EFFECTS OF STRATIFICATION ON THE GERMINATION OF SIX PIEDMONT ROCK OUTCROP SPECIES AND DEVELOPMENT OF A MODEL PIEDMONT ROCK OUTCROP HABITAT GARDEN

by

SUZZANNE CLAYTON TATE

(Under Direction the of James M. Affolter)

ABSTRACT

Rock outcrops occur in the piedmont of the southeastern United States and support a unique flora. Seeds of six outcrop species were subjected to temperature fluctuations in order to break dormancy and induce germination. Fresh seeds were exposed to warm (35/20^{o}C), cold (8^{o}C) or warm plus cold stratification periods of varying lengths. Seeds were then moved to temperatures representing those of spring and/or fall (18/10^{o}C) and germination observed. Warm plus cold stratification was the most effective for inducing germination in the species whose seeds ripened during the summer or late summer and early fall months. Cold germination was necessary for germination in the species whose seeds ripened during the fall months. A piedmont rock outcrop habitat garden offers schools the opportunity to showcase the beauty and diversity of outcrop vegetation and to communicate the importance of protecting this ecosystem as a home for these unique plants.

INDEX WORDS: granite outcrops, rock outcrops, dormancy, germination, habitat garden

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DEDICATION

To my husband Michael whose love is unfailing.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Introduction

The Piedmont region of the eastern United States is a band of gently rolling hills sandwiched between the steep Appalachian mountain range and the flat Coastal Plain. Granitic rock outcrops of various sizes and shapes occur in the southern piedmont from Virginia into central Alabama (Godfrey 1997). They support a unique flora that includes numerous endemic and endangered species (Wyatt and Allison 2000). It is estimated that they compose approximately 8,000 acres total with about 6,000 of those acres falling within the state of Georgia (McVaugh 1943). Usually the outcrops are either "flat-rocks", whose topography nearly matches that of the surrounding area, or "mountains" reaching 200 meters or more in height. They can be quite small, measuring a few hundred square feet, to rather large covering several hundred acres. Outcrops vary in rock type being composed of granite, gneiss, or quartzite, and are high in silica and aluminum and low in iron and magnesium. This is a distinctly different composition compared to rocks found in the Appalachian Mountains to the west (Wharton 1978). Geologic evidence suggests that at least 150 million years ago the piedmont province contained bare rock expanses (Wyatt 1997). However, individual outcrops may be much younger as erosion cycles uncovered new outcrops and covered existing ones (Burbank and Platt 1964, Murdy 1968, Wyatt and Fowler 1977).

The piedmont province is described as one of America’s most densely populated regions (Godfrey 1997) and human activity is threatening the outcrop communities. The moderating influences of surrounding forests on the extreme conditions on the outcrops are lost when forests are cleared for subdivisions and businesses. Outcrops are attractive locations for outdoor activities like hiking and bike riding but foot and wheel traffic damage the fragile outcrop soils and can completely kill lichens and mosses that grow on the bare rock surface (Wyatt and Allison 2000). Granite mining is an important industry in Georgia and according to Quarterman et al. (1993) there are twenty-two active quarries in the Atlanta metro area alone. Remote or privately held smaller outcrops are often used as dumping grounds for household trash, old appliances and even abandoned vehicles. Air pollution and acid rain pose significant problems to the non-vascular community in particular (Quaterman et al. 1993). The combined result of these pressures is that this habitat is becoming severely degraded or is disappearing altogether (Quarterman et al. 1993, Wyatt and Allison 2000).

Objectives

Understanding the biology of the rock outcrop species is the first step towards their effective management and conservation (Hilton and Boyd 1996). Understanding dormancy patterns and ways to induce germination not only will add to the general knowledge about outcrop ecology but will also aid in the restoration of damaged outcrops and provide information for the conservation of relatively undamaged sites. The objectives of this investigation were to study the effects of warm and cold stratification on the germination response of six piedmont outcrop species and to develop protocols for building and maintaining a piedmont rock outcrop habitat garden. The creation of outcrop habitat gardens offers institutions like nature centers, botanical gardens, and schools the opportunity to educate the public about the importance of protecting the vulnerable outcrop plant community in particular and plant conservation in general.

Piedmont Rock Outcrop Ecology

The environmental conditions on the outcrops are quite different than those encountered in the surrounding mosaic of oak/hickory/pine forest. The Piedmont region is characterized by warm summers averaging between 22-27°C, cool winters averaging between 5-10°C and rainfall of over 100 cm annually (Wyatt and Allison 2000). The high light environment and the heat absorbing capacity of the rocks results in temperatures that can surpass 50°C during the summer months. Rainfall runs off at an extraordinarily high rate (Wyatt and Allison 2000). Not surprisingly, outcrop vegetation varies significantly from that of the adjacent plant communities and exhibits a high degree of endemism (Wyatt and Fowler 1977). Wyatt (1997) compares the piedmont outcrops to an “archipelago” of desert islands in a “sea” of otherwise mesic conditions. Many authors (Murdy 1968, Sharitz and McCormick 1973, Quarterman et al. 1993, Shure 1999) describe the area just east of Atlanta, Georgia as the geographic center of piedmont outcrops as well as the center of endemism for piedmont outcrop flora. Ten endemic species are found here, with eight endemics found on the most southwestern outcrops in Alabama and none in the most northeastern reaches of the piedmont outcrops in Virginia (Murdy 1968). A peculiar endemic found on the outcrops is *Amphianthus pusillus.* Occurring only in temporary pools of specific dimensions and soil depth, it produces one flower at its base under water and one flower floating on the surface of the water (Murdy 1968, Hilton and Boyd 1996). Although *Amphianthus* is a monotypic genus, Wyatt and

Allison (2000) suggest a probable phylogenetic link to other genera occurring on granite outcrops in both Australia and Africa. Another monotypic genus, *Diamorpha*, is a major constituent of the outcrop flora.

The piedmont is between two distinct physiographic provinces- the Appalachian Mountains and the Atlantic coastal plain. The geographic ranges of flora from both provinces overlap in the piedmont making an ideal situation for hybridization between species (Murdy 1968, Wyatt and Fowler 1977, Shure 1999, Wyatt and Allison 2000). This is particularly true on rock outcrops due to the extreme environmental conditions which occur there and the presence of distinct microhabitats. Both Murdy (1968) and Wyatt (1997) discuss the genetic evidence for the role outcrops play in the evolution of new species or varieties. Murdy (1968) indicates that *Phacelia dubia* "is presently in the act of speciation" and has produced *Phacelia dubia* var. *georgiana,* which is found only on piedmont rock outcrops. *Cyperus granitifolia,* also an outcrop endemic, is reported to have arisen from the more commonly distributed *Cyperus aristatus* (Murdy 1968). Wyatt and Allison (2000) suggest that some plants may have "perfected" their ability to grow in shallow sandy soil when living on the outcrops and then spread into the coastal plain by out-competing species already growing there or vice versa. It is clear however that many plants endemic to or associated with the piedmont outcrops are most closely related to species found in deserts of northern Mexico and the southwestern United States (McVaugh 1943, Braun 1955). Braun (1955) argues that during a warmer and dryer time in the Tertiary period these western species underwent range expansion into the piedmont via the Ozark Plateau and then found refuge on the existing outcrops once the climate in the Southeast became cooler and moister.

Clearly the outcrops are worthy of continued inquiry based on their flora alone, but other branches of science could also benefit from studying them. Several endemic invertebrates including the Rock Grasshopper (*Trimerotrophis saxatillis*) and the Stone Mountain Fairy Shrimp (*Brachinella lithaca*) live on the outcrops. *Brachinella lithaca* was last documented in the wild in the 1950's but is rumored to still exist. The principles of primary and secondary succession as well as soil formation are clearly demonstrated on outcrops (McVaugh 1942, Wyatt 1997, Wyatt and Fowler 1977, Wyatt and Allison 2000). Plant and animal relationships such as herbivory and pollination on the outcrops have received little study (Quarterman et al. 1993). Although some taxonomic work has been completed on outcrop species' relationships to each other and to the surrounding vegetation, a large majority remain unrevised using modern taxonomic techniques (Wyatt and Allison 2000). Several authors have studied groups of plants or individual members of the outcrop community, but many species have not yet been carefully investigated.

Piedmont outcrops are not unbroken expanses of bare rock. Irregular weathering of the rock face creates several distinct microhabitats. Shallow depressions containing soil ranging in depth from 2-50 cm are frequently observed. Different plant species or groups of species exploit the varying degrees of soil depth as described by McVaugh (1943) and Burbank and Platt (1964):

Dominant Vegetation Type	**Soil Depth (cm)**
Diamorpha smallii	2-9
Lichen-moss-annual herb	7-15
Annual-perennial herb	14-41
Herb-shrub-small tree	40-50

Often all of these mini-communities can be observed in concentric zones within a single depression. These depressions are generally referred to as soil islands or solution pits. They are often irregularly shaped but can be nearly circular in outline. Crevices in the rocks and talus piles of exfoliated rock also allow for soil to accumulate to various depths. The larger and deeper soil deposits tend to discharge excessive rainwater gradually creating seepage areas where aquatic or semi-aquatic plants can survive. Shallow vernal pools are found on some outcrops and provide additional habitat for aquatic plants (McVaugh 1943). At the edges of the outcrops yet another ecotone occurs as outcrop plants grow in close proximity to species commonly found throughout the piedmont. This microhabitat in particular provides excellent hybridization opportunities (Wyatt and Allison 2000).

Succession on Piedmont Rock Outcrops

Soil formation on the rock surface can begin in two ways. Weathering patterns can create depressions in the rock which catch wind borne and water borne soil particles, or lichens (*Cladonia* spp. and *Parmelia* spp.) and mosses (*Grimmia* spp.) can colonize bare rock and begin to collect soil particles around them (Oosting and Anderson 1939, McVaugh 1943, Burbank and Platt 1964). Either way, once soil depth reaches approximately two centimeters the annual *Diamorpha smallii* (syn. *D. cymosa*) can begin colonization. The presence of *D. smallii* can trap additional soil particles, and decaying plant parts continue to build soil. At approximately seven centimeters, other annuals such as *Arenaria uniflora* (syn. *Minuartia uniflora*) and *Talinum teretifolium* grow along with *Grimmia* spp. and the foliose lichens. The additional plant material accelerates soil deposition, and weathering of the rock under the deepening soil continues (Burbank and

Platt 1964; Wyatt 1997). The third general stage of development occurs when soil depths reach approximately fourteen centimeters. At this depth more annuals such as *Viguiera porteri* and some perennials like *Andropogon* spp. begin to take over. Burbank and Platt (1964) note that the presence of Haircap moss (*Polytrichum* spp.) is a good indication that soils are deep enough to support perennials. They also note that the most diverse collection of herbaceous material occurs in this zone. Shrubs, small trees, or stunted versions of larger trees begin to appear when soil depth reaches forty centimeters. The endemic Georgia Oak (*Quercus georgianus*) can be found in these deeper areas as well as woody species common in the piedmont. The herbaceous component beneath the woody plants is very similar to that of the annual – perennial stage (Burbank and Platt 1964).

Burbank and Platt (1964) and Shure and Ragsdale (1977) reported that certain trends can be identified when moving from the shallowest soils to the deepest soils within solution pits or crevice areas. The cation exchange capacity increases three to five times, and the pH increases slightly from an average of 4.0 to an average of 4.5. Daily soil temperature fluctuations tend to decrease. The soil in the *D. smallii* zones experienced an average 10ºC temperature change in one 24 hour period during August while temperature changes in the lichen-annual zone averaged 6ºC and the annual-perennial zone averaged only a 2ºC change over the same 24 hour period (Shure and Ragsdale 1977). Although Shure and Ragsdale (1977) did not study daily moisture fluctuations, they did study annual moisture fluctuations within each community. They found that the *D. smallii* zones experienced total saturation and total desiccation with regularity while the annual-perennial zone reached total saturation but never fully dried out even during the hottest summer months. Moisture levels in the lichen-annual zone also became saturated, but only occasionally became completely desiccated. These trends in conditions clearly illustrate why different species of plants can be found growing in each soil depth zone.

It is tempting to conclude that succession in the solution pits is generally a straight line from *D. smallii* to the herb-shrub-small tree stage with the latter being the climax community. In fact, each stage can sometimes represent the climax community for a given location (Shure and Ragsdale 1977). Exposed areas and the thinner soils of the *D. smallii* areas are affected more by erosion from wind, water, and frost heave. Over twenty-two years Burbank and Phillips (1983) observed no significant successional advancement in a solution pit made up exclusively of *D. smallii*. Additionally, woody plants in the deepest soils are vulnerable to extended periods of drought. Campbell (1921) observed stands of small trees on Stone Mountain, an outcrop in Lithonia, Georgia, but forty-three years later Burbank and Platt (1964) reported that those trees were no longer there. Entire soil island communities can wash away during severe flooding, leaving bare rock in their place (McVaugh 1943). McVaugh (1943) reports that on most outcrops a general equilibrium is reached between the destruction and construction of solution pit communities.

Adaptations of Rock Outcrop Flora

Wyatt (1997) states that rock outcrop plants, like those commonly found in deserts have evolved mechanisms to cope with the extreme heat, high irradiance and lack of moisture present in the outcrop environment. The annual *Talinum teretifolium* and the cactus *Opuntia humifusa* store water in their succulent leaves. The perennial *Tradescantia hirsuticaulis* is covered with fine grey hairs to reflect light and reduce moisture loss. CAM (Crassulacean Acid Metabolism) is used by several species such as

Sedum pusillum and *Diamorpha smallii*. The long thin leaves of *Viguiera porteri* or reduced leaves of *Hypericum gentianoides* help keep water loss to a minimum. Avoiding drought conditions altogether is also an effective strategy. (Freas and Kemp 1983l; Wyatt 1997; Wyatt and Allison 2000; Schutz et al. 2002). Wyatt (1997) reports that the winter annual life cycle is a very common drought avoidance technique for piedmont rock outcrop species. By germinating in the fall or early spring and then flowering and setting fruit before summer begins, plants survive the hottest and driest months of the year as dormant seeds.

Dormancy and Germination

Many branches of plant science have contributed to our understanding of seed dormancy and germination patterns. It is generally agreed that they are two distinct but obviously related processes, and that germination potential is a function of the state of dormancy. Only a non-dormant seed will germinate and a dormant seed will not germinate. The Association of Official Seed Analysts (AOSA) define germination as “the emergence and development from the seed embryo of those essential structures which for the kind of seed in question, are indicative of the ability to produce a normal plant under favorable conditions” (AOSA 2000). Bewley and Black (1985) state that no biochemical sign for the initiation of germination has been generally accepted, but most germination experiments recognize elongation of the radical as the sign germination has occurred. They go on to state that the elongation of the radical is actually believed to be the last stage of germination and that the actual process begins with the absorption of water and cellular changes initiated by hydration of the seed. Young and Young (1986) recognize four distinct stages of germination beginning with the imbibition of water. They contend that the presence of water activates enzymes that release stored nutrients and initiate the manufacture of necessary materials for cellular division. Once these products are in place, the embryo begins to grow, completing germination by rupturing the seed coat. Baskin and Baskin (1988) disagree and believe that although water must be imbibed for germination to occur, the presence of water inside the seed coat is not necessarily the trigger for the cellular changes generally associated with the germination response.

Many, if not most, apparently mature seeds do not germinate upon release from the mother plant. This condition is known as dormancy and is an adaptation for seeds to delay germination until conditions are favorable for maximum seedling survivorship (Freas and Kemp 1983, Bewley and Black 1985, Baskin and Baskin 1988, Schutz et al. 2002). There is disagreement within the literature as to how to categorize different forms of dormancy (Vleeshouwers et al. 1995). Some focus on the types of cellular responses as well as seed structure to classify kinds of dormancy (Baskin and Baskin 1988), while others classify dormancy based on internal verses external forces in addition to the interaction between them (Bewley and Black 1985, Vleeshouwers et al.1995). Bewley and Black (1985) refer to two distinct forms of dormancy- primary and secondary dormancy, but concede that sometimes they are difficult to distinguish from each other. Vleeshouwers et al. (1995) contend that dormancy is not either “on” or “off” but is rather like a continuum having “a value between all and nothing”.

When a seed is dispersed from the mother plant and is unable to germinate under any environmental conditions, it is said to be in a state of primary dormancy (Bewley and Black 1985, Shutz et al. 2002). In other words something within the seed itself is preventing germination such as an immature embryo or an impermeable seed coat.

Secondary dormancy occurs when mature seeds are exposed to one or more environmental conditions that induce a dormant state (Bewley and Black 1985). This type of dormancy can be released by the right combination of external factors. Water, temperature and light are the main environmental influences on secondary dormancy, but soil chemistry also plays an important role (Bewely and Black 1985, Baskin and Baskin 1988). These elements can work alone or in concert with one another in various combinations to control the level of dormancy experienced by seeds.

The effect of temperature on dormancy and the germination response has been studied extensively with many species and temperature has long been known to be an important controlling factor. Baskin and Baskin (1988) contend that it is the most important influence on dormancy, over moisture and light availability. They go on to say that temperature changes register within seeds as signals of seasonal changes, and therefore indicate favorable conditions for seedling establishment. In their study of the rock outcrop winter annual, *Diamorpha smalli (*syn. *D. cymosa)*, Baskin and Baskin (1972) showed that this species needed a period of warm stratification for optimal germination. Seeds collected upon maturity in June germinated poorly (less than 5%) while those exposed to warm stratification for at least three months germinated to well over 80% (Baskin and Baskin 1988). *Arenaria glabra*, also a winter annual of rock outcrops, exhibited a similar germination response (Baskin and Baskin 1982). Baskin and Baskin (2002) showed that the seeds of the shale barren endemic *Arabis serotina* are dormant upon maturity in the autumn. Germination rates for fresh seeds were negligible. After twelve weeks of cold stratification however, dormancy had been significantly reduced in *A. serotina* as over 70% germination was observed.

Habitat Gardens

A habitat garden can be defined as any garden that represents a naturally occurring plant community. It can be developed for aesthetic appreciation alone or to shelter and feed wildlife (http://www.nwf.org/). Habitat gardens can be used as educational tools and serve as links to the natural world for people who are removed from the cycles of nature in their daily lives. Basic biological and ecological principles as well as the impact of humans on these systems can be illustrated by habitat gardens (http://www.temple.edu/env-stud/seniorsem/section2A.htm).

A piedmont rock outcrop habitat garden would offer institutions such as botanical gardens, nature centers, and schools the opportunity to showcase the beauty and diversity of outcrop vegetation as well as communicate the importance of protecting this ecosystem as a home for these unique plants.

The State Botanical Garden of Georgia currently uses a bog habitat garden as an integral part of its education programs. Classes for the general public use the bog garden to illustrate the importance of protecting ecosystems as a way to protect individual species. Through the Georgia Endangered Plant Stewardship Network (GEPSN), developed by the State Botanical Garden, school children in Georgia build and maintain a bog habitat garden on their school property. The students receive seeds of endangered bog species from GEPSN and either sow them directly into the bog garden or grow them out in the classroom and transplant the full grown plants into the bog garden. GEPSN has developed a unit on rock outcrops for Georgia teachers to use in their classrooms. Based on the bog habitat garden model, a series of activities revolving around rock outcrop ecology and protection have been developed for elementary and middle school students (Jennifer Ceska, personal communication). An on-site piedmont rock outcrop habitat garden will be an integral part of this program.

The purpose of this study was to develop protocols for building a rock outcrop habitat garden suitable for the GEPSN program as well as other interested institutions. The model must fulfill several requirements to be considered successful. It must support a diverse collection of outcrop plants including species that are strict endemics or near endemics as well as other species found in association with the rare outcrop plants. The materials needed to build the garden must be relatively easy to obtain and low in cost. The garden itself should be easy to build, install and maintain. It must be aesthetically pleasing throughout the year and it must be relatively self sustaining.

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CHAPTER 2

EFFECTS OF STRATIFICATION ON THE GERMINATION OF SIX PEIDMONT ROCK OUTCROP SPECIES[1]

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[1] Tate, S.C. and J.M. Affolter. To be submitted to Natural Areas Journal

Abstract

Rock outcrops occur in the piedmont province of the southeastern United States and support a unique flora including several endemic species. Seeds of six rock outcrop species were subjected to temperature fluctuations in order to break dormancy and induce germination. Fresh seeds were exposed to warm (35/20^{o}C), cold (8^{o}C) or warm plus cold stratification periods of varying lengths. Seeds were then moved to temperatures representing those of spring or fall (18/10^{o}C) and germination observed. Warm plus cold stratification was the most effective for inducing germination in the species whose seeds ripened during the summer or late summer and early fall months. Cold germination was necessary for germination in the species whose seeds ripened during the fall months.

Introduction

Rock outcrops of various sizes and shapes occur in the southern piedmont province of the United States. They support a unique flora that includes numerous endemic and endangered species (Wyatt and Allison 2000). Usually the outcrops are either “flat- rocks”, whose topography nearly matches that of the surrounding area, or “mountains” reaching 200 meters or more in height. They can be quite small, measuring a few hundred square feet, to rather large covering several hundred acres. Piedmont outcrops are composed of granite, gneiss, or quartzite, are high in silica and aluminum and low in iron and magnesium (Wharton 1978). Geologic evidence suggests that at least 150 million years ago the piedmont province contained bare rock expanses (Wyatt 1997). However, individual outcrops may be much younger as erosion cycles uncovered new outcrops and covered existing ones (Burbank and Platt 1964, Murdy 1968, Wyatt and Fowler 1977).

The piedmont province is described as one of America's most densely populated regions (Godfrey 1997) and human activity is threatening outcrop communities. The moderating influences of surrounding forests on the extreme conditions on the outcrops are lost when forests are cleared for subdivisions and businesses. Outcrops are attractive locations for outdoor activities like hiking and bike riding but foot and wheel traffic damage the fragile outcrop soils and can completely kill lichens and mosses that grow on the bare rock surface (Wyatt and Allison 2000). Remote or privately held smaller outcrops are often used as dumping grounds for household trash, old appliances and even abandoned vehicles. Air pollution and acid rain pose significant problems to the non-vascular community in particular (Quarterman et al. 1993). The combined result of these pressures is that this habitat is becoming severely degraded or is disappearing altogether (Quarterman et al. 1993, Wyatt and Allison 2000).

The objectives of this investigation were to study the effects of warm and cold stratification on the germination response of six piedmont outcrop species. Understanding dormancy patterns and ways to induce germination not only will add to the general knowledge about outcrop ecology but will also aid in the restoration of damaged outcrops and provide information for the conservation of relatively undamaged sites. Understanding the biology of the rock outcrop species is the first step towards their effective management and conservation (Hilton and Boyd 1996).

The environmental conditions on the outcrops are quite different than those encountered in the surrounding mosaic of oak/hickory/pine forest. The piedmont region is characterized by warm summers averaging between 22-27°C, cool winters averaging between 5-10°C, and rainfall of over 100 cm annually (Wyatt and Allison 2000). The high light environment and the heat absorbing capacity of the rocks result in temperatures that can surpass 50°C during the summer months and rainfall runs off at an extraordinarily high rate (Wyatt and Allison 2000). Irregular weathering of the rock face creates several distinct microhabitats. Shallow depressions containing soil ranging in depth from 2-50 cm are frequently observed and are referred to as solution pits. Different plant species or groups of species exploit the varying degrees of soil depth as described by McVaugh (1943) and Burbank and Platt (1964). The larger and deeper soil deposits tend to discharge rainwater gradually, creating seepage areas where aquatic or semi-aquatic plants can survive. Shallow vernal pools are found on some outcrops and provide additional habitat for aquatic plants (McVaugh 1943). At the edges of the outcrops yet another ecotone occurs as outcrop plants grow in close proximity to species commonly found throughout the piedmont.

Wyatt (1997) compares the piedmont outcrops to an “archipelago” of desert islands in a “sea” of otherwise mesic conditions. Not surprisingly, outcrop vegetation varies significantly from that of the adjacent plant communities and exhibits a high degree of endemism (Wyatt and Fowler 1977). Wyatt (1997) states that rock outcrop plants, like those commonly found in deserts have evolved mechanisms to cope with the extreme heat, high irradiance and lack of moisture present in the outcrop environment. Avoiding drought conditions altogether is also an effective strategy. (Freas and Kemp 1983l; Wyatt 1997, Wyatt and Allison 2000, Schutz et al. 2002). Wyatt (1997) reports that the winter annual life cycle is a very common drought avoidance technique for piedmont rock outcrop species. By germinating in the fall or early spring and then flowering and setting fruit before summer begins, plants survive the hottest and driest months of the year as dormant seeds.

Many branches of plant science have contributed to our understanding of seed dormancy and germination patterns. It is generally agreed that they are two distinct but obviously related processes, and that germination potential is a function of the state of dormancy. Only a non-dormant seed will germinate and a dormant seed will not germinate. Many, if not most, apparently mature seeds do not germinate upon release from the mother plant. This condition is known as dormancy and is an adaptation for seeds to delay germination until conditions are favorable for maximum seedling survivorship. (Freas and Kemp 1983, Bewley and Black 1985, Baskin and Baskin 1988, Schutz et al. 2002). There is a general disagreement within the literature as to how to categorize different forms of dormancy, but Vleeshouwers et al. (1995) contend that dormancy is neither “on” or “off” but is rather like a continuum having “a value between all and nothing”

When a seed is dispersed from the mother plant and is unable to germinate under any environmental conditions, it is said to be in a state of primary dormancy (Bewley and Black 1985, Shutz et al. 2002). In other words something within the seed itself is preventing germination such as an immature embryo or an impermeable seed coat. Secondary dormancy occurs when mature seeds are exposed to one or more environmental conditions that induce a dormant state (Bewley and Black 1985). This type of dormancy can be released by the right combination of external factors. Water, temperature and light are the main environmental influences on secondary dormancy, but soil chemistry also plays an important role (Bewely and Black 1985, Baskin and Baskin 1988). These elements can work alone or in concert with one another in various combinations to control the level of dormancy experienced by seeds.

The effect of temperature on dormancy and the germination response has been studied extensively with many species and has long been known to be an important controlling factor. Baskin and Baskin (1988) contend that it is the most important influence on dormancy, over moisture and light availability. They go on to say that temperature changes register within seeds as signals of seasonal changes, and therefore indicate favorable conditions for seedling establishment. In their study of the rock outcrop winter annual, *Diamorpha smalli (*syn. *D. cymosa)*, Baskin and Baskin (1972) showed that this species needed a period of warm stratification for optimal germination. Seeds collected upon maturity in June germinated poorly (less than 5%) while those exposed to warm stratification for at least three months germinated to well over 80% (Baskin and Baskin 1988).

Materials and Methods

The six species chosen for this study represent plants growing in the different soil depth zones or microhabitats present on rock outcrops. They are either annuals or perennials, come from five different plant families and are either endemic, nearly endemic or are associates of the outcrop plant community. The associate plants are found throughout the piedmont in areas of thin or degraded soil. These characteristics are summarized in Table 2.1.

All seeds used in these studies were collected from two outcrops in Lithonia, Georgia (33.712 N, 84.105 W): Davidson-Arabia County Park and an outcrop located on private property. Davidson- Arabia was scouted every week to ten days to monitor the phenology of each species during the months of April through November 2004. The private outcrop was visited three times during September and October of 2004 to monitor and collect *Aster avitus* seeds. Permission to collect seeds was obtained from the Park Manager of Arabia-Davidson County Park and from the landowner of the private outcrop. *Juncus georgianus* was collected on June 29th, *Lindernia monticola* on July 20th and 30th, and *Hypericum gentianoides* on September 3rd. *Crotonopsis elliptica* was collected on September 19th, October 1st, and October 26th. *Viguiera porteri* and *Aster avitus* were collected on October 22nd and November 6th respectively.

Upon collection, seeds of all six species were cleaned (using a dissecting microscope for the very small seeds) and stored at room temperature. Within two to four days of collection, germination experiments began. The summer group (*Juncus georgianus, Lindernia monticola,* and *Hypericum gentianoides*) was exposed to a total of three temperature regimes simulating spring and/or fall (18/10ºC), summer (35/20ºC), and winter temperatures (8ºC). The fall group (V*iguiera porteri* and *Aster avitus)* was exposed to two temperature regimes simulating winter (8ºC) and spring and/or fall temperatures (18/10ºC). The intermediate *Crotonopsis elliptica* produced seeds at the end of the summer and into early fall, so it received the treatments for both the summer group and the fall group. Lots of *J. georgianus, H. gentianoides, V. porteri* and *A. avitus* each contained four replications of 50 seeds each. *Lindernia monticola* lots contained four replications of 30 seeds each. Lots of *C. elliptica* contained between 15 to 25 seeds per replication (four replications total) due to the relatively low rate of seed production for this species.

To test the germination response of fresh, unstratified seeds, one lot of each species was sown on filter paper moistened with distilled water in petri dishes and sealed with parafilm. The dishes were placed in an incubator with a twelve hour photoperiod and corresponding light and dark temperatures of 18/10°C. Light was provided by flourescent bulbs with an overall average intensity of 24.5 μmolsm^{-2} s^{-1}. Every other day each petri dish was opened and germinated seeds were counted and discarded. The emergence of the radical defined germination (Baskin and Baskin 1988). The filter paper was remoistened with distilled water if needed while the plates were open. The plates were then resealed with parafilm and returned to the incubator for a total of sixteen days.

All seeds of the summer group as well as the intermediate species *C. elliptica* received warm treatments of varying lengths based on time of collection. Seeds were sown dry (with the exception of *H. gentianoides* which is discussed below) in petri dishes, sealed with parafilm, and placed in a growth chamber with a twelve hour photoperiod and corresponding light and dark summer temperatures of 35 and 20°C. Light was provided by fluorescent bulbs with an overall average intensity of 252.7 μmolsm^{-2} s^{-1}. After the desired weeks of warm stratification, enough seeds for two lots were removed from warm stratification, sown onto filter paper moistened with distilled water in petri dishes, and sealed with parafilm. One lot was placed in the incubator (spring and fall temperatures of 18/10°C) and germinated seeds were counted using the above mentioned procedure. The second lot was placed in a cooler for eight weeks at 8°C in darkness. Every ten to fourteen days each plate was opened, the filter paper remoistened if necessary, and any moldy seeds removed. The plates were then resealed with parafilm and returned to cold stratification. If germination had commenced during the cold treatment, germinated seeds were counted and discarded every other day until the scheduled end of the cold period. After eight weeks all lots were moved to the spring/fall incubator and germination counted for sixteen days. This entire procedure was repeated after four, eight, twelve, and sixteen weeks for *J. georgianus,* four, eight and twelve weeks for *L. monticola*, four and eight weeks for *H. gentianoides* and four weeks for *C. elliptica* (see Figure 2.1).

Hypericum gentianoides seeds were sown in two batches for their warm stratification periods. This species was particularly prolific and the great number of seeds available allowed for the additional treatment of watering the seeds during the warm stratification periods. Half the seeds were sown dry in petri dishes and sealed with parafilm. The other half were sown in petri dishes and wetted with enough distilled water to cover the seeds (approximately 20 ml) at the beginning of the warm treatment and then again every two subsequent weeks during the warm stratification periods. The covers of the petri dishes were replaced but not sealed with parafilm. Both the “watered” and the “unwatered” seeds then proceeded through the above mentioned sequence of trails.

In addition to the 18/10ºC control treatment described above, seeds of the fall group, *V. porteri* and *A. avitus,* were exposed to three periods of cold stratification: four, eight, and eleven (*A. avitus*) or twelve weeks (*V. porteri*). (Originally *A. avitus* was scheduled to receive twelve weeks of cold stratification also, but a power failure in the cold incubator forced an early transfer of the *A. avitus* seeds to the spring/fall incubator.) Three lots of each species were sown on filter paper moistened with distilled water in petri dishes, sealed with parafilm, and placed in a cooler at 8°C in the dark. The fall group was monitored during cold stratification by the same procedure as described above for the summer group. After each period of cold stratification, one lot of each species was moved to the incubator under the spring/fall conditions and germination counted every other day for sixteen days (see Figure 2.2).

The intermediate species, *Crotonopsis elliptica*, received an additional treatment due to its long period of seed production (nearly six weeks). One lot received no warm stratification at all and only an eight week cold stratification. This species was also monitored during cold stratification as with the spring and fall groups. After these eight weeks, the seeds were moved to the spring and fall incubator and germination counted as with the other species (see Figures 2.1 and 2.2).

An imbibition test was performed for *C. elliptica*, *V. porteri*, and *A. avitus* to determine if their seed coats were permeable to water. Within four days of collection, seeds were weighed dry and then allowed to soak in distilled water for twenty-four hours, blotted dry and weighed again. All three species had four replications with either one hundred seeds per replication (*V. porteri* and *A. avitus*) or sixty seeds per replication (*C. elliptica*). The seeds of *J. georgianus*, *L. monticola*, and *H. gentianoides* were too small (less than 0.5 mm long) to perform this test with acceptable accuracy.

The collection protocols and sequence of temperature trials for all six species were modeled on the procedures developed by Baskin and Caudle (1967), Baskin and Baskin (1988), Deno (1983) and Carol Baskin (personal communication 2004). A two way analysis of variance was used to determine significant differences in treatments for the summer group and a one way analysis of variance was used for the fall group. Differences between means were determined by a Tukey-Kramer comparison. Data were arcsin transformed before analysis as indicated by Shutz et al. (2002).

Results

Summer Group

Germination percentages for *Juncus georgianus* were below 5 % for all treatments except the two sixteen week warm storage trials. A significant interaction was found between the warm and cold treatments ($p < 0.01$). The sixteen weeks warm (35/20ºC) plus eight weeks cold treatment (8ºC) yielded nearly three times the germination rate as the warm treatment alone, but still only about a third of the seeds germinated (29.5 ± 1.7 %) (see Table 2.2 and Figure 2.3). Warm treatment alone did not induce more than 6.6 ± 1.2 % germination in *Lindernia monticola.* However, combining the warm and cold treatments had a significant effect on germination percent ($p < 0.01$). In the cold stratified group, germination increased from the four week warm period (13.2 ± 2.8 %) to the eight week warm period (47.3 ± 1.3 %), but no significant increase in germination rate occurred by exposing the seeds to an additional four week period of warm storage (48.8 ± 1.3 %) (see Table 2.2 and Figure 2.3).

Nearly half of the *Hypericum gentianoides* germinated in the control group (46.5 ± 6.4 %). Within the "unwatered" group, germination percents for four weeks of warm stratification did not vary significantly from the control group (see Table 2.2 and Figure 2.4). The addition of cold stratification to four weeks warm did increase germination by approximately 12 %. Eight weeks of warm stratification alone as well as eight weeks warm plus eight weeks cold did not produce significantly different germination rate from that of the four weeks warm plus eight weeks cold treatment (see Table 2.2 and Figure 2.4). Within the "watered" group, the effect of adding a cold treatment to a warm treatment was highly significant ($p < 0.01$) (see Table 2.2 and Figure 2.4). When comparing total germination percentages between the "unwatered" and the "watered" groups, the addition of water during both the warm treatment periods (four weeks and the eight weeks) reduced total germination for seeds that received only warm treatments. It increased germination rates for seeds receiving the warm plus the cold treatments (at both the four and the eight week level of warm treatment). Germination began during cold stratification for all the "unwatered" and the "watered" for both the warm treatment levels. The "watered" group germinated faster and to a greater extent during the cold treatments than did the "unwatered" group (see Figure 2.4).

Intermediate and Fall Groups

Both the control group and the four weeks warm treatment yielded no germination for the intermediate species *Crotonopsis elliptica*. The highest germination rate occurred with the addition of a cold treatment following four weeks of warm treatment (78.5 ± 8.8 %), but an eight week cold treatment alone (no warm stratification period) induced only 20.0 ± 6.2 % to germinate (see Table 2.3 and Figure 2.4). Cold stratification did have a strongly significant effect on the germination percentage for *Viguiera porteri* ($p < 0.01$). The twelve week cold storage period resulted in the highest germination rate, but still only about half of the seeds germinated. Four week cold storage only induced a small percentage of seeds to germinate (4.0 ± 0.5 %). Increasing the cold storage to eight weeks did increase germination percentage, but only to roughly one quarter of the total seeds treated (see Table 2.4 and Figure 2.5). *Aster avitus* germinated well at all three cold stratification periods and the effect of the treatments were shown to be significant relative to the control ($p<0.01$). During the final three weeks of the eleven week cold treatment, nearly sixty percent of *A. avitus* seeds germinated. No germination occurred during the other cold treatment periods (see Table 2.4 and Figure 2.5).

All three species that were tested for imbibition did absorb water. *Crotonopsis elliptica* experienced an 18.0 % increase in weight while *V. porteri* and *A. avitus* increased in weight by 37.3 % and 98.9 % respectively.

Discussion

Shutz et al. (2002) report that the average length of dormancy a seed experiences generally corresponds with the length of the inauspicious season it is exposed to in its natural habitat. In this investigation fruit maturation time was a good indicator for stratification times needed to break dormancy and induce germination in the six piedmont rock outcrop species studied. *Juncus georgianus* seeds ripen in late June and early July at the beginning of the hottest and driest time on the rock outcrops. Consequently, a full sixteen weeks of warm stratification was needed to induce a portion of the seeds to germinate. However, germination rates increased with the addition of eight weeks of cold stratification to the long warm stratification period. As *J. georgianus* reaches the end of the warm season in its natural habitat, dormancy begins to weaken and some seeds gain the ability to germinate during the fall. Dormancy is further weakened during the winter months and a higher percentage of seeds can germinate the following spring. Spreading out germination across time has long been recognized as a strategy to ensure long term survival in unpredictable climates (Rice and Dyer 2001).

Lindernia monticola also needed both the warm and cold stratification combination to weaken dormancy. A dramatic shift in dormancy level was observed between the four week warm (plus cold) stratification to the eight week warm (plus cold) stratification level. Another month of warm treatment did not significantly increase germination even though mature seeds of this species generally experience three months of summer temperatures. This species flowered profusely early in the summer and seeds were collected from this main flush of flowering. However, it was observed that *L. monticola* continued to produce flowers sporadically throughout the rest of the summer. The ability to lose dormancy after two months of warm treatment (plus cold stratification) could allow these "late" seeds to germinate the following spring.

Without water, roughly half of the *H. gentianoides* seeds germinated in the laboratory after four and eight weeks of warm stratification. However, no seedlings of this species were ever observed in the field during the fall. Seeds that received water during warm stratification germinated at 1.0 ± 0.3 % (four weeks) and 11.5 ± 2.0 % (eight weeks). Thus the presence of water at some point or points during the summer seems to inhibit seeds from germinating in the fall.

In the warm plus cold stratification categories, the addition of water during warm treatment increased germination by approximately thirty percent at both the four and eight week levels. However, germination began during the cold treatments for every trial for both the "watered" and the "unwatered" seeds. For the "unwatered" group, one third to one half of the total germination occurred during cold stratification. In the "watered" group, nearly eighty percent of the total germination occurred during cold stratification (See Figure 2.4). However, no seedlings were observed in the field during the winter or early spring. Some other factor must be involved that keeps *H. gentianoides* dormant during the winter months. The most likely candidate is light (Baskin and Baskin 1988). In their natural habitat, seeds of this species would be exposed to strong light conditions throughout the year (Wyatt and Allison 2000). However, soil chemistry could also be a controlling factor (Bewley and Black 1985). Further investigation is needed to clarify what is contributing to dormancy in *H. gentianoides*.

Like *Lindernia monticola, Crotonopsis elliptica* did not exhibit a discreet period of fruit set. Seeds ripened slowly over the course of five to six weeks in the late summer and early fall. In fact, seed maturation slowed significantly in September and was assumed to be coming to an end. However, in late August and September of 2004, the remnants of three hurricanes passed over the Atlanta area. Seed production in *C. elliptica* picked up again in October, presumably in response to the abundant rainfall. These later seeds would not have received any warm stratification, only cold stratification during the upcoming winter. Seeds that received only a cold stratification period in this study germinated at a much lower rate (20.0 ± 6.2 %) than those that were exposed to warm plus cold stratification (78.5 ± 8.8 %). *Crotonopsis elliptica* seeds maturing in the fall can still germinate the following spring, but at a lower rate.

Both *Viguiera porteri* and *Aster avitus* appear to be dormant upon maturity and this dormancy can be relieved with cold stratification. Cold treatment seemed to gradually wear away dormancy in *V. porteri* as each stratification period produced an increasing rate of germination. A majority of dormancy seems to disappear abruptly in *A. avitus* after four weeks of cold treatment. A smaller additional dormancy loss occurred with four more weeks of cold stratification, but beyond eight weeks of cold treatment, no significant increase in germination rate was observed. *Aster avitus* did begin to germinate in the last cold stratification period. Like *Hypericum gentianoides,* another factor such as light may be involved in maintaining dormancy in this species. However, unlike *H. gentianoides*, the time of seedling appearance for *A. avitus* was difficult to determine in this study. Seedlings of *H. gentianoides* are very distinctive where those of *A. avitus* look very similar to other species of *Asters*. Germination during cold temperatures could be the norm for *A. avitus*. Further study is needed to clarify this point.

The imbibition of water has been recognized by Young and Young (1986) as the beginning of the germination process. They contend that the presence of water activates enzymes that release stored nutrients and initiate the manufacture of necessary materials for cellular division. Once these products are in place, the embryo begins to grow, completing germination by rupturing the seed coat. Baskin and Baskin (1988) disagree and believe that although water must be imbibed for germination to occur, the presence of water inside the seed coat is not necessarily the trigger for the cellular changes generally associated with the germination response. Fresh seeds of *Crotonopsis elliptica, Viguiera porteri*, and *Aster avitus* all imbibed water but all three needed exposure to temperature fluctuations for dormancy to be overcome and germination to occur.

The pH of solution pit soil ranges from 4.0-4.5 (Shure and Ragsdale 1977). The acidic nature of these soils could have an influence on seed dormancy such as the weakening of the seed coat. Freeman (1973) reports that the germination rate of *Fouquieria splendens* was clearly affected by pH. Germination rates at a pH of 7.5 were approaching 70%, while germination rates at a pH of 8.5 were less than 10%. However, Barbour (1968) reports that pH had no effect on the germination rate for seeds of *Larrea divaricata*. The pH of the germination medium in this study was neutral. Further study is needed to elucidate the effect of pH on the germination response of rock outcrop species.

When compared to horticultural or agricultural seeds, germination rates for *J. georgianus*, *L. monticola*, and *V. porteri* were low (Hemmerly and Quarterman 1978). However, many species have evolved mechanisms to delay germination beyond the first period of environmentally favorable conditions after seed maturation (Hemmerly and Quarterman 1978, Rice and Dyer 2001). In other words, these species produce seed banks to hedge against a season of catastrophic loss. Bewley and Black (1985) suggest that seeds that do not germinate during that first period of favorable environmental conditions reenter dormancy and temperature fluctuations then release dormancy during the next growing season. Future studies might include additional cycles of warm and cold stratification to investigate if this phenomenon is occurring in *J. georgianus, L. monticola,* and *V. porteri.*

Table 2.1 Species names and attributes

Species	Seed Production Season	Soil Depth or Microhabitat	Annual or Perennial	Family	Level of Endemism
Junucus georgianus	Summer	7-15 cm	Perennial	Juncaceae	Endemic
Lindernia monticola	Summer	Aquatic	Perennial	Schrophulariaceae	Near-endemic
Hypericum gentianoides	Summer	7-15 cm	Annual	Hypericaceae	Associate
Viguiera porteri	Fall	14-41 cm	Annual	Asteraceae	Near-endemic
Aster avitus	Fall	14-41 cm	Perennial	Asteraceae	Endemic
Crotonopsis elliptica	Intermediate	7-15 cm	Annual	Euphorbiaceae	Associate

Table 2.2. Germination percentages (Mean ± SE) for the summer group. Means within a column with the same letter are not significantly different from each other at p = 0.05.

Stratification Times	*J. georgianus*	*L. monticola*	*H. gentianoides* (no water)	*H. gentianoides* (water)
0 weeks (18/10ºC)	1.0 ± 1.0^{a}	5.0 ± 2.5^{a}	46.5 ± 6.4^{a}	46.5 ± 6.4^{a}
4 weeks 35/20ºC	0^{a}	6.6 ± 1.2^{a}	45.0 ± 6.5^{a}	1.0 ± 0.3^{b}
4 weeks 35/20ºC 8 weeks 8ºC	2.0 ± 0.6^{a}	13.2 ± 2.8^{b}	57.5 ± 4.5^{b}	85.5 ± 1.4^{c}
8 weeks 35/20ºC	0.5 ± 0.3^{a}	0^{a}	54.0 ± 5.4^{b}	11.5 ± 2.0^{d}
8 weeks 35/20ºC 8 weeks 8ºC	0^{a}	47.3 ± 1.3^{c}	59.0 ± 5.8^{b}	91.5 ± 1.9^{c}
12 weeks 35/20ºC	3.5 ± 0.5^{a}	1.7 ± 0.83^{a}		
12 weeks 35/20ºC 8 weeks 8ºC	2.5 ± 0.8^{a}	48.8 ± 1.3^{c}		
16 weeks 35/20ºC	10.0 ± 2.6^{b}			
16 weeks 35/20ºC 8 weeks 8ºC	29.5 ± 1.7^{c}			

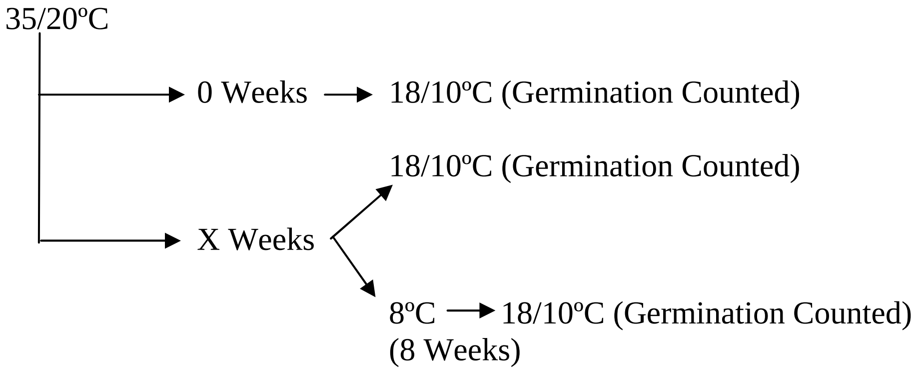
Table 2.3. Germination percantages for *Crotonopsis elliptica.* Means within the row followed by the same letter are not significant from each other at p = 0.05.

Stratification Times	0 weeks 18/10ºC	4 weeks 35/2 ºC	4 weeks 35/2 ºC 8 weeks 8ºC	8 weeks 8ºC
Germination percentages (Mean ± SE)	0^{a}	0^{a}	78.5 ± 8.8^{b}	20.0 ± 6.2^{c}

Table 2.4. Germination percentages (Mean ± SE) for the fall group. Means in the same column followed by the same letter are not significant from each other at p = 0.05.

Stratification Times	*V. porteri*	*A. avitus*
0 weeks (18/10ºC)	0^{a}	4.5 ± 1.6^{a}
4 weeks 8ºC	4.0 ± 0.5^{a}	74.5 ± 0.1^{b}
8 weeks 8ºC	26.0 ± 3.7^{b}	87.5 ± 1.8^{c}
12 weeks 8ºC (*V. porteri*) 11weeks 8ºC (*A. avitus)*	55.5 ± 1.9^{c}	88.0 ± 3.1^{c}

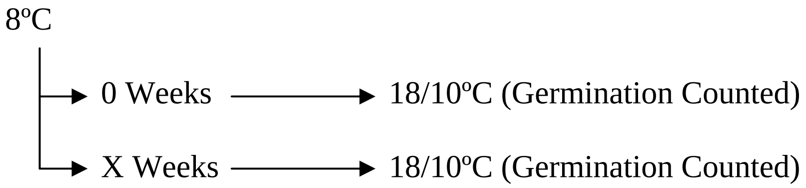
X = 4, 8, 12, or 16 weeks warm stratification



Juncus georgianus	X = 4, 8, 12, and 16
Lindernia monticola	X = 4, 8, and 12
Hypericum gentianoides	X = 4 and 8
Crotonopsis elliptica	X = 4

Figure 2.1 Summer Group Summary of Treatments

X = 4, 8, or 11/12 weeks cold stratification



Viguiera porteri	X = 4, 8, and 12
Aster avitus	X = 4, 8, and 11
Crotonopsis ellitica	X = 8

Figure 2.2 Fall Group Summary of Treatments

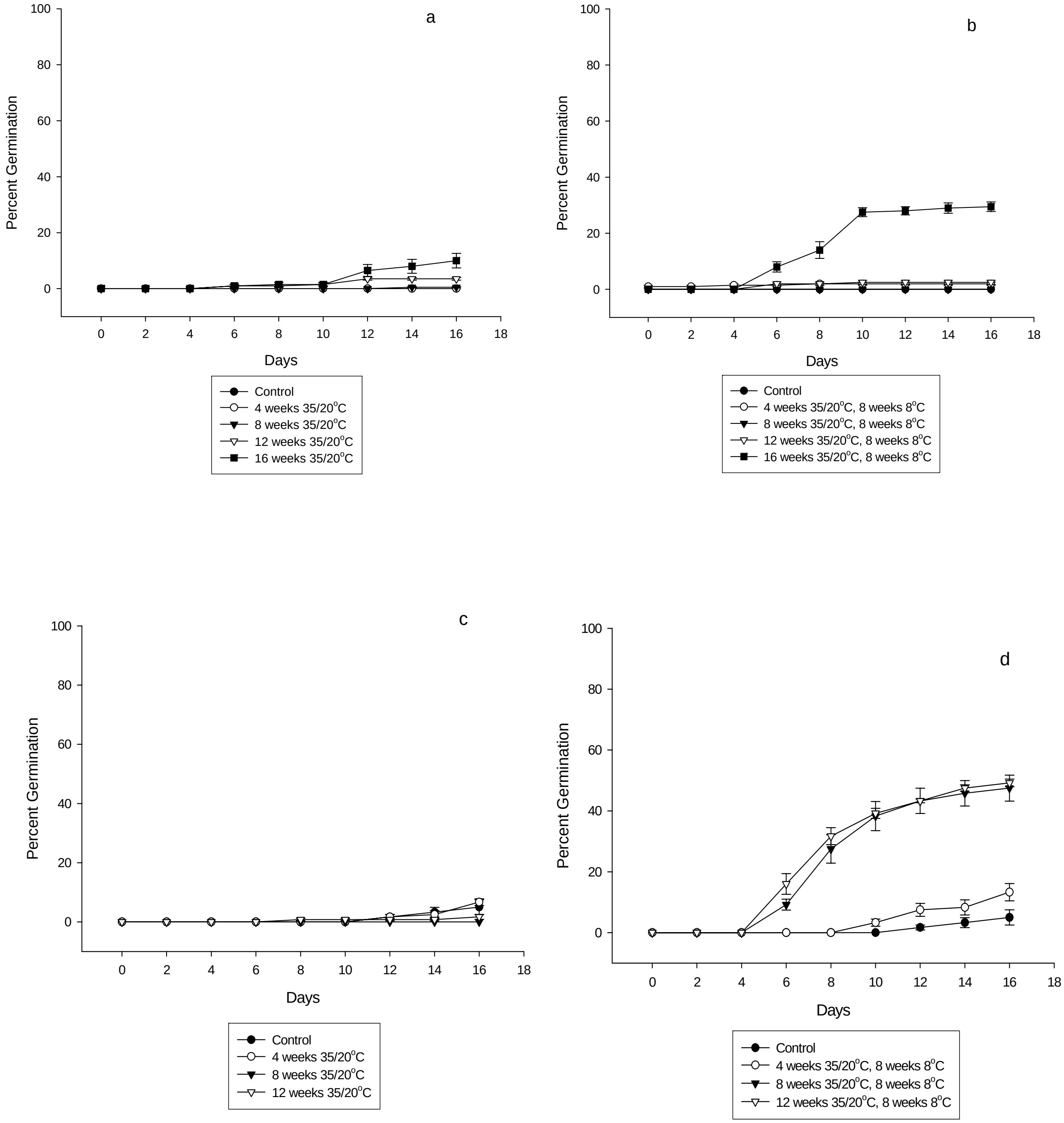


Figure 2.3 Cumulative germination percentages (Mean ± SE) for *Juncus georgianus* and *Lindernia monticola*. (a) *J. georgianus* warm treatments, (b*) J. georgianus* warm plus cold treatments, (c) *L. monticola* warm treatments, (d) *L. monticola* warm plus cold treatments.

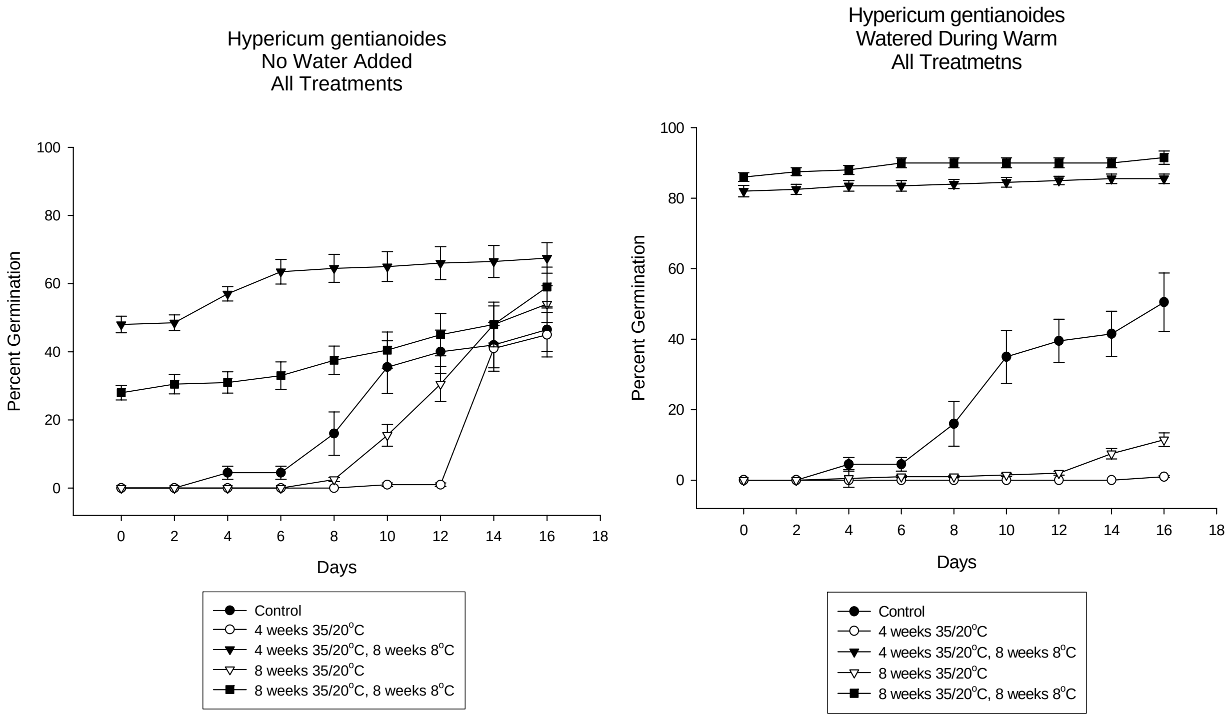


Figure 7. *Crotonopsis elliptica* mean (+/- se) germination percentages for all treatments

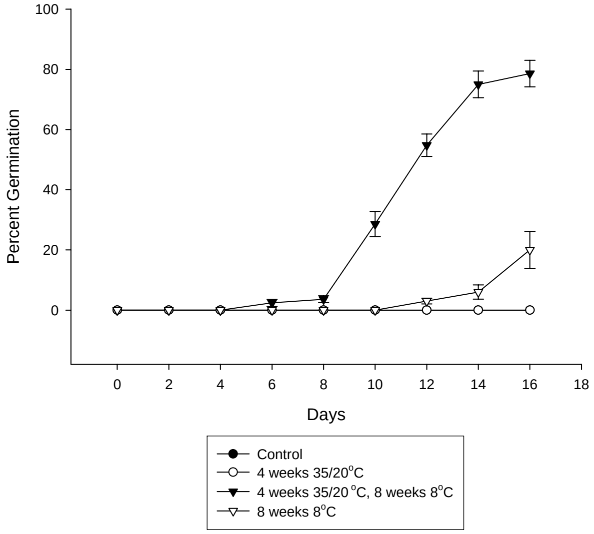


Figure 2.4 Cumulative germination percentages (Mean ± SE) for all *Hypericum gentianoides* treatments: (a) seeds unwatered during warm treatments, (b) seeds watered during warm treatments, and (c) *Crotonopsis elliptica* all treatments.

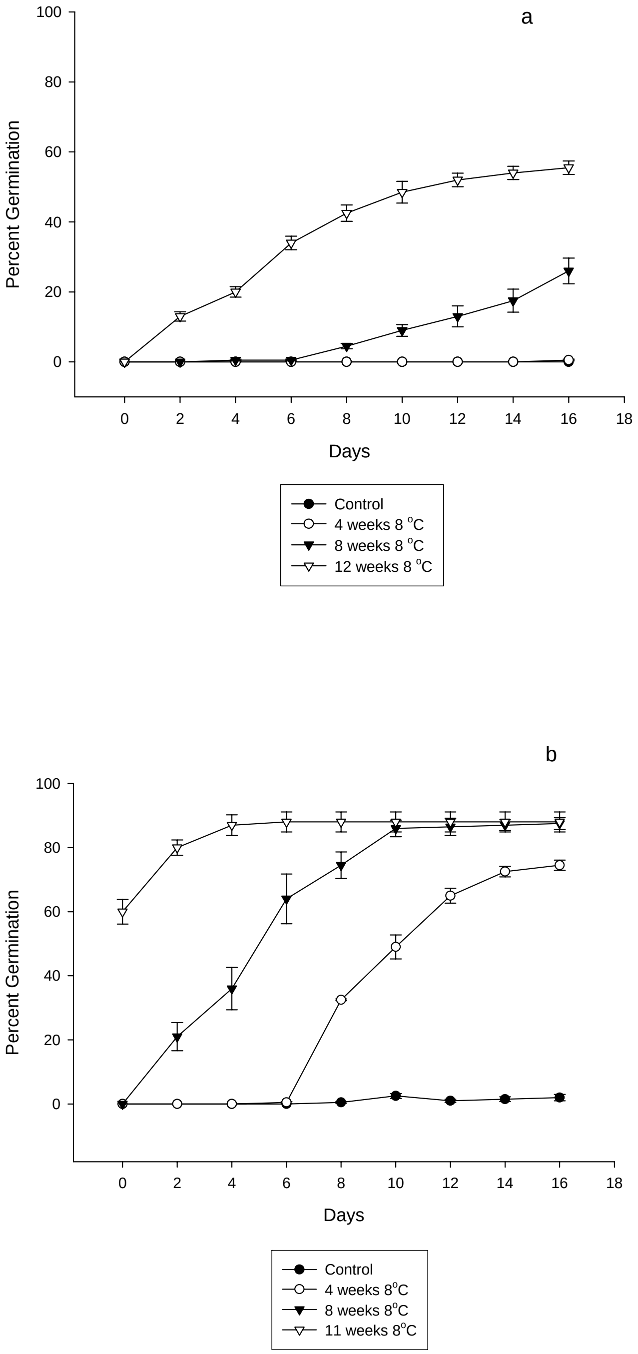


Figure 2.5 Cumulative germination percentages (Mean ± SE) for the fall group (a) *Viguiera porteri* and (b) *Aster avitus*

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CHAPTER 3

THE DEVELOPMENT OF A MODEL ROCK OUTCROP HABITAT GARDEN[1]

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[1] Tate, S.C. and J.M. Affolter. To be submitted to *Tipularia*

Introduction

A habitat garden can be defined as any garden that represents a naturally occurring plant community. They can be quite large, covering many acres to quite small such as a suburban back yard. They can be terrestrial, aquatic, or both. The reasons for creating such a garden are often multifaceted. Habitat gardens can be developed for aesthetic appreciation alone or to shelter and feed wildlife (http://www.nwf.org/). They can be used as educational tools and serve as links to the natural world for people who are removed from the cycles of nature in their daily lives. Basic biological and ecological principles as well as the impact of humans on these systems can be illustrated by habitat gardens (http://www.temple.edu/env-stud/seniorsem/section2A.htm). Larger gardens can easily incorporate all these functions.

A piedmont rock outcrop habitat garden offers institutions such as botanical gardens, nature centers, and schools the opportunity to showcase the beauty and diversity of outcrop vegetation as well as communicate the importance of protecting this ecosystem as a home for these unique plants. Endemism as a function of environmental forces and the ways plants adapt to harsh environments can be observed in the outcrop flora. The geologic history of the piedmont and how rocks weather and erode are clearly demonstrated on rock outcrops. Succession and soil formation are easily discussed in relation to outcrops. Schools can integrate growing plants for the garden as well as building and maintaining it into their math and science curriculums.

The State Botanical Garden of Georgia currently uses a bog habitat garden as an integral part of its education programs. Classes for the general public use the bog garden to illustrate the importance of protecting ecosystems as a way to protect individual species. Through the Georgia Endangered Plant Stewardship Network (GEPSN), developed by the State Botanical Garden, school children in Georgia build bog habitat gardens on their school property. The students receive seeds of endangered bog species from GEPSN and either sow them directly into the bog garden or grow them out in the classroom and transplant the full grown plants into the bog garden. GEPSN has developed a unit on rock outcrops for Georgia teachers to use in their classrooms. Based on the bog habitat garden model, a series of activities revolving around rock outcrop ecology and protection have been developed for elementary and middle school students (Jennifer Ceska, personal communication). An on-site piedmont rock outcrop habitat garden will be an integral part of this program.

The purpose of this study was to develop protocols for building a rock outcrop habitat garden suitable for the GEPSN program as well as other interested institutions. The model must fulfill several requirements to be considered successful. It must support a diverse collection of outcrop plants including species that are strict endemics or near endemics as well as other species found in association with the rare outcrop plants. The materials needed to build the garden must be relatively easy to obtain and low in cost. The garden itself should be easy to build, install and maintain. It must be aesthetically pleasing throughout the year and it must be relatively self sustaining.

Several distinct microhabitats exist within an outcrop plant community based primarily on soil depth (McVaugh 1943, Burbank and Platt 1964). Different species or groups of species exploit the different soil depth zones. Often several or all of the zones can be observed together in one depression in the rock face called a solution pit. Solution pits generally are irregular in outline and depth. Wharton (1978) described an idealized version of a solution pit as a “dish garden” that is circular in outline. The shallowest soil would occur at the edges and gradually deepen towards the center. The habitat gardens built for this study were based on the concept of dish gardens.

Methods and Materials

A total of 14 circular test gardens were built in mid-July 2004 at the University of Georgia Horticulture Farm in Oconee County, Georgia. Each garden measured one meter in diameter and had three depth zones of five, 18, and 40 centimeters. Zone one (5 cm) was 20 cm wide and occupied the outer ring of the circle. Zone two (18 cm) was also 20 cm wide but occupied the next ring towards the center of the circle. Zone three (40 cm) consisted of the remaining 20 cm at the center of each circle. Because outcrop soil is much more porous than that of the surrounding area, special soil mixes were used to back fill the excavated pits. Granite sand and commercial potting soil (Fafard Professional Quality Mix) in three ratios (4:0, 3:1, and 2:2) were used in six of the gardens. Six other gardens used river sand and potting soil (Fafard Professional Quality Mix) in the same ratios. The two remaining gardens received potting soil (Fafard Professional Quality Mix) only. The ratios were measured roughly using a regular garden shovel. For example, a 3:1 ratio garden, three shovels of sand were placed in a large container and then one shovel of potting soil was added, mixed thoroughly and then dumped into the excavated garden. This mixing process was repeated until each garden was full (see Table 3.1).

In addition to testing the soil/sand mixes and potting soil alone, a plastic liner (with a thickness of six mil) was used for half of the gardens. Several small holes were punched in the liner. Water tends to collect in naturally occurring solution pits and drain slowly through small cracks in the underlying rock. Small holes in the liner would mimic these natural conditions (see Table 3.1). A ring of granite rocks was placed around each garden to hold the liner in place, act as a weed barrier, and make the gardens more attractive. Five inches of rough mulch was spread around the gardens also to help control weeds. The gardens were hand weeded regularly throughout the summer and fall of 2004 and again during the spring, summer, and fall of 2005. On two occasions (once in August of 2004 and once in August of 2005) the herbicide Round-Up was sprayed to control difficult to pull grasses that encroached into the mulched area. Stem counts and overall plant vigor were observed and recorded every month beginning in September of 2004 and continuing through November of 2005.

The species used in this project represent a cross section of plants found on rock outcrops. They grow in differing soil depths, come from several plant families, and as a group make an attractive foliage and floral display for most of the year. With the exception of the perennial *Juncus georgianus,* all species were annuals (see Table 3.2). All seeds were obtained during 2004 from Arabia-Davidson County Park in Lithonia, Georgia or from Rock and Shoals Natural Area in Athens, Georgia. Seeds of *Diamorpha smallii, Arenaria uniflora* and *Schoenolirion croceum* were collected in mid to late May and stored at room temperature until mid-July when they were sown into the test gardens. *Juncus georgianus* was collected in late June, stored for three weeks at room temperature, and also sown into the test gardens in mid-July. *Talinum teritifolium* and *Hypericum gentianiodes* were collected in early September and sown within ten days of collection. *Crotonopsis elliptica* was collected in mid-October and also sown into the gardens within one week. Each species was sown into the appropriate soil depth zone in each test garden and watered. No additional irrigation was provided for the test gardens.

For the species with larger seeds (*S. croceum a* and *C. elliptica)*, an equal number of seeds were sown into each test garden. A total of 658 seeds of *S. croceum* and 196 seeds of *C. elliptica* were collected. Into each garden 47 and 14 seeds respectively were sown. The small seeded species (*D. smallii, A. uniflora, J. georgianus, T. teritifolium,* and *H. gentianiodes)* were divided by weight into 14 lots containing an approximately equal number of seeds per lot. One lot of each species was sown into each test garden (see Table 3.3).

Perennials often occupy outcrop soils that are between fourteen and forty centimeters deep (Burbank and Platt 1964). Soil depth zone three (40 cm) of the test gardens was constructed to support the perennial species *Tradescantia hirsuticaulis*. *T. hirsuticaulis* grows in the deeper outcrop soils as well as in the thinner piedmont soils surrounding outcrops. This species was propagated from seeds collected in 2003 from Rock and Shoals Natural Area. Plants were then grown out in the greenhouse in order to plant into zone three during the fall of 2004. However, during the late summer of 2004, the remnants of three hurricanes passed over the Athens, Georgia area. The test gardens were built on relatively flat ground, but the heavy rain associated with the hurricanes resulted in some washing of the test gardens. The decision was made not to plant the T. *hirsuticaulis* for fear of disturbing any of the annual species that might have washed into zone three.

Results and Discussion

Germination percentages were calculated and compared for *Diamorpha smallii, Arenaria uniflora, Juncus georgianus,* and *Talinum teretifolium* (See Table 3.4). The garden(s) with the highest percentage(s) were judged to be most successful. Only a small number of *Crotonopsis elliptica* and *Hypericum gentianoides* germinated in all the gardens combined making numerical comparisons between gardens less meaningful. Plant size and vigor was used to draw conclusions about differences between the test gardens. No seeds of *Schoenolirion croceum* germinated in any of the test gardens. The number of seeds (if any) that washed out of the test gardens during the hurricanes could not be accurately determined.

Diamorpha smalli produced the most seedlings in test gardens # 2 and 3 with 29.0 and 22.2 % germination respectively. Overall, *D. smallii* preferred the river sand mixtures and the presence of a liner. The granite sand gardens did produce some seedlings, but far fewer than the river sand. Gardens # 1 and 2 were favored by *Arenaria uniflora* with 12.2 and 11.1 % germination respectively. This species also preferred the river sand, but not so dramatically as *D. smallii*. The effect of a liner on *A. uniflora* was unclear as lined river sand gardens produced more plants than the unlined ones, but the unlined granite sand gardens produced slightly more plants than the lined granite sand ones. *Juncus georgianus* seemed to prefer the granite sand gardens overall, but did produce some plants in the river sand gardens. The presence or absence of a liner appeared not to affect this species. *Talinum teretifolium* preferred a lining and plain potting soil to any of the sand mixes and produced 20 uncharacteristically large plants (13.8 % germination). The granite sand did support more individuals of *T. teretifolium* than the river sand with a seventy five percent mix yielding thirteen plants of a more typical size. Overall, individual plants of *Diamorpha smalli, A. uniflora*, and *T. teretifolium* flowered well and produced seeds abundantly. Less than one third of the *Juncus georgianus* plants flowered and produced seed.

A total of 15 *Crotonopsis elliptica* plants came up in all the gardens combined (a total germination rate of 2.3 %). They remained quite small (less than 10 centimeters high) in the river sand and did not flower or set fruit normally. They did reach normal size (between 25 and 35 centimeters) in the granite sand gardens and these plants flowered and set fruit. The presence of a liner did appear to inhibit the growth of this species. The individuals in the lined gardens were smaller than the individuals in the unlined gardens. The largest and most floriferous individual of *C. elliptica* grew in garden #8 (100 % potting soil without a liner) and reached over 40 centimeters in height. Like *T. teritifolium*, this species responded quite well to plain potting soil. A total of thirteen *Hypericum gentianoides* plants were counted in all the test gardens combined (an overall germination rate of 3.3%). Nine of those individuals occurred in the unlined granite sand gardens. These individuals were between 15 and 20 centimeters high. The remaining four plants that grew in the lined river sand gardens were between seven and 12 centimeters high. The larger plants produced many more flowers and seeds than the smaller individuals.

Weed and Fire Ant control proved to be a difficult problem at the edges of all the test gardens. Regardless of whether or not a liner affected the performance of the seeds sown into the test gardens, a liner should be used for pest control alone. The liner should be large enough to extend at least two feet beyond the edges of the garden. It should be made of heavier (than the 6 mil) plastic and covered with mulch and rocks to hold it in place. Additionally, the interior of the gardens should be weeded at least every ten days during the growing season and at least once a month during the winter season. To control washing, the gardens should be built on a perfectly flat area of ground or should be enclosed by a berm that will direct excess water around the garden and hold seeds within the confines of the garden.

Plain sand of either type was not as effective as either the 75 or 50 % sand mixes. *Diamorpha smallii* and *Arenaria uniflora* seemed to prefer the river sand mixes while the other species generally preferred the granite sand mixes. Gardens # 2 and 3 were the most aesthetically pleasing during March, April and early May, while *Diamorpha smallii* and *Arenaria uniflora* were in bloom. During late August and September while *Talinum teretifolium*, *Hypericum gentianoides, Crotonopsis elliptica*, and *Telinum teretifolium* were in bloom, gardens # 13, and 14 were the most attractive. Taken as a group, the gardens produced attractive blooming plants for several months out of the year and aesthetically pleasing seedlings for another two months of the year.

Both *Telinum teretifolium* and *Crotonopsis elliptica* grew well in the gardens containing 50% potting soil and quite large in the gardens containing only potting soil. A good compromise for both the spring flowering species and the summer flowering species could be to use an equal amount of both sand types. To prevent excessive growth of either *T. tertifolium* or *C. elliptica*, no less than 50 % sand should be used. The peat moss and perlite present in the potting soil tended to separate out form the sand and formed a layer on top of the gardens. Not only was it unattractive, but once the layer dried out it formed a hard crust that could have inhibited seed germination. Although organic matter is an important component of outcrop soil, commercial potting soil should not be used. Another source such as sterilized top soil should be used instead. A good soil mixture based on these observations would be to use one third river sand, one third granite sand and one third sterilized top soil.

Uniformly mixing sand types and organic matter does not accurately represent the soil matrix found in natural solution pits. Distinct soil profiles can be observed even in the shallowest soils. Organic matter tends to sink to the lower levels while sand tends to reside on the upper levels. This layering could be a factor influencing the survivability of some species. However, constructing different soil levels within the habitat garden adds complications. As one of the goals of this project was to make building a habitat garden relatively easy, the decision was made to not attempt construction of a distinct soil profile.

The construction of the test gardens was relatively easy and the cost remained under twenty dollars per garden. Even with the substitution of a heavier and therefore more expensive liner, the cost per square meter should stay under thirty dollars. All the materials needed to build the garden were obtained easily from local hardware stores. Seeds were easily collected from local outcrops. Schools participating in the GEPSN program will receive seeds from GEPSN. The annual species appeared to produce enough seeds this year to produce plants next year.

In addition to the above mentioned recommendations for building a rock outcrop habitat garden, provisions should be made for watering the garden during particularly dry times. Rainfall during the fall of 2004 as well as the summer of 2005 was higher than normal and the success of the test gardens were surely influenced by this factor. This is true for a dry winter and spring as well as a dry summer. Many outcrop annuals complete their life cycles during the winter and spring months. Without additional moisture they might not produce enough seeds to repopulate the garden the following growing season. This is very important in successive drought years and critical if the garden flora is principally composed of annual species. If at all possible, perennials should also be included to hedge against a season of poor annual seed production, to more accurately represent the outcrop plant community, and to extend the blooming season into the autumn months. A rock outcrop habitat garden should be at least three meters in diameter to accurately display species growing in different soil depths. This additional space would provide room for more species as well as more individuals of each species.

Tables

Table 3.1 Summary of Habitat Garden Sand/Soil Ratios and Liner Usage

Garden	Sand Type	% Sand	% Potting Soil	Liner
1	River	100	0	Y
2	River	75	25	Y
3	River	50	50	Y
4	n/a	0	100	Y
5	River	100	0	N
6	River	75	25	N
7	River	50	50	N
8	n/a	0	100	N
9	Granite	100	0	Y
10	Granite	75	25	Y
11	Granite	50	50	Y
12	Granite	100	0	N
13	Granite	75	25	N
14	Granite	50	50	N

Table 3.2 Summary of species characteristics

Species	Family	Flowering Season	Soil Depth Zone
Diamorpha smallii	Crassulaceae	Early Spring	1
Arenaria uniflora	Caryophyllaceae	Early Spring	1
Schoenolirion croceum	Liliaceae	Spring	2
Juncus georgianus	Juncaceae	Early Summer	2
Hypericum gentianoides	Hypericaceae	Summer	2
Talinum teretifolium	Portulacaceae	Summer and Fall	2
Crotonopsis elliptica	Euphorbiaceae	Summer and Fall	2

Table 3.3 Approximate number of small seeded species per test garden

Species	Total Weight of Collected Seeds(g)	Approximate Number Seeds per Garden
Diamorpha smallii	0.34	220
Arenaria uniflora	2.49	180
Juncus georgianus	2.25	80
Hypericum gentianoides	0.22	30
Talinum teretifolium	0.33	145

Table 3.4 Approximate percent germination per test garden for *Diamorpha smallii, Arenaria uniflora, Juncus georgianus* , and *Talinum teretifolium*

Test Garden	*Diamorpha smallii*	*Arenaria uniflora*	*Juncus georgianus*	*Talinum teretifolium*
1	13.6	12.2	11.3	1.4
2	29	11.1	5	0
3	22.2	5.6	1.3	1.4
4	1.8	0	1.3	13.8
5	3.2	0.6	0	0
6	13.2	2.8	0	4.1
7	13.6	5	0	3.4
8	0	1.6	0	0
9	0.5	0.6	0	1.4
10	3	1.6	0	5.5
11	5	5	7.5	1.4
12	0.5	1.1	6.3	6.2
13	1.4	6.1	11.3	9
14	1.4	4.4	6.3	1.4

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CHAPTER 4

CONCLUSIONS

Germination Study

In this investigation fruit maturation time was a good indicator for stratification times needed to break dormancy and induce germination. *Juncus georgianus* seeds ripened in late June and early July and consequently needed sixteen weeks of warm