searsia* species and combined *Cliffortia* species. (? indicates uncertainty in life history type)

Species	Life history type	Growth form	n
<i>Diospyros glabra</i>	OS	Dioecious shrub or small tree	45
<b><i>Searsia</i> sp:</b>			(47)
<i>Searsia angustifolia</i>	OS	Dioecious shrub or small tree	4
<i>Searsia lucida</i>	OS	Dioecious shrub or small tree	1
<i>Searsia rosmarinifolia</i>	OS	Dioecious scrambling shrub	13
<i>Searsia tomentosa</i>	OS	Dioecious shrub or small tree	29
<i>Diosma hirsuta</i>	FS	Dioecious dwarf shrub	37
<b><i>Cliffortia</i> sp:</b>			(55)
<i>Cliffortia juniperina</i>	FS	Ericoid shrublet	34
<i>Cliffortia ruscifolia</i>	FS	Small leaved shrub	21
<i>Aspalathus bracteata</i>	FS	Scrambling dwarf shrub	51
<i>Leucadendron salignum</i> male	FS	Small proteoid shrub	44
<i>Leucadendron salignum</i> female	FS	Small proteoid shrub	43
<i>Leucadendron salignum</i> ?	FS	Small proteoid shrub	7
<i>Asparagus rubicundus</i>	OS	Erect spiny shrub	1
<i>Protea nitida</i>	FS	Large proteoid shrub	1
<i>Montinia caryophyllaceae</i>	OS	Erect spiny shrub	1
<i>Zygophyllum fulvum</i>	FS	straggling shrublet	1
<i>Phylica spicata</i>	OS ?	Ericoid shrublet	1
<i>Clutia polygonoides</i>	OS ?	Dioecious shrublet	1
<i>cf Anthospermum spathulatum</i>	Non-sprouter		7
<i>cf Podalyria</i> sp	Non-sprouter		2
Unidentified plants	Non-sprouter		5
<b>TOTAL</b>			<b>349</b>



## Appendix B

Other factors influencing postfire survival – a species specific approach

**Table B.1** Effects of stored reserves, fire intensity and erosion on five species after a summer season fire (3-7 March 2009), in the Paarl Mountain Nature Reserve, South Africa. Plants that had resprouted and survived the second dry season after the fire were compared to plants that did not. Circumference was used as an indicator of stored reserves; minimum branch diameter directly postfire was used as an indicator of fire intensity; the height of the lignotuber above the soil surface divided by the basal area was used as an index for erosion and therefore exposure to the fire. Means are displayed with the Standard Error in brackets. An ANOVA was used to analyze the data and where the data were not normally distributed, a Mann-Whitney U test was used. Significant results are in bold.

Species	Survived	Died	p-value
<b>Stored reserves (basal circumference in cm)</b>			
<i>Aspalathus bracteata</i>	30.31 (2.36)	27.41 (5.10)	0.61
<i>Diosma hirsuta</i>	26.87 (1.70)	27.65 (4.87)	0.88
<i>Leucadendron salignum</i> F	54.77 (4.51)	51.54 (5.07)	0.64
<i>Leucadendron salignum</i> M	55.74 (4.99)	57.09 (6.29)	0.87
<b><i>Cliffortia juniperina</i></b>	<b>67.80 (5.92)</b>	<b>49.31 (7.07)</b>	<b>0.05</b>
<i>Cliffortia ruscifolia</i>	17.28 (8.02)	28.24 (5.07)	0.26
<b>Fire intensity (minimum branch diameter in mm)</b>			
<i>Aspalathus bracteata</i>	2.20 (0.19)	2.18 (0.42)	0.97
<i>Diosma hirsuta</i>	2.77 (0.11)	2.28 (0.31)	0.15
<i>Leucadendron salignum</i> F	1.54 (0.08)	1.52 (0.09)	0.83
<b><i>Leucadendron salignum</i> M</b>	<b>1.47 (0.07)</b>	<b>1.25 (0.09)</b>	<b>0.05</b>
<i>Cliffortia juniperina</i>	1.53 (0.10)	1.64 (0.12)	0.90
<i>Cliffortia ruscifolia</i>	1.68 (0.28)	2.09 (0.17)	0.22
<b>Erosion (lignotuber exposure)</b>			
<i>Aspalathus bracteata</i>	0.004 (0.002)	0.008 (0.004)	0.36
<i>Diosma hirsuta</i>	0.007 (0.003)	0.005 (0.010)	0.92
<i>Leucadendron salignum</i> F	0.040 (0.009)	0.045 (0.011)	0.74
<i>Leucadendron salignum</i> M	0.042 (0.009)	0.042 (0.012)	0.98
<b><i>Cliffortia juniperina</i></b>	<b>0.030 (0.009)</b>	<b>0.086 (0.011)</b>	<b>&lt;0.01</b>
<i>Cliffortia ruscifolia</i>	0.030 (0.095)	0.150 (0.060)	0.30

The high mortality experienced by FS species allowed me to assess the potential influence of other measured variables on a per species basis, however the data for mortality due to the fire and mortality after the fire had to be lumped to have enough overall mortality data for analyses. Circumference (in cm) was used as an indicator of stored reserves; minimum branch diameter directly postfire (in mm) was used as an indicator of fire intensity; the height of the lignotuber (in cm) above the soil surface divided by the basal area (in cm<sup>2</sup>) was used as an index for erosion and lignotuber exposure to the fire. In general, I found no evidence that lignotuber size, burnt branch diameter or lignotuber height above soil can be used as predictors of postfire survival (Table B.1). However a significant relationship was observed in one species, *Cliffortia juniperina*. Lignotuber size correlated positively with survival and plants with bigger lignotubers were more likely to survive ( $p=0.05$ ), while erosion had a strong negative influence where plants with lignotubers that were more exposed had a lower survival rate ( $p<0.01$ ). *Diosma hirsuta* showed a negative trend between branch diameter and mortality, where a smaller diameter was correlated to mortality. This was statistically significant in male *Leucadendron salignum* plants. *Cliffortia ruscifolia* showed a positive trend between branch diameter and mortality. Although no generalized patterns linking predictor variables to postfire survival were detected, species-specific differences were apparent.

## Appendix C

### FOLLOWING PAGES:

**Appendix C** Flowering phenology table over 2 years. # = species recorded outside of the original study site, but within compartment 4, 7 or 8 (see Figure 4.1, Chapter 4); \* = alien taxa; 1 = months that flowers were recorded for each species. Species in blue at the bottom of the table were target species in chapter 2 and 3, but did not flower within the two year study period. Abbreviations for growth form are explained in Table 4.1 in Chapter 4.



Cyphia volubilis	Lobeliaceae	GEO	resprouter						1	1						1			5
Diascia sp	Scrophulariaceae	AH	NS						1							1			5
Disa longipetala #	Orchidaceae	GEO	resprouter						1										5
Dischisma ciliatum	Scrophulariaceae	LS	?						1	1	1					1			5
Disperis capensis #	Orchidaceae	GEO	resprouter						1										5
Drosera pauciflora	Droseraceae	PH	resprouter						1										5
Ficinia cf nigrescens	Cyperaceae	GRA	resprouter						1						1	1			5
Geissorhiza aspera	Iridaceae	GEO	resprouter						1	1									5
Geissorhiza inflexa #	Iridaceae	GEO	resprouter						1	1									5
Geissorhiza juncea #	Iridaceae	GEO	resprouter						1										5
Geissorhiza ovata	Iridaceae	GEO	resprouter						1	1						1			5
Gladiolus carinatus #	Iridaceae	GEO	resprouter						1										5
Heliophila diffusa	Brassicaceae	AH	NS						1							1			5
Heliophila macowaniana	Brassicaceae	AH	NS						1	1									5
Hermannia grossularifolia	Malvaceae	DS	resprouter						1	1									5
Hesperantha falcata	Iridaceae	GEO	resprouter						1	1									5
Hesperantha pilosa #	Iridaceae	GEO	resprouter						1										5
Lachenalia orchoides	Hyacinthaceae	GEO	resprouter						1										5
Lotononis prostrata #	Fabaceae	DS	?						1										5
Moraea ciliata #	Iridaceae	GEO	resprouter						1										5
Moraea gawleri #	Iridaceae	GEO	resprouter						1										5
Moraea versicolor	Iridaceae	GEO	resprouter						1						1				5
Nemesia barbata #	Scrophulariaceae	AH	NS						1										5
Othonna heterophylla #	Asteraceae	GEO	resprouter						1										5
Oxalis obtusa	Oxalidaceae	GEO	resprouter						1						1	1			5
Phyllopodium heterophyllum #	Scrophulariaceae	AH	NS						1										5
Pterygodium alatum #	Orchidaceae	GEO	resprouter						1										5
Spiloxene capensis #	Hypoxidaceae	GEO	resprouter						1										5
Spiloxene schlechteri #	Hypoxidaceae	GEO	resprouter						1						1				5
Trachyandra hirsutiflora #	Asphodelaceae	GEO	resprouter						1										5
Wachendorfia cf multiflora #	Haemodoraceae	GEO	resprouter						1										5
Wurmbea cf recurva	Colchicaceae	GEO	resprouter						1	1									5
Berkheya cf carlinoides	Asteraceae	PH	resprouter							1	1								7
Bobartia indica	Iridaceae	GEO	resprouter							1	1	1							7









Helichrysum zeyheri	Asteraceae	LS	?																10
Ischyrolepis gaudichaudiana	Restionaceae	GRA	resprouter																10
Muraltia cf decipiens	Polygalaceae	DS	resprouter																10
Ornithogalum graminifolium	Hyacinthaceae	GEO	resprouter															1	10
Ornithogalum hispidum	Hyacinthaceae	GEO	resprouter															1	10
Plantago lanceolata *	Plantaginaceae	PH	?																10
Polygala lehmanniana	Polygalaceae	DS	?															1	10
Prismatocarpus cf diffusus	Campanulaceae	LS	resprouter																10
Salvia chamelaeagnea	Lamiaceae	MS	FS															1	10
Senecio angustifolius	Asteraceae	LS	NS																10
Themeda triandra #	Poaceae	GRA	resprouter																10
Aspalathus arida procumbens #	Fabaceae	LS	resprouter															1	11
Cymbopogon marginatus	Poaceae	GRA	resprouter															1	11
Lachnospermum fasciculatum	Asteraceae	LS	?															1	11
Leucadendron salignum	Proteaceae	MS	FS																11
Osteospermum spinosum	Asteraceae	LS	NS																11
Polygonum undulatum	Polygonaceae	LS	?																11
Thesium strictum	Santalaceae	MS	NS																11
Inula graveolens *	Asteraceae	LS	NS															1	13
Searsia tomentosa	Anacardiaceae	TS	OS															1	13
Senecio pubigerus	Asteraceae	LS	NS															1	14
Anthospermum galioides	Rubiaceae	LS	NS															1	16
Aspalathus araneosa	Fabaceae	MS	NS															1	16
Chrysanthemoides monilifera	Asteraceae	MS	NS															1	16
Erica sp.	Ericaceae	DS	resprouter															1	16
Ficinia oligantha	Cyperaceae	GRA	resprouter															1	16
Gladiolus watsonius	Iridaceae	GEO	resprouter															1	16
Gnidia laxa	Thymelaeaceae	LS	NS															1	16
Helichrysum teretifolium	Asteraceae	DS	resprouter															1	16
Hermannia althaeifolia	Malvaceae	LS	resprouter															1	16
Hermannia rugosa	Malvaceae	LS	resprouter															1	16
Lachenalia reflexa	Hyacinthaceae	GEO	resprouter															1	16
Ruschia rubicaulis	Aizoaceae	DS	?															1	16
Moraea fugacissima #	Iridaceae	GEO	resprouter															1	16



## Appendix D

Paarl Mountain Nature Reserve species list including growth form; fire response (life history type), if known; new records indicated by an “x”; specimens present in the Paarl herbarium; current IUCN red list status. All FOT specimens were collected by me. Observations by Sue Milton are indicated by SM and most KM (Karen Marais) observations have a photographic record. Abbreviations for the IUCN status is as follows: LC = least concerned; NT = near threatened; VU = vulnerable; EN = endangered; CR = critically endangered; DDT = data deficient taxa and NE = not evaluated. The \* after a species indicates that it is an alien species.

<b>Species</b>	<b>Family</b>	<b>growth form</b>	<b>Fire response</b>	<b>New</b>	<b>Observations and specimen numbers</b>	<b>present in Paarl herbarium</b>	<b>Red data status</b>
<i>Acacia longifolia</i> (Andrews) Willd.*	Fabaceae	Tree	FS		observed SM	0	
<i>Acacia mearnsii</i> De Wild.*	Fabaceae	Tree	NS		observed SM	0	
<i>Acacia saligna</i> (Labill.) H.L.Wendl.*	Fabaceae	Tree	FS		observed SM	0	
<i>Acer buergianum</i> Miq.*	Aceraceae	Tree	?		Scott 977#	1	
<i>Acrosanthes teretifolia</i> Eckl. & Zeyh.	Aizoaceae	LS	?		observed KM	0	LC
<i>Adenandra marginata</i> (L.f.) Roem. & Schult. subsp. <i>serpyllacea</i> (Bartl.) Strid	Rutaceae	MS	?		Low 5586#, Martin 31#	2	LC
<i>Adenandra villosa</i> (P.J.Bergius) Licht. ex Roem. & Schult. subsp. <i>villosa</i>	Rutaceae	LS	resprouter		Isham 136#	1	LC
<i>Agathosma bifida</i> (Jacq.) Bartl. & H.L.Wendl.	Rutaceae	MS	?		previously recorded	0	LC
<i>Agathosma capensis</i> (L.) Dummer	Rutaceae	MS	resprouter		Scott 942#	1	LC
<i>Agathosma hispida</i> (Thunb.) Bartl. & H.L.Wendl.	Rutaceae	MS	resprouter		Milton 1181#, Scott 766#	2	NT
<i>Agrostis avenacea</i> C.C.Gmel.*	Poaceae	GRA	?		Isham 82#	1	
<i>Agrostis lachnantha</i> Nees	Poaceae	GRA	?		Scott 957#	1	LC
<i>Aira cupaniana</i> Guss.*	Poaceae	GRA	?		previously recorded	0	
<i>Aizoon sarmentosum</i> L.f.	Aizoaceae	PH	?		Scott 788#	1	LC
<i>Albuca canadensis</i> (L.) F.M.Leight. (= <i>Albuca maxima</i> Burm.f.)	Hyacinthaceae	GEO	resprouter		Scott 856#	1	LC
<i>Alectra sessiliflora</i> (Vahl) Kuntze	Orobanchaceae	AH	NS		Isham 87#, Milton 1219#	2	LC
<i>Allium triquetrum</i> L.*	Asphodelaceae	GEO	resprouter	x	FOT 780	1	
<i>Aloe perfoliata</i> L. (= <i>Aloe mitriformis</i> Mill.)	Asphodelaceae	MS	?		Scott 988#	1	LC

<i>Aloe plicatilis</i> (L.) Mill.	Asphodelaceae	TS	?		observed SM	0	LC
<i>Anagallis arvensis</i> L. subsp. <i>arvensis</i> *	Primulaceae	AH	NS		Scott 844#	1	
<i>Andropogon eucomus</i> Nees	Poaceae	GRA			Isham 78#, Scott 979#	2	LC
<i>Anemone tenuifolia</i> (L.f.) DC.	Ranunculaceae	PH	resprouter	x	FOT 785	1	LC
<i>Anisodontea biflora</i> (Desr.) Bates	Malvaceae	LS	?		Scott 915#	1	LC
<i>Anthospermum galioides</i> Rchb.f.	Rubiaceae	LS	NS		observed KM	0	LC
<i>Anthospermum spathulatum</i> Spreng. subsp. <i>spathulatum</i>	Rubiaceae	TS	NS		Low 5114#, 5597#, Scott 871#, Milton 1248#	4	LC
<i>Antimima aristulata</i> (Sond.) Chess. & Gideon F.Sm. (= <i>Ruschia aristulata</i> (Sond) Schwantes)	Aizoaceae	DS	resprouter		observed SM	0	VU
<i>Arctopus echinatus</i> L.	Apiaceae	PH	resprouter		observed SM	0	LC
<i>Arctotheca calendula</i> (L.) Levyns	Asteraceae	AH	NS		Scott 835#	1	LC
<i>Arctotis aspera</i> L.	Asteraceae	PH	NS		Scott 865#	1	LC
<i>Argyrolobium angustissimum</i> (E.Mey.) T.J.Edwards	Fabaceae	DS	resprouter	x	FOT 902, 903, 904, 910	0	EN
<i>Aristea africana</i> (L.) Hoffmanns.	Iridaceae	PH	resprouter		van Schalkwyk A14#, Isham 105#, Scott 870#	3	LC
<i>Aristea bakeri</i> Klatt	Iridaceae	PH	resprouter	x	observed KM		LC
<i>Aristea major</i> Andrews	Iridaceae	PH	resprouter		Isham 133#	1	LC
<i>Aristea cf cuspidata</i> Schinz	Iridaceae	PH	resprouter	x	observed KM	0	LC
<i>Aristea cf glauca</i> Klatt	Iridaceae	PH	resprouter	x	observed KM	0	LC
<i>Aristea spiralis</i> (L.f.) Ker Gawl.	Iridaceae	PH	resprouter		Roberts TRV17633, Scott 790#	2	LC
<i>Aristida junciformis</i> Trin & Rupr.	Poaceae	GRA	resprouter		Scott 989#	1	LC
<i>Aspalathus cf. acuminata</i> Lam. subsp. <i>acuminata</i>	Fabaceae	LS	resprouter		FOT 932	1	LC
<i>Aspalathus angustifolia</i> (Lam.) R.Dahlgren subsp. <i>angustifolia</i>	Fabaceae	LS	?		observed KM	0	LC
<i>Aspalathus araneosa</i> L.	Fabaceae	MS	NS		Isham 72#, Low 5082#, Scott 965#	3	VU
<i>Aspalathus arida</i> E.Mey. subsp. <i>procumbens</i> (E.Mey.) R.Dahlgren	Fabaceae	LS	resprouter		Scott 971#	1	LC
<i>Aspalathus astroites</i> L.	Fabaceae	MS	NS		van Schalkwyk A1#, Isham 138#, FOT920	3	LC
<i>Aspalathus bracteata</i> Thunb	Fabaceae	LS	FS		Scott 969#, 995#, FOT 799	3	LC
<i>Aspalathus cephalotes</i> Thunb subsp. <i>violaceae</i> R.Dahlgren	Fabaceae	MS	FS		Isham 73#, Scott 914#	2	LC

<i>Aspalathus cf ciliaris</i> L.	Fabaceae	LS	NS		observed KM	0	LC
<i>Aspalathus cordata</i> (L.) R.Dahlgren	Fabaceae	LS	NS	x	observed KM	0	LC
<i>Aspalathus crenata</i> (L.) R.Dahlgren	Fabaceae	MS	resprouter		Low# 5615, Scott 881#, FOT 924	3	LC
<i>Aspalathus cymbiformis</i> DC.	Fabaceae	LS	NS	x	FOT 928	1	LC
<i>Aspalathus divaricata</i> Thunb	Fabaceae	LS	resprouter		Scott 920#	1	LC
<i>Aspalathus ericifolia</i> L. subsp <i>ericifolia</i>	Fabaceae	LS	NS		observed KM	0	LC
<i>Aspalathus hispida</i> Thunb subsp <i>hispida</i>	Fabaceae	LS	NS		FOT 930	1	LC
<i>Aspalathus juniperina</i> Thunb subsp <i>juniperina</i>	Fabaceae	LS	NS	x	FOT 926	1	LC
<i>Aspalathus stricticlada</i> (R.Dahlgren) R.Dahlgren	Fabaceae	DS	NS	x	FOT 905,906	2	EN
<i>Aspalathus uniflora</i> L. subsp <i>wildenowiana</i> (Benth.) R.Dahlgren	Fabaceae	TS	NS		Jordaan 1273, Low 5080#, Scott 909#	3	LC
<i>Asparagus rubicundus</i> (Berg.) Oberm.	Asparagaceae	MS	OS		Low 5091#, Milton 1226#	2	LC
<i>Asparagus scandens</i> Thunb.	Asparagaceae	MS	resprouter		Low 5092#, 5596#	2	LC
<i>Aster subulatus</i> Michx*	Asteraceae	AH	NS		Milton 1224#	1	
<i>Athanasia crithmifolia</i> (L.) L.	Asteraceae	MS	NS	x	observed KM	0	LC
<i>Athanasia trifurcata</i> (L.) L.	Asteraceae	MS	NS		Scott 932#	1	LC
<i>Avena barbata</i> Brot.*	Poaceae	GRA	NS		Scott 959#	1	
<i>Babiana ambigua</i> (Roem. & Schult.) G.J.Lewis	Iridaceae	GEO	resprouter	x	FOT 777	1	LC
<i>Babiana angustifolia</i> Sweet	Iridaceae	GEO	resprouter	x	FOT 774	1	NT
<i>Babiana fragrans</i> (Jacq.) Steud. (= <i>Babiana disticha</i> Ker Gawl.)	Iridaceae	GEO	resprouter		Scott 767#	1	NT
<i>Babiana villosula</i> (J.F.Gmel.) Ker Gawl. ex Steud.	Iridaceae	GEO	resprouter		FOT 744, 776	2	EN
<i>Baeometra uniflora</i> (Jacq.) G.J.Lewis	Colchicaceae	GEO	resprouter		Scott 858#	1	LC
<i>Bartsia trixago</i> L.	Scrophulariaceae	AH	NS		Scott 908#, 966#	2	LC
<i>Berkheya carlinoides</i> (Vahl) Willd	Asteraceae	PH	resprouter		Scott 892#	1	LC
<i>Berkheya herbacea</i> (L.f.) Druce	Asteraceae	PH	resprouter		Scott 922#	1	LC
<i>Berzelia lanuginosa</i> (L.) Brongn.	Bruniaceae	TS	?		Isham 95#, Milton 1199#, Low#	3	LC
<i>Bobartia indica</i> L.	Iridaceae	GEO	resprouter		Scott 926#	1	LC
<i>Bolusafrá bituminosa</i> (L.) Kuntze	Fabaceae	LS	?		Scott 947#	1	LC
<i>Brabejum stellatifolium</i> L.	Proteaceae	Tree	resprouter		Scott 984#	1	LC
<i>Briza maxima</i> L*	Poaceae	GRA	NS		Scott 837#	1	
<i>Briza minor</i> L*	Poaceae	GRA	NS	x	FOT866	1	

<i>Brunia nodiflora</i> L.	Bruniaceae	TS	resprouter		Isham#, Milton 1198#	2	LC
<i>Bulbine praenorsa</i> (Jacq.) Spreng.	Asphodelaceae	GEO	resprouter		Scott 836#	1	LC
<i>Bulbinella trinervis</i> (Baker) P.L.Perry	Asphodelaceae	GEO	resprouter	x	observed KM	0	LC
<i>Caesia contorta</i> (L.f.) T.Durand & Schinz	Hemerocallidaceae	GEO	resprouter		observed KM	0	LC
<i>Cassine peragua</i> L.	Celastraceae	Tree	?		Scott 985#, Low#	2	LC
<i>Cassytha ciliolata</i> Nees	Lauraceae	PH	?		Scott 774#	1	LC
<i>Centella villosa</i> L.	Apiaceae	PH	?		Milton 1223#, 1242#	2	LC
<i>Centranthus ruber</i> (L.) DC.*	Valerianaceae	PH	?		Scott 961#	1	
<i>Ceratandra atrata</i> (L.) T.Durand & Schinz	Orchidaceae	GEO	resprouter	x	observed KM	0	LC
<i>Chaenostoma hispidum</i> (Thunb.) Benth. (=Sutera hispida)	Scrophulariaceae	LS	?		Scott 896#	1	LC
<i>Chaenostoma uncinatum</i> (Desr.) Kornhall (=Sutera uncinata)	Scrophulariaceae	LS	?		previously recorded & observed SM	0	LC
<i>Chasmanthe aethiopica</i> (L.) N.E.Br.	Iridaceae	GEO	resprouter		Scott 772#	1	LC
<i>Chironia baccifera</i> L.	Gentianaceae	MS	?		Milton 1174#	1	LC
<i>Chrysanthemoides monilifera</i> L.	Asteraceae	MS	NS		v Schalkwyk#, Martin 57#	2	LC
<i>Chrysocoma coma-aurea</i> L.	Asteraceae	LS	?		Scott 883#	1	LC
<i>Cineraria erosa</i> (Thunb.) Harv.	Asteraceae	LS	?		observed SM	0	LC
<i>Cissampelos capensis</i> L.f.	Menispermaceae	LS	?		observed SM	0	LC
<i>Cliffortia erectisepala</i> Weim.	Rosaceae	MS	NS		Isham 71#, Low 5101#	2	LC
<i>Cliffortia ericifolia</i> L.f.	Rosaceae	MS	?		observed SM		EN
<i>Cliffortia fillifolia</i> L.	Rosaceae	LS	?		Low 5098#	1	LC
<i>Cliffortia juniperina</i> L.f.	Rosaceae	LS	FS		Low 5100#	1	NE
<i>Cliffortia polygonifolia</i> L. var. <i>trifoliata</i> (L.) Harv.	Rosaceae	MS	?		Isham 127#	1	LC
<i>Cliffortia ruscifolia</i> L. var. <i>ruscifolia</i>	Rosaceae	MS	FS		Milton1250#	1	LC
<i>Cliffortia stobillifera</i> Murr.	Rosaceae	TS	?		Milton 1220#	1	LC
<i>Clutia alaternoides</i> L.	Euphorbiaceae	LS	?		observed SM	0	LC
<i>Clutia laxa</i> Eckl. ex Sond.	Euphorbiaceae	MS	?		observed SM	0	LC
<i>Clutia polifolia</i> Jacq.	Euphorbiaceae	MS	?		Scott 784#	1	LC
<i>Clutia polygonoides</i> L.	Euphorbiaceae	DS	resprouter		observed SM & KM	0	LC
<i>Clutia pubescens</i> Thunb.	Euphorbiaceae	LS	?		observed SM	0	LC
<i>Clutia rubricaulis</i> Eckl. ex Sond	Euphorbiaceae	LS	?		Milton 1235#	1	LC

<i>Colchicum capense</i> (L.) J.C.Manning & Vinn. (= <i>Androcymbium capense</i> (L.) K.Krause)	Colchicaceae	GEO	resprouter		previously recorded	0	LC
<i>Colchicum eucomoides</i> (Jacq.) J.C.Manning & Vinn. (= <i>Androcymbium eucomoides</i> (Jacq.) Willd.)	Colchicaceae	GEO	resprouter		Scott 789#	1	LC
<i>Conophytum turrigerum</i> (N.E. Br.) N.E. Br.	Aizoaceae	DS	?		Milton 1208#	1	rare
<i>Conyza bonariensis</i> (L.) Cronquist*	Asteraceae	AH	NS		observed SM	0	
<i>Conyza scabrida</i> DC.	Asteraceae	TS	?		observed SM	0	LC
<i>Corycium orobanchoides</i> (L.f.) Sw.	Orchidaceae	GEO	resprouter	x	observed KM	1	LC
<i>Corymbium glabrum</i> L. var. <i>glabrum</i>	Asteraceae	PH	resprouter		Scott 936#	1	LC
<i>Cotula turbinata</i> (L.) Pers.	Asteraceae	AH	NS		Scott 793#	1	LC
<i>Crassula atropurpurea</i> (Haw.) Dietr. var. <i>anomala</i> (Schönland & Baker f.) Toelken	Crassulaceae	LS	?		Low 5607#, Scott 982a	2	LC
<i>Crassula capensis</i> (L.) Baill.	Crassulaceae	GEO	resprouter		observed SM & KM	0	LC
<i>Crassula ciliata</i> L.	Crassulaceae	DS	?		Scott 981#, Milton 1265#	2	LC
<i>Crassula dejecta</i> Jacq.	Crassulaceae	LS	?		observed MS	0	LC
<i>Crassula fallax</i> Friedrich	Crassulaceae	LS	?		previously recorded	0	LC
<i>Crassula fascicularis</i>	Crassulaceae	LS	?		Anon#	1	LC
<i>Crassula muscosa</i>	Crassulaceae	LS	?		Milton 1264#	1	LC
<i>Crassula natans</i> Thunb.	Crassulaceae	AH	NS		Milton 1253#, 1255#	2	LC
<i>Crassula saxifraga</i> Harv.	Crassulaceae	GEO	resprouter		previously recorded	0	LC
<i>Crassula subaphylla</i> (Eckl. & Zeyh.) var. <i>subaphylla</i>	Crassulaceae	MS	?		Scott 982b#, Milton 1266#	2	LC
<i>Crossyne guttata</i> D. & U.Müll.-Doblies	Amaryllidaceae	GEO	resprouter	x	observed KM	0	LC
<i>Cunonia capensis</i> L.	Cunoniaceae	Tree	?		Scott 993#	1	LC
<i>Cyanella hyacinthoides</i> L.	Tecophyllaceae	GEO	resprouter		observed Sm & KM	0	LC
<i>Cyanella lutea</i> L.f.	Tecophyllaceae	GEO	resprouter		observed SM	0	LC
<i>Cyclopia maculata</i> (Andr.) Kies.	Fabaceae	TS	NS		Isham 129#	1	LC
<i>Cymbopogon marginatus</i> (Steud.) Stapf ex Burtt Davy	Poaceae	GRA	resprouter		observed SM & KM	0	LC
<i>Cyphia digitata</i> (Thunb.) Willd.	Lobeliaceae	GEO	resprouter		Low 5581#	1	LC
<i>Cyphia incisa</i> (Thunb.) Willd.	Lobeliaceae	GEO	resprouter		Anon#	1	LC
<i>Cyphia volubilis</i> (Burm.f.) Willd	Lobeliaceae	GEO	resprouter		Isham 120#, Low 5584#, Scott 854#	3	LC
<i>Diascia grantiana</i> K Steiner (unresolved name)	Scrophulariaceae	AH	NS		Milton 1259#	1	
<i>Diascia longicornis</i> (Thunb.) Druce	Scrophulariaceae	AH	NS		Scott 882#	1	LC



<i>Didymodoxa capensis</i> (L.f.) Frus & Wilcot-Dear	Urticaceae	AH	NS		Milton 1254#	1	LC
<i>Dimorphotheca pluvialis</i> (L.) Munch.	Asteraceae	AH	NS		Scott 853#	1	LC
<i>Diosma hirsuta</i> L.	Rutaceae	MS	FS		Isham 15#, Low#, Milton 1182#, 1192#	4	LC
<i>Diospyros glabra</i> (L.) De Winter	Ebenaceae	MS	OS		observed SM & KM	0	LC
<i>Dipogon lignosus</i> (L.) Verdc.	Fabaceae	woody climber	?		Isham 131#, Low#, Scott 987#, FOT 916	4	LC
<i>Disa bracteata</i> Sw.	Orchidaceae	GEO	resprouter	x	observed KM	0	LC
<i>Disa longipetala</i> (Lindl.) Bolus	Orchidaceae	GEO	resprouter	x	FOT 781, 782	2	CR
<i>Disa physodes</i> Sw.	Orchidaceae	GEO	resprouter	x	FOT 828	1	CR
<i>Dischisma ciliatum</i> (P.J.Bergius) Choisy	Scrophulariaceae	LS	?		Scott 919#	1	LC
<i>Disperis bolusiana</i> Schltr. var. <i>bolusiana</i>	Orchidaceae	GEO	resprouter		observed SM	0	LC
<i>Disperis capensis</i> (L.f.) Sw. var. <i>capensis</i>	Orchidaceae	GEO	resprouter		FOT 784	1	LC
<i>Dodonaea viscosa</i> Jacq. var. <i>angustifolia</i> (L.f.) Benth.	Sapindaceae	TS	resprouter		observed SM & KM	0	LC
<i>Dolichos decumbens</i> Thunb.	Fabaceae	LS	?		observed KM	0	LC
<i>Drosera pauciflora</i> Banks ex DC.	Droseraceae	PH	resprouter		Scott 794#	1	LC
<i>Drosera trinervia</i> Spreng.	Droseraceae	PH	resprouter		Milton 1251#	1	LC
<i>Echiostachys spicatus</i> (Burm.f.) Levyns	Boraginaceae	PH	resprouter	x	observed KM	0	EN
<i>Echium plantagineum</i> L.*	Boraginaceae	AH	NS		Scott 864#	1	
<i>Ehrharta calycina</i> Sm.	Poaceae	PH	?		Scott 846#	1	LC
<i>Ehrharta capensis</i> Thunb.	Poaceae	GRA, GEO	resprouter		observed KM	0	LC
<i>Ehrharta longiflora</i> Sm.	Poaceae	GRA	NS		Scott 840#	1	LC
<i>Ehrharta ottonis</i> Kunth ex Nees	Poaceae	GRA, GEO	resprouter		Scott 851#	1	LC
<i>Elegia capensis</i> (Burm.f.) Schelpe	Restionaceae	GRA	?		observed SM	0	LC
<i>Elegia filacea</i> Must.	Restionaceae	GRA	?		Low 5154#	1	LC
<i>Elytropappus glandulosus</i> Less.	Asteraceae	LS	?		Milton 1163#	1	LC
<i>Elytropappus rhinocerotis</i> (L.f.) Less.	Asteraceae	MS	NS		observed SM	0	LC
<i>Epilobium tetragonum</i> L.	Onagraceae	PH	?		Scott 945#	1	LC
<i>Eragrostis curvula</i> (Schrud.) Nees	Poaceae	GRA	?		observed SM	0	LC
<i>Erepsia bracteata</i> (Aiton) Schwantes	Aizoaceae	LS	?		observed SM	0	LC
<i>Erepsia heteropetala</i> (Haw.) Schwantes	Aizoaceae	DS	?		previously recorded	0	LC
<i>Erepsia lacera</i> (Haw.) Liede	Aizoaceae	LS	NS		Milton 1209#	1	LC

<i>Erepsia patula</i> (Haw.) Schwantes	Aizoaceae	LS	?	x	observed KM	0	VU
<i>Erepsia ramosa</i> L.Bolus	Aizoaceae	LS	?		Low 5144#, Milton 1178#	2	VU
<i>Erica bicolor</i> Thunb.	Ericaceae	TS	?		observed SM	0	LC
<i>Erica cerinthoides</i> L.	Ericaceae	LS	resprouter		Martin#	1	LC
<i>Erica coccinea</i> L. var. <i>coccinea</i>	Ericaceae	MS	?		Isham 62#	1	LC
<i>Erica hispidula</i> L.	Ericaceae	TS	?		Isham 126#	1	LC
<i>Erica imbricata</i> L.	Ericaceae	MS	?		Isham 124#, Scott 823#	2	LC
<i>Erica lucida</i> Salisb.	Ericaceae	MS	?		Isham 140#	1	LC
<i>Erica mauritanica</i> L.	Ericaceae	MS	?		Anon#	1	LC
<i>Erica nudiflora</i> L.	Ericaceae	DS	?		Isham 28#, 43#, Milton 1197#	3	LC
<i>Erica paniculata</i> L.	Ericaceae	LS	?		Isham 119#, Scott 775#, 822#	3	LC
<i>Erica parviflora</i> L.	Ericaceae	MS	?		Isham#, Milton 1217#	2	LC
<i>Erica plukenetii</i> L. var. <i>plukenetii</i>	Ericaceae	MS	?		Isham 51#, 125#	2	LC
<i>Erica setacea</i> Andr.	Ericaceae	LS	?		Low 5093#	1	LC
<i>Erica totta</i> Thunb.	Ericaceae	DS	?		Milton 1258#	1	LC
<i>Erica vestita</i> Thunb.	Ericaceae	MS	?		Anon#	1	LC
<i>Eriocephalus africanus</i> L var. <i>paniculatus</i> (Cass.) M.A.N.Müll., P.P.J.Herman & Kolberg	Asteraceae	MS	NS		Isham 46#, Milton 1221#	2	LC
<i>Eriospermum capense</i> (L.) Thunb.	Eriospermaceae	GEO	resprouter		observed SM	0	LC
<i>Eriospermum lancefolium</i> Jacq.	Eriospermaceae	GEO	resprouter		observed SM	0	LC
<i>Euclea acutifolia</i> E.Mey. ex A.DC.	Ebenaceae	MS	?		Scott 894#	1	LC
<i>Euphorbia burmannii</i> E.Mey. ex Boiss.	Euphorbiaceae	LS	?		observed SM	0	LC
<i>Euphorbia erythrina</i> Link	Euphorbiaceae	MS	?		Low 5141#	1	LC
<i>Euphorbia genistoides</i> P.J. Bergius	Euphorbiaceae	LS	?		Low5140#, Scott 796#, Milton 1247#	3	LC
<i>Euphorbia peplus</i> L.*	Euphorbiaceae	AH	NS		observed SM	0	
<i>Euryops linifolius</i> (L.) DC	Asteraceae				observed SM	0	LC
<i>Eustegia minuta</i> (L.f.) R.Br.	Apocynaceae	PH	resprouter	x	observed KM	0	LC
<i>Felicia dubia</i> Cass.	Asteraceae	AH	NS		Scott 873#	1	LC
<i>Felicia filifolia</i> (Vent.) Burt Davy subsp. <i>filifolia</i>	Asteraceae	MS	?		Scott 866#, Milton 1261#	2	LC
<i>Felicia tenella</i> (L.) Nees	Asteraceae	AH	NS		Low#, Milton 1261#	2	LC
<i>Ficinia acuminata</i> (Nees) Nees (= <i>Ficinia involuta</i> Nees)	Cyperaceae	GRA	?		Isham 54#, Scott 980#, Low 5593#	3	LC

<i>Ficinia distans</i> C.B.Cl.	Cyperaceae	GRA	?		Milton 1172#	1	VU
<i>Ficinia filiformis</i> (Lam.) Schrad.	Cyperaceae	GRA	?		Isham 64#	1	LC
<i>Ficinia indica</i> (Lam.) Pfeiffer	Cyperaceae	GRA	?		Scott 797#, Milton 1211#	2	LC
<i>Ficinia nigrescens</i> (Schrad.) J.Raynal	Cyperaceae	GRA	resprouter		Scott 814#	1	LC
<i>Ficinia oligantha</i> (Steud.) J.Raynal	Cyperaceae	GRA	resprouter		Low 5155#	1	LC
<i>Fuirena hirsuta</i> (P.J.Berg.) P.L.Forbes	Cyperaceae	GRA	?		Scott 958#	1	LC
<i>Galium subvillosum</i> Sond.	Rubiaceae	PH	?		Scott 805#, 877#	2	LC
<i>Gazania ciliaris</i> DC	Asteraceae	PH	?		Anon#, Low 6673#	2	LC
<i>Gazania pectinata</i> (Thunb.) Spreng.	Asteraceae	AH	NS		Anon#	1	LC
<i>Geissorhiza aspera</i> Goldblatt	Iridaceae	GEO	resprouter		van Schalkwyk A7#, Low 5049#, Scott 842#	3	LC
<i>Geissorhiza inflexa</i> (D.Delaroche) Ker Gawl.	Iridaceae	GEO	resprouter		Scott 829#	1	LC
<i>Geissorhiza juncea</i> (Link) A.Dietr.	Iridaceae	GEO	resprouter	x	FOT 783	1	LC
<i>Geissorhiza ovata</i> (Burm.f.) Asch. & Graebn.	Iridaceae	GEO	resprouter		Low 5051#, FOT 773	2	LC
<i>Gerbera crocea</i> (L.) Kuntze	Asteraceae	PH	resprouter		observed SM & KM	0	LC
<i>Gladiolus alatus</i> L.	Iridaceae	GEO	resprouter		observed SM	0	LC
<i>Gladiolus brevifolius</i> Jacq.	Iridaceae	GEO	resprouter	x	FOT 742	1	LC
<i>Gladiolus carinatus</i> Aiton	Iridaceae	GEO	resprouter	x	FOT 779	1	LC
<i>Gladiolus maculatus</i>	Iridaceae	GEO	resprouter		Low 5050#	1	LC
<i>Gladiolus recurvus</i> L.	Iridaceae	GEO	resprouter		Scott 765#	1	VU
<i>Gladiolus undulatus</i> L.	Iridaceae	GEO	resprouter		FOT 874	1	LC
<i>Gladiolus watsonius</i> Thunb.	Iridaceae	GEO	resprouter	x	observed KM	0	NT
<i>Globulariopsis adpressa</i> (Choisy) Hilliard (=Selago tephrodes)	Scrophulariaceae	PH	?		Low 5588#	1	LC
<i>Gnaphalium coarctatum</i> Willd. *	Asteraceae	AH	NS		Scott 928#	1	
<i>Gnidia inconspicua</i> Meisn.	Thymelaeaceae	DS	?		observed SM & KM	0	LC
<i>Gnidia laxa</i> (L.f.) Gilg.	Thymelaeaceae	LS	NS	x	observed KM	0	LC
<i>Gomphocarpus cancellatus</i> Bruyns*	Apocynaceae	TS	NS		Isham 139#, Scott 996#	2	
<i>Haemanthus coccineus</i> L.	Amaryllidaceae	GEO	resprouter		observed SM & KM	0	LC
<i>Hakea sericea</i> Schrad.*	Proteaceae	TS	NS		observed SM	0	
<i>Halleria elliptica</i> Thunb.	Scrophulariaceae	TS	?		Scott 817#	1	LC
<i>Haplocarpha lanata</i> (Thunb.) Less.	Asteraceae	PH	resprouter	x	observed KM	0	LC
<i>Hebenstretia paarlensis</i>	Scrophulariaceae	LS	?		observed SM	0	LC
<i>Heeria argentia</i> (Thunb) Meisn.	Anacardiaceae	Tree	resprouter		Milton 1175#	1	LC

<i>Helichrysum crispum</i> (L.) D.Don	Asteraceae	LS	?		observed SM	0	LC
<i>Helichrysum cylindriflorum</i> (L.) Hilliard & Burt	Asteraceae	DS	?		Scott 923#	1	LC
<i>Helichrysum cymosum</i> (L.) D.Don	Asteraceae	MS	NS		Isham 63#	1	LC
<i>Helichrysum dasyanthum</i> (Willd.) Sweet	Asteraceae	LS	NS		Isham 42#	1	LC
<i>Helichrysum foetidum</i> (L.) Moench	Asteraceae	AH	NS		Scott 962#	1	LC
<i>Helichrysum patulum</i> (L.) D.Don	Asteraceae	LS	?		Anon#, Low 5068#	2	LC
<i>Helichrysum rosum</i> (P.J. Berg.) Less.	Asteraceae	TS	?		observed SM	0	LC
<i>Helichrysum teretifolium</i> (L.) D.Don	Asteraceae	DS	resprouter		Isham 70#, 121#, Scott 830#	3	LC
<i>Helichrysum zeyheri</i> Less.	Asteraceae	LS	?		previously recorded & observed KM	0	LC
<i>Heliophila diffusa</i> (Thunb.) DC. var. <i>diffusa</i>	Brassicaceae	AH	NS		observed KM	0	LC
<i>Heliophila macowaniana</i> Schltr.	Brassicaceae	AH	NS	x	observed KM	0	LC
<i>Heliophila scoparia</i> Burch. ex DC. var. <i>scoparia</i>	Brassicaceae	LS	NS		Carter 12#, Scott 779#	2	LC
<i>Hemimeris gracilis</i> Schltr.	Scrophulariaceae	AH	NS		Anon#	1	LC
<i>Hemimeris racemosa</i> (Houtt.) Merr. (= <i>Hemimeris montana</i> L.f.)	Scrophulariaceae	AH	NS		Anon#, Scott 831#	2	LC
<i>Hermannia alnifolia</i> L.	Malvaceae	MS	?		Low 5582#, Scott 820#, 862#, Anon#	4	LC
<i>Hermannia althaeifolia</i> L.	Malvaceae	LS	resprouter		observed SM & KM	0	LC
<i>Hermannia cuneifolia</i> Jacq. var. <i>cuneifolia</i>	Malvaceae	MS	?		previously recorded & observed SM	0	LC
<i>Hermannia flammea</i> Jacq.	Malvaceae	LS	resprouter		Isham 122#, Low 5136#	2	LC
<i>Hermannia grossularifolia</i> L.	Malvaceae	LS	FS	x	observed KM	0	LC
<i>Hermannia hyssopifolia</i> L.	Malvaceae	DS	resprouter		Anon#	1	LC
<i>Hermannia cf. multiflora</i> Jacq.	Malvaceae	MS	NS	x	observed KM	0	LC
<i>Hermannia prismatocarpa</i> E.Mey. ex Harv.	Malvaceae	LS	?		previously recorded	0	LC
<i>Hermannia rugosa</i> Adamson	Malvaceae	LS	resprouter		observed KM	0	VU
<i>Hermannia salviifolia</i> L.f.	Malvaceae	TS	?		Scott 798#	1	LC
<i>Hermannia ternifolia</i> C.Presl ex Harv.	Malvaceae	DS	?		Anon#	1	LC
<i>Hesperantha falcata</i> (L.f.) Ker Gawl.	Iridaceae	GEO	resprouter		Scott 855#	1	LC
<i>Hesperantha pilosa</i> (L.f.) Ker Gawl.	Iridaceae	GEO	resprouter	x	observed KM	0	LC
<i>Hesperantha spicata</i> (Burm.f.) N.E.Br. subsp. <i>spicata</i>	Iridaceae	GEO	resprouter		previously recorded	0	VU
<i>Heterolepis aliena</i> (L.f.) Druce	Asteraceae	DS	?		Milton 1222#	1	LC
<i>Hibiscus aethiopicus</i> L.	Malvaceae	DS	resprouter	x	observed KM	0	LC

<i>Hippia frutescens</i> (L.) L.	Asteraceae	LS	?		previously recorded	0	LC
<i>Holothrix cernua</i> (Burm.f.) Schelpe	Orchidaceae	GEO	resprouter	x	observed KM	0	LC
<i>Holothrix villosa</i> Lindl.	Orchidaceae	GEO	resprouter		observed KM	0	LC
<i>Hymenolepis parviflora</i> (L.) DC.	Asteraceae	TS	?		Scott 899#	1	LC
<i>Hyobanche sanguinea</i> L.	Orobanchaceae	parasite			Low#	1	LC
<i>Hyparrhenia hirta</i> (L.) Stapf.	Poaceae	GRA	?		Low 5152#, Scott 852#	2	LC
<i>Hypericum perforatum</i> L.*	Hypericaceae	PH	?		Scott 954#	1	
<i>Hypochoeris radicata</i> L*	Asteraceae	PH	?		Scott 951#	1	
<i>Ilex mitis</i> L. Radlk	Aquifoliaceae	Tree	?		Scott 983#	1	declining
<i>Indigofera digitata</i> Thunb.	Fabaceae	LS	resprouter		Scott 886#	1	LC
<i>Indigofera gracilis</i> Spreng.	Fabaceae	LS	NS		Scott 878#	1	LC
<i>Indigofera incana</i> Thunb.	Fabaceae	LS	resprouter	x	observed KM	0	LC
<i>Inula graveolens</i> *	Asteraceae	LS	NS		Scott 990#	1	
<i>Isolepis antarctica</i> (L.) Roem. & Schult.	Cyperaceae	GRA	NS		Low 5161#	1	LC
<i>Itasina filifolia</i> (Thunb.) Raf.	Apiaceae	PH	?		Scott 935#	1	LC
<i>Ixia cf dubia</i> Vent.	Iridaceae	GEO	resprouter	x	FOT 908	1	declining
<i>Ixia polystachya</i> L.	Iridaceae	GEO	resprouter		Scott 934#, FOT 918	2	LC
<i>Ixia scillaris</i> L.	Iridaceae	GEO	resprouter		Scott 880#, 939#	2	LC
<i>Juncus dregeanus</i> Kunth	Juncaceae	GRA	?		Scott 941#	1	LC
<i>Juncus effuses</i> L.	Juncaceae	GRA	?		Isham 79#	1	LC
<i>Juncus lomatophyllus</i> Spreng.	Juncaceae	GRA	?		Scott 944#	1	LC
<i>Juncus oxycarpus</i> E. Mey. Ex Kunth.	Juncaceae	GRA	?		Isham 80#	1	LC
<i>Kiggelaria africana</i> L.	Achariaceae	Tree	resprouter		Anon 118	1	LC
<i>Knowltonia anemonoides</i> H.Rasm.	Ranunculaceae	PH	?		Scott 813#	1	LC
<i>Lachenalia orchioides</i> (L.) Aiton.	Hyacinthaceae	GEO	resprouter		Scott 801#	1	LC
<i>Lachenalia pallida</i> Aiton	Hyacinthaceae	GEO	resprouter		previously recorded & observed SM	0	declining
<i>Lachenalia reflexa</i> Thunb.	Hyacinthaceae	GEO	resprouter	x	observed KM	0	VU
<i>Lachnospermum fasciculatum</i> (Thunb.) Baill.	Asteraceae	LS	?	x	observed KM	0	LC
<i>Lampranthus aduncus</i> (Haw) NEBr	Aizoaceae	LS	?		Low 6505#	1	DDT
<i>Lantana camara</i> L.*	Verbenaceae	TS	resprouter		Scott 849#	1	
<i>Laurembergia repens</i> P.J.Bergius ssp. <i>brachypoda</i> (Hiern) Oberm.	Haloragaceae	PH	?		Isham 88#, Milton 1219	2	LC
<i>Leonotis leonurus</i> (L.) R.Br.	Lamiaceae	MS	?		Milton 1190#, Scott 946	2	LC

<i>Leucadendron argenteum</i> (L.) R.Br.	Proteaceae	Tree	NS		observed SM	0	EN
<i>Leucadendron lanigerum</i> H.Buek ex Meisn. var. <i>lanigerum</i>	Proteaceae	MS	resprouter		Isham 117#, Milton 1229#	2	EN
<i>Leucadendron rubrum</i> Burm.f.	Proteaceae	TS	NS		Anon#, Milton 1160#	2	LC
<i>Leucadendron salignum</i> P.J.Bergius	Proteaceae	MS	FS		Isham#	1	LC
<i>Leucadendron spissifolium</i> (Salisb. ex Knight) <i>I.Williams</i> subsp. <i>spissifolium</i>	Proteaceae	TS	resprouter		observed SM	0	LC
<i>Leucospermum grandiflorum</i> (Salisb.) R.Br.	Proteaceae	TS	NS		Isham 47#, Anon#	2	EN
<i>Leysera gnaphalodes</i> (L.) L.	Asteraceae	MS	?		previously recorded & observed SM	0	LC
<i>Lichtensteinia lacera</i> Cham. & Schtdl.	Apiaceae	PH	resprouter		observed SM & KM	0	LC
<i>Lobelia erinus</i> L.	Lobeliaceae	AH	NS		Scott 771#, Milton 1078#	2	LC
<i>Lobostemon fruticosus</i> (L.) H.Buek	Boraginaceae	LS	NS		Martin 39#	1	LC
<i>Lobostemon glaucophyllus</i> (Jacq.) H.Buek	Boraginaceae	LS	?		Scott 802#	1	LC
<i>Lotononis involucrata</i> (P.J.Bergius) Benth. subsp. <i>involucrata</i>	Fabaceae	DS	?		Scott 825#	1	LC
<i>Lotononis prostrata</i> (L.) Benth.	Fabaceae	DS	?		Scott 803#	1	NT
<i>Maytenus acuminata</i> (L.f) Loes	Celastraceae	Tree	?		Milton 1239#, Scott 986#	2	LC
<i>Maytenus oleoides</i> (Lam.) Loes.	Celastraceae	Tree	?		Low 5129#	1	LC
<i>Melasphaerula ramosa</i> (L.) N.E.Br.	Iridaceae	GEO	resprouter		Scott 848#	1	LC
<i>Melinis repens</i> (Willd.) Zizka	Poaceae	GRA	NS		Scott 940#	1	LC
<i>Merxmuellera cincta</i> (Nees) Conert subsp. <i>cincta</i>	Poaceae	GRA	?		Scott 956#	1	LC
<i>Merxmuellera lupulina</i> (Thunb.) Conert	Poaceae	GRA	resprouter		Scott 930#	1	LC
<i>Merxmuellera stricta</i> (Schrad.) Conert	Poaceae	GRA	?		Isham 55#	1	LC
<i>Metalasia densa</i> (Lam.) P.O.Karis	Asteraceae	TS	?		Low 5107#, Milton 1212#	2	LC
<i>Metalasia dregeana</i> DC.	Asteraceae	TS	?		Milton 1180#, 1214#	2	LC
<i>Metalasia muricata</i> (L.) D.Don	Asteraceae	TS	?		Isham 30#	1	LC
<i>Metrosideros angustifolia</i> (L.) Sm.	Myrtaceae	Tree	?		Milton 1188#	1	LC
<i>Micranthus alopecuroides</i> (L.) Rothm.	Iridaceae	GEO	resprouter		Scott 937#	1	LC
<i>Micranthus tubulosus</i> (Burm.) N.E.Br.	Iridaceae	GEO	resprouter		observed KM	0	LC
<i>Microdon dubius</i> (L.) Hilliard	Scrophulariaceae	LS	?		Scott 879#, 976#	2	LC
<i>Microloma tenuifolium</i> (L.) K.Schum.	Apocynaceae	LS	resprouter		Isham 45# Anon#, Low 5062#	3	LC
<i>Monopsis lutea</i> (L.) Urb.	Lobeliaceae	PH	?		Scott 975#	1	LC
<i>Monsonia speciosa</i> L.	Geraniaceae	GEO	resprouter	x	FOT 864	1	EN



<i>Montinia caryophyllacea</i> Thunb.	Montiniaceae	MS	resprouter		Isham 60#, Milton 1207#	1	LC
<i>Moraea bituminosa</i> (L.f.) Ker Gawl.	Iridaceae	GEO	resprouter	x	observed KM	0	LC
<i>Moraea ciliata</i> (L.f.) Ker Gawl.	Iridaceae	GEO	resprouter	x	FOT 778	1	LC
<i>Moraea collina</i> Thunb.	Iridaceae	GEO	resprouter		previously recorded	0	LC
<i>Moraea fugacissima</i> (L.f.) Goldblatt	Iridaceae	GEO	resprouter		Scott 787#	1	LC
<i>Moraea fugax</i> (Del.) Jacq.	Iridaceae	GEO	resprouter		v Schalkwyk A9#	1	LC
<i>Moraea gawleri</i> Spreng.	Iridaceae	GEO	resprouter		Anon#	1	LC
<i>Moraea ochroleuca</i> (Salisb.) Drapiez	Iridaceae	GEO	resprouter		Isham 137#	1	LC
<i>Moraea papilionacea</i> (L.f.) Ker Gawl.	Iridaceae	GEO	resprouter		previously recorded, observed KM	0	LC
<i>Moraea ramosissima</i> (L.f.) Druce	Iridaceae	GEO	resprouter	x	FOT 876	1	LC
<i>Moraea tripetala</i> (L.f.) Ker-Gawl.	Iridaceae	GEO	resprouter		observed SM	0	LC
<i>Moraea vegeta</i> L.	Iridaceae	GEO	resprouter		Scott 868#	1	LC
<i>Moraea versicolor</i> (Salisb. ex Klatt) Goldblatt	Iridaceae	GEO	resprouter	x	FOT 776	1	VU
<i>Moraea virgata</i> Jacq. subsp. <i>virgata</i>	Iridaceae	GEO	resprouter	x	observed KM	0	LC
<i>Morella integra</i> (A.Chev.) Killick	Myricaceae	TS	?		Milton 1191#	1	LC
<i>Morella quercifolia</i> L.	Myricaceae	LS	resprouter		FOT 743	1	LC
<i>Muraltia alopecuroides</i> (L.) DC.	Polygalaceae	MS	?		previously recorded	0	LC
<i>Muraltia cf decipiens</i> Schltr.	Polygalaceae	DS	resprouter		observed KM	0	EN
<i>Muraltia heisteria</i> (L.) DC.	Polygalaceae	TS	?		Martin 30#, Isham 40#	2	LC
<i>Muraltia serpylloides</i> DC.	Polygalaceae	DS	?		previously recorded	0	LC
<i>Muraltia vulpina</i> Chodat	Polygalaceae	MS	?		Scott 918#	1	LC
<i>Myrsine africana</i> L.	Myrsinaceae	TS	resprouter		observed SM & KM	0	LC
<i>Myrtus communis</i> L. var. <i>communis</i> *	Myrtaceae		?		previously recorded	0	
<i>Nemesia barbata</i> (Thunb.) Benth.	Scrophulariaceae	AH	NS		Scott 827#	1	LC
<i>Nemesia diffusa</i> Benth.	Scrophulariaceae	PH	NS		Scott 997#	1	LC
<i>Nemesia lucida</i> Benth.	Scrophulariaceae	AH	NS		observed SM	0	DDT
<i>Nerine humilis</i> (Jacq) Herb.	Amaryllidaceae	GEO	resprouter		Scott 769#	1	LC
<i>Nidorella foetida</i> (L.) DC.	Asteraceae	LS	?		observed SM	0	LC
<i>Notobubon galbanum</i> (L.) Magee (=Peucedanum galbanum (L.) Drude)	Apiaceae	TS	?		Scott 955#	1	LC
<i>Nymphoides indica</i> (L.) Kuntze	Menyanthaceae	PH	?		Isham 89#	1	LC
<i>Oftia africana</i> (L.) Bocq.	Scrophulariaceae	LS	resprouter		observed SM & KM	0	LC
<i>Olea capensis</i> subsp. <i>capensis</i>	Oleaceae	Tree	resprouter		observed SM	0	LC

<i>Olea europaea</i> L. subsp. <i>africana</i> (Mill.) P.S.Green	Oleaceae	Tree	resprouter		Milton 1240#	1	LC
<i>Olinia ventosa</i> (L.) Cufod.	Oliniaceae	Tree	?		previously recorded; observed SM	0	LC
<i>Onixotis punctata</i> (L.) Mabb. (= <i>Wurmbea punctata</i> )	Colchicaceae	GEO	resprouter		Low 5048#	1	LC
<i>Oplismenus hirtellus</i> (L.) P. Beauv. *	Poaceae	GRA	?		observed SM	0	LC
<i>Ornithogalum graminifolium</i> Thunb.	Hyacinthaceae	GEO	resprouter	x	observed KM	0	LC
<i>Ornithogalum hispidum</i> Hornem.	Hyacinthaceae	GEO	resprouter		Scott 964#	1	LC
<i>Ornithogalum thyrsoides</i> Jacq.	Hyacinthaceae	GEO	resprouter		Scott 924#	1	LC
<i>Oscularia deltoides</i> (L.) Schwantes	Aizoaceae	DS	?		Milton 1233#	1	LC
<i>Osteospermum spinosum</i> L. var. <i>runcinatum</i> P.J.Bergius	Asteraceae	MS	?		Anon##, Low 5075#, Milton 1228#	4	LC
<i>Osteospermum spinosum</i> L. var. <i>spinosum</i>	Asteraceae	LS	NS		Low 5602#	1	LC
<i>Otholobium hirtum</i> (L.) C.H.Stirt.	Fabaceae	TS	NS		previously recorded, observed SM	0	LC
<i>Otholobium obliquum</i> (E.Mey.) C.H.Stirt.	Fabaceae	MS	resprouter		Anon#	1	LC
<i>Otholobium virgatum</i> (Burm.f.) C.H.Stirt.	Fabaceae	DS	resprouter	x	observed KM	0	LC
<i>Othonna amplexifolia</i> DC.	Asteraceae	GEO	resprouter		Milton 1184#, Scott 768#	2	NE
<i>Othonna arborescens</i> L.	Asteraceae	MS	?		Scott 816#	1	LC
<i>Othonna heterophylla</i> L.f.	Asteraceae	GEO	resprouter	x	observed KM	0	LC
<i>Othonna parviflora</i> P.J.Bergius	Asteraceae	TS	?		Isham 45#, 115#	2	LC
<i>Oxalis bifida</i> Thunb.	Oxalidaceae	GEO	resprouter		previously recorded	0	LC
<i>Oxalis commutata</i> Sond. var. <i>commutata</i>	Oxalidaceae	GEO	resprouter		Milton 1177#, 1205#	2	LC
<i>Oxalis compressa</i> L.f. var. <i>compressa</i>	Oxalidaceae	GEO	resprouter		previously recorded	0	LC
<i>Oxalis eckloniana</i> C.Presl	Oxalidaceae	GEO	resprouter		Scott 999#	1	LC
<i>Oxalis glabra</i> Thunb.	Oxalidaceae	GEO	resprouter		previously recorded	0	LC
<i>Oxalis hirta</i> L.	Oxalidaceae	GEO	resprouter	x	FOT 741	1	LC
<i>Oxalis livida</i> Jacq.	Oxalidaceae	GEO	resprouter		Scott 991#, Milton 1201#	2	LC
<i>Oxalis multicaulis</i> Eckl. & Zeyh.	Oxalidaceae	GEO	resprouter		previously recorded	0	LC
<i>Oxalis nidulans</i> Eckl. & Zeyh. var. <i>denticulata</i> (Wolley-Dod) Salter	Oxalidaceae	GEO	resprouter		previously recorded	0	LC
<i>Oxalis obtusa</i> Jacq.	Oxalidaceae	GEO	resprouter		Martin 43#, Low#	2	LC
<i>Oxalis pardalis</i> Sond.	Oxalidaceae	GEO	resprouter		Low 5055#	1	DDT
<i>Oxalis pes-caprae</i> L.	Oxalidaceae	GEO	resprouter		Low#	1	LC
<i>Oxalis purpurea</i> L.	Oxalidaceae	GEO	resprouter		Anon#, Milton 1183#, 1206#	3	LC



<i>Oxalis tenuifolia</i> Jacq.	Oxalidaceae	GEO	resprouter		Milton 1171#, 1202#, Scott 773#	3	LC
<i>Paraserianthes lophantha</i> (Willd) Nielsen*	Fabaceae	Tree	NS		Scott 850#	1	
<i>Paspalum dilitatum</i> Poir.	Poaceae	GRA	resprouter		Scott 938#	1	NE
<i>Passerina vulgaris</i> Thoday	Thymelaeaceae	TS	NS		Milton 1166#	1	LC
<i>Pauridia minuta</i> (L.f.) T.Durand & Schinz	Hypoxidaceae	GEO	resprouter		Milton 1176#	1	NT
<i>Pelargonium alchemilloides</i> (L.) L'Hér.	Geraniaceae	DS	?		previously recorded	0	LC
<i>Pelargonium candicans</i> Spreng.	Geraniaceae	DS	?		previously recorded & observed KM	0	LC
<i>Pelargonium capitatum</i> (L.) L'Hér.	Geraniaceae	LS	?		previously recorded	0	LC
<i>Pelargonium chamaedryfolium</i> Jacq.	Geraniaceae	AH	NS	x	observed KM	0	LC
<i>Pelargonium cf ovale</i> (Burm.) L'Hér.	Geraniaceae	GEO	resprouter		Milton 1260#	1	LC
<i>Pelargonium cucullatum</i> (L.) L'Hér.	Geraniaceae	TS	?		Isham 59#	1	LC
<i>Pelargonium elongatum</i> (Cav.) Salisb.	Geraniaceae	DS	NS		Low 5589#	1	LC
<i>Pelargonium hirtum</i> (Burm.f.) Jacq.	Geraniaceae	DS	?		previously recorded	0	LC
<i>Pelargonium longifolium</i> (Burm.f.) Jacq.	Geraniaceae	GEO	resprouter		observed KM	0	LC
<i>Pelargonium myrrhifolium</i> (L.) L'Hér.	Geraniaceae	DS	?		Pienaar 50#, Milton 1216#	2	LC
<i>Pelargonium myrrhifolium</i> (L.) L'Hér var. <i>coriandrifolium</i> (L.) Harv.	Geraniaceae	DS	?		Isham 50#, Scott 875#	2	LC
<i>Pelargonium nanum</i> L'Hér.	Geraniaceae	AH	NS	x	observed KM	0	LC
<i>Pelargonium scabrum</i> (Burm.f.) L'Hér.	Geraniaceae	MS	?	x	observed KM	0	LC
<i>Pelargonium tabulare</i> (Burm.f.) L'Hér.	Geraniaceae	DS	?		Scott 1001#	1	LC
<i>Pelargonium triste</i> (L.) L'Hér.	Geraniaceae	GEO	resprouter		Scott 863#	1	LC
<i>Pennisetum macrourum</i> Trin.	Poaceae	GRA	?		Isham 90#	1	LC
<i>Pentaschistis airoides</i> (Nees) Stapf subsp. <i>airoides</i>	Poaceae	GRA	NS		Scott 888#	1	LC
<i>Pentaschistis curvifolia</i> (Schrad.) Stapf	Poaceae	GRA	?		Scott 931#	1	LC
<i>Pentaschistis densifolia</i> (Nees) Stapf	Poaceae	GRA	?		Scott 948#	1	LC
<i>Petrorhagia prolifera</i> (L.) P.W.Ball & Heywood *	Caryophyllaceae	AH	NS		Scott 839#	1	
<i>Phalaris minor</i> Retz*	Poaceae	GRA	?		Scott 925a#	1	
<i>Phylica atrata</i> Licht. Ex Roem. & Schult.	Rhamnaceae	LS	?		Low 5086#	1	LC
<i>Phylica callosa</i> L.f.	Rhamnaceae	LS	NS		Isham 7#, Milton 1169#, 1170#, Scott 994#	5	LC
<i>Phylica spicata</i> L.f. var. <i>spicata</i>	Rhamnaceae	MS	resprouter		Isham 22#, Low 5085#, Milton 1227#, Scott 970#	4	LC
<i>Phyllopodium heterophyllum</i> (L.f.) Benth.	Scrophulariaceae	AH	NS	x	observed KM	0	LC

<i>Pittosporum undulatum</i> Vent. *	Pittosporaceae	Tree	NS		Milton 1170#	1	
<i>Plantago lanceolata</i> *	Plantaginaceae	PH	?		Scott 847#	1	
<i>Podalyria biflora</i> Lam.	Fabaceae	LS	resprouter		previously recorded & observed KM	0	LC
<i>Podalyria calyprata</i> (Retz.) Willd.	Fabaceae	TS	NS		Anon#	1	LC
<i>Podalyria rotundifolia</i> (P.J.Bergius) A.L. Schutte	Fabaceae	MS	resprouter	x	observed KM	0	NE
<i>Podalyria sericea</i> (Andr.) R.Br.	Fabaceae	MS	NS		Milton 1238#	1	NT
<i>Polygala bracteolata</i> L.	Polygalaceae	LS	?		observed SM & KM	0	LC
<i>Polygala fruticosa</i> P.J.Bergius	Polygalaceae	TS	?		previously recorded	0	LC
<i>Polygala garcinii</i> DC.	Polygalaceae	DS	?		v Schalkwyk A12#, Isham 132#	2	LC
<i>Polygala lehmanniana</i> Eckl. & Zeyh.	Polygalaceae	DS	?		previously recorded & observed KM	0	LC
<i>Polygala scabra</i> L. (=Polygala affinis DC.)	Polygalaceae	DS	?		Low 5575#	1	LC
<i>Polygala triquetra</i> Presl.	Polygalaceae	LS	resprouter		observed SM	0	LC
<i>Polygala virgata</i> Thunb. *	Polygalaceae	TS	NS		Isham 116#, Milton 1241#	2	LC
<i>Polygonum undulatum</i> (L.) P.J.Bergius	Polygonaceae	LS	?	x	observed KM	0	LC
<i>Printzia polifolia</i> (L.) Hutch.	Asteraceae	MS	resprouter		Anon#, Scott 874#	2	LC
<i>Prismatocarpus diffusus</i> (L.f) A.DC.	Campanulaceae	LS	resprouter		Anon#, Milton 1232#	2	LC
<i>Prismatocarpus fruticosus</i> L'Hér.	Campanulaceae	LS	?		Scott 953#	1	LC
<i>Protea acaulis</i> (L.) Reichard	Proteaceae	DS	resprouter		Scott 1000#	1	LC
<i>Protea aurea</i> (Burm. F.) Rourke	Proteaceae	TS	NS		Milton 1196#	1	LC
<i>Protea burchellii</i> Stapf	Proteaceae	TS	NS		Milton 1195#	1	VU
<i>Protea laurifolia</i> Thunb.	Proteaceae	Tree	NS		Carter#, Milton 1231#	2	LC
<i>Protea laurifolia</i> x <i>nerifolia</i>	Proteaceae				observed SM		
<i>Protea mundii</i> x <i>hybrid</i>	Proteaceae				Scott 967#	1	
<i>Protea neriifolia</i> R.Br.	Proteaceae	TS	NS		Scott 821#, Milton 1193#, 1194#, 1230#	4	LC
<i>Protea nitida</i> Mill.	Proteaceae	TS	FS		Carter#	1	LC
<i>Protea repens</i> (L.) L.	Proteaceae	TS	NS		Milton 1159#	1	LC
<i>Protea scabra</i> R.Br.	Proteaceae	LS	resprouter		Milton 1164#, 1225#	2	NT
<i>Pseudognaphalium luteo-album</i> (L.) Hilliard & B.L.Burt *	Asteraceae	AH	NS		Isham 84#	1	
<i>Pseudoselago gracilis</i> Hilliard	Scrophulariaceae	PH	?		previously recorded & observed KM	0	LC

<i>Pseudoselago spuria</i> (L.) Hilliard (=Selago spuria)	Scrophulariaceae	PH	?		van Schalkwyk A0#	1	LC
<i>Pseudoselago cf subglabra</i> Hilliard	Scrophulariaceae	AH	NS	x	observed KM	0	LC
<i>Pseudoselago verbenacea</i> (L.f.) Hilliard	Scrophulariaceae	PH	?		Scott 973#	1	LC
<i>Psoralea aphylla</i> L.	Fabaceae	TS	FS		Isham 94#	1	LC
<i>Psoralea imbricata</i> (L.) T.M.Salter	Fabaceae	LS	resprouter	x	observed KM	1	LC
<i>Psoralea monophylla</i> (L.) C.H.Stirt.	Fabaceae	DS	resprouter		Scott 972#, FOT 922	2	LC
<i>Pteronia camphorata</i> L. var. <i>longifolia</i> Harv.	Asteraceae	MS	?		Scott 885#	1	LC
<i>Pterygodium alatum</i> (Thunb.) Sw.	Orchidaceae	GEO	resprouter		Low 5045#	1	LC
<i>Pterygodium cafferum</i> (L.) Sw.	Orchidaceae	GEO	resprouter	x	observed KM	0	LC
<i>Pterygodium catholicum</i> (L.) Sw.	Orchidaceae	GEO	resprouter		Low 5047#	1	LC
<i>Rafnia acuminata</i> (E.Mey.) G.J.Campbell & B.- E.van Wyk (=Rafnia perfoliata E. Mey.)	Fabaceae	LS	?		observed SM	0	LC
<i>Rafnia amplexicaulis</i> Thunb.	Fabaceae	TS	?		Milton 1249#, Scott 791#	2	LC
<i>Restio capensis</i> (L.) H.P.Linder & C.R.Hardy (=Ischyrolepis capensis)	Restionaceae	GRA	resprouter		Isham 66#, 103#	2	LC
<i>Restio distichus</i> Rottb.	Restionaceae	GRA	?		observed SM	0	LC
<i>Restio filiformis</i> Poir.	Restionaceae	GRA	?		observed SM	0	LC
<i>Restio gaudichaudianus</i> Kunth (=Ischyrolepis <i>gaudichaudiana</i> )	Restionaceae	GRA	resprouter		Isham 101#	1	LC
<i>Restio multiflorus</i> Spreng	Restionaceae	GRA	?		Scott 780#	1	LC
<i>Restio paniculatus</i> Rottb. (=Calopsis paniculata (Rottb.) Desv.)	Restionaceae	GRA	resprouter		Milton 1187#	1	LC
<i>Restio sieberi</i> Kunth (=Ischyrolepis sieberi)	Restionaceae	GRA	resprouter		Isham 23#, Milton 1165#	2	LC
<i>Restio triflora</i> Rottb. (=Ischyrolepis triflora)	Restionaceae	GRA	?		Isham 96#	1	LC
<i>Restio triticeus</i> Rottb.	Restionaceae	GRA	?		Isham 75#, 106#	2	LC
<i>Rhynchospora brownii</i> Roem & Schult.	Cyperaceae	GRA	?		Isham 81#	1	LC
<i>Roella ciliata</i> L.	Campanulaceae	LS	NS		Milton 1218#, Scott 841#	2	LC
<i>Romulea cruciata</i> (Jacq) Baker	Iridaceae	GEO	resprouter		Scott 833#	1	LC
<i>Romulea flava</i> (Lam.) M.P.de Vos var. <i>flava</i>	Iridaceae	GEO	resprouter		Scott 843#	1	LC
<i>Romulea rosea</i> (L.) Eckl. var. <i>rosea</i>	Iridaceae	GEO	resprouter		Low 5040#	1	LC
<i>Ruschia rubicaulis</i> (Haw.) L.Bolus	Aizoaceae	DS	?		Milton 1210#; FOT 872	2	VU
<i>Salvia africana-caerulea</i> L.	Lamiaceae	MS	?		Anon#	1	LC
<i>Salvia chamelaeagnea</i> P.J.Bergius	Lamiaceae	MS	FS		Milton 1215#	1	LC
<i>Satyrium bicallosum</i> Thunb.	Orchidaceae	GEO	resprouter	x	observed KM	0	LC

<i>Satyrium bicornis</i> (L.) Thunb.	Orchidaceae	GEO	resprouter		Low 5043#, Scott 857#	2	LC
<i>Satyrium coriifolium</i> Sw.	Orchidaceae	GEO	resprouter		Scott 906#	1	LC
<i>Satyrium lupulinum</i> Lindl.	Orchidaceae	GEO	resprouter	x	FOT 830	1	LC
<i>Satyrium odorum</i> Sond.	Orchidaceae	GEO	resprouter		Milton 1257#	1	LC
<i>Scabiosa columbaria</i> L.	Dipsacaceae	PH	?		Scott 884#	1	LC
<i>Searsia angustifolia</i> (L.) F.A.Barkley (=Rhus angustifolia)	Anacardiaceae	TS	OS		Isham 74#	1	LC
<i>Searsia laevigata</i> (L.) F.A.Barkley var. <i>villosa</i> (L.f.) Moffett (=Rhus laevigata L. var. <i>villosa</i> )	Anacardiaceae	TS	OS		observed SM & KM	0	LC
<i>Searsia lucida</i> (L.) F.A.Barkley (=Rhus lucida)	Anacardiaceae	TS	OS		Isham 69#, 97#	2	LC
<i>Searsia rosmarinifolia</i> (Vahl) F.A.Barkley (=Rhus rosmarinifolia)	Anacardiaceae	LS	OS		Isham 107#, Milton 1162#	2	LC
<i>Searsia tomentosa</i> (L.) F.A.Barkley (=Rhus tomentosa)	Anacardiaceae	TS	OS		Isham 5#	1	LC
<i>Sebaea aurea</i> (L.f.) Roem. & Schult.	Gentianaceae	AH	NS		Scott 869#	1	LC
<i>Sebaea exacoides</i> (L.) Schinz.	Gentianaceae	AH	NS		v Schalkwyk A5#	1	LC
<i>Secamone alpini</i> Schult.	Apocynaceae	TS	?		observed SM	0	LC
<i>Selago corymbosa</i> L.	Scrophulariaceae	LS	?		Scott 963#	1	LC
<i>Selago fruticosa</i> L.	Scrophulariaceae	DS	?		Scott 861#	1	LC
<i>Senecio angustifolius</i> DC.	Asteraceae	LS	NS	x	observed KM	0	LC
<i>Senecio burchellii</i> DC	Asteraceae	LS	?		Low 5072#	1	LC
<i>Senecio elegans</i> L.	Asteraceae	AH	NS		v Schalkwyk A18#	1	LC
<i>Senecio hastatus</i> L.	Asteraceae	PH	resprouter		Milton 1173#, Anon#	2	LC
<i>Senecio lanifer</i> Mart. Ex C. Jeffrey (name unresolved)	Asteraceae	PH	?		Low 5610#	1	
<i>Senecio pinifolius</i> (L.) Lam.	Asteraceae	LS	?		Milton 1204#	1	LC
<i>Senecio pinnulatus</i> Thunb.	Asteraceae	PH	NS		Scott 845#, 992#	2	LC
<i>Senecio pterophorus</i> DC.	Asteraceae	AH	NS		Scott 960#	1	LC
<i>Senecio pubigerus</i> L.	Asteraceae	LS	NS		Isham 20#, Milton 1189#	2	LC
<i>Senecio umbellatus</i> L.	Asteraceae	PH	?		observed SM & KM	0	LC
<i>Silene bellidioides</i> Sond.	Caryophyllaceae	PH	?		Anon#	1	LC
<i>Silene undulata</i> Ait.	Caryophyllaceae	PH	?		Scott 895#	1	LC
<i>Spergula arvensis</i> *	Caryophyllaceae	AH	NS	x	observed KM	0	
<i>Sparaxis bulbifera</i> (L.) Ker Gawl.	Iridaceae	GEO	resprouter		observed SM	0	LC

<i>Sparaxis villosa</i> (Burm f.) Goldblatt	Iridaceae	GEO	resprouter		Scott 832#	1	LC
<i>Spiloxene capensis</i> (L.) Garside	Hypoxidaceae	GEO	resprouter		Scott 811#, 872#	3	LC
<i>Spiloxene schlechteri</i> (Bolus) Garside	Hypoxidaceae	GEO	resprouter		Scott 778#	1	LC
<i>Sporobolus africanus</i> (Poir.) Robyns & Tournay	Poaceae	GRA	resprouter		Scott 838#	1	LC
<i>Stachys aethiopica</i> L.	Lamiaceae	PH	?		Pienaar 48#, Scott 896#	2	LC
<i>Stoebe cinerea</i> (L.) Thunb.	Asteraceae	TS	?		Milton 1200#, 1167#	2	LC
<i>Stoebe fusca</i> (L.) Thunb.	Asteraceae	DS	?		previously recorded	0	LC
<i>Stoebe plumosa</i> (L.) Thunb.	Asteraceae	MS	?		Isham 99#	1	LC
<i>Stoebe spiralis</i> Less.	Asteraceae	LS	?		Isham 93#	1	LC
<i>Teedia lucida</i> Rudolphi	Scrophulariaceae	MS	?		v Schalkwyk A25	1	LC
<i>Tephrosia capensis</i> (Jacq.) Pers.	Fabaceae	DS	resprouter	x	FOT 914	1	LC
<i>Tetaria bromoides</i> (Lam.) Pfeiff.	Cyperaceae	GRA	?		Isham 102#	1	LC
<i>Tetaria ustulata</i> (L.) C.B. Clarke	Cyperaceae	GRA	?		Isham 76#, 97#	1	LC
<i>Thamnochortus insignis</i> Mast.	Restionaceae	GRA			Scott 998#	1	LC
<i>Themeda triandra</i> Forssk.	Poaceae	GRA	resprouter		observed SM & KM	0	LC
<i>Thereianthus spicatus</i> (L.) G.J. Lewis	Iridaceae	GEO	resprouter		Scott 921#	1	LC
<i>Thesium aggregatum</i> A.W. Hill	Santalaceae	LS	?		observed SM	0	LC
<i>Thesium capitatum</i> L.	Santalaceae	DS	NS	x	FOT 798	1	LC
<i>Thesium strictum</i> P.J. Bergius	Santalaceae	MS	NS		Milton 1244#	1	LC
<i>Thesium subnudum</i> Sond.	Santalaceae	MS	?		Milton 1243#, Scott 804#	2	LC
<i>Trachyandra flexifolia</i> (L.f.) Kunth	Asphodelaceae	GEO	resprouter	x	observed KM	0	LC
<i>Trachyandra hirsuta</i> (Thunb.) Kunth	Asphodelaceae	GEO	resprouter		Scott 818#	1	LC
<i>Trachyandra hirsutiflora</i> (Adamson) Oberm.	Asphodelaceae	GEO	resprouter	x	observed KM	0	LC
<i>Trachyandra hispida</i> (L.) Kunth.	Asphodelaceae	GEO	resprouter		observed SM	0	LC
<i>Tribolium hispidum</i> (Thunb.) Desv.	Poaceae	GRA	resprouter		Scott 910#, 949#	2	LC
<i>Tribolium uniolae</i> (L.f.) Renvoize (= <i>Tribolium amplexum</i> )	Poaceae	GRA	resprouter		Milton 1245#, Scott 815#; Low 5153#	3	LC
<i>Trifolium campestre</i> Schreb.*	Poaceae	GRA	?		Scott 907#	1	
<i>Tritonia cf cooperi</i> (Baker) Klatt	Iridaceae	GEO	resprouter		observed KM	0	LC
<i>Tritonia undulata</i> (Burm.f.) Baker (= <i>T. crispa</i> )	Iridaceae	GEO	resprouter		FOT 912	1	LC
<i>Tritoniopsis antholyza</i> (Poir.) Goldblatt	Iridaceae	GEO	resprouter	x	observed KM	0	LC
<i>Tritoniopsis burchellii</i> (N.E.Br.) Goldblatt	Iridaceae	GEO	resprouter		Isham 68#, Scott 968a#	1	LC
<i>Troglophyton parvulum</i> (Harv.) Hilliard & Burt	Asteraceae	AH	NS		Low 5612#, Milton 1252#	2	LC

<i>Ursinia abrotanifolia</i> (R.Br.) Spreng.	Asteraceae	LS	?		Isham 57#, Milton 1236#, Scott 974#	3	LC
<i>Ursinia anthemoides</i> (L.) Poir. subsp. <i>anthemoides</i>	Asteraceae	AH	NS		Low 5071#, Scott 806#, 859#, Milton 1262#	4	LC
<i>Ursinia paleacea</i> (L.) Moench	Asteraceae	LS	NS		Martin 58, Isham 41#, Low 5073#	3	LC
<i>Virgillia oroboides</i> (P.J.Berg.) T.M.Salter	Fabaceae	Tree	NS		Scott 867	1	LC
<i>Viscum capense</i> L.f.	Viscaceae	parasite	NS		observed SM	0	LC
<i>Viscum rotundifolium</i> L.f.	Viscaceae	parasite	NS		observed SM	0	LC
<i>Vulpia</i> sp.*	Poaceae	GRA	?		Scott 925b#	1	
<i>Wachendorfia multiflora</i> (Klatt) J.C.Manning & <i>Goldblatt</i> (=W. <i>parviflora</i> )	Haemodoraceae	GEO	resprouter		Low 5042#	1	LC
<i>Wachendorfia paniculata</i> Burm.	Haemodoraceae	GEO	resprouter		observed SM & KM	0	LC
<i>Wachendorfia thyrsoiflora</i>	Haemodoraceae	GEO	resprouter		Scott 943#	1	LC
<i>Wahlenbergia capensis</i> (L.) A.DC.	Campanulaceae	AH	NS		Scott 929#	1	LC
<i>Wahlenbergia exilis</i> A.DC.	Campanulaceae	AH	NS		Scott 927#	1	LC
<i>Wahlenbergia subulata</i> (L'Hér.) Lammers	Campanulaceae	DS	resprouter	x	FOT 907	1	LC
<i>Watsonia borbonica</i> (Pourr.) Goldblatt	Iridaceae	GEO	resprouter	x	FOT 862	1	LC
<i>Watsonia spectabilis</i> Schinz	Iridaceae	GEO	resprouter	x	FOT 870	1	LC
<i>Wimmerella secunda</i> (L.f.) L.Serra, M.B.Crespo & <i>Lammers</i> (=Laurentia <i>secunda</i> )	Lobeliaceae	PH	?		Isham 86#	1	LC
<i>Wurmbea recurva</i> B.Nord.	Colchicaceae	GEO	resprouter		Milton 1263#	1	LC
<i>Wurmbea spicata</i> (Burm.f.) Dur.	Colchicaceae	GEO	resprouter		Anon#	1	LC
<i>Xiphotheca lanceolata</i> (E.Mey.) Eckl. & Zeyh.	Fabaceae	LS	NS		Scott 860#	1	EN
<i>Xiphotheca tecta</i> (Thunb.) A.L.Schutte & B.-E.van Wyk	Fabaceae	MS	resprouter		Low#	1	LC
<i>Xyris capensis</i> Thunb.	Xyridaceae	PH	?		Isham 83#	1	LC
<i>Zaluzianskya capensis</i> (L.) Walp.	Scrophulariaceae	AH	NS		Milton 1237#, Scott 785#	2	LC
<i>Zaluzianskya divaricata</i> Walp.	Scrophulariaceae	AH	NS		Scott 807#	1	LC
<i>Zaluzianskya pusilla</i> (Benth.) Walp.	Scrophulariaceae	AH	NS		Milton 1256#	1	LC
<i>Zantedeschia aethiopica</i> (L.) Spreng.	Araceae	GEO	resprouter		observed SM	0	LC
<i>Zygophyllum fulvum</i> L.	Zygophyllaceae	LS	FS		Isham 100#, 135#	2	LC
<i>Zygophyllum sessilifolium</i> L.	Zygophyllaceae	DS	?		observed SM	0	LC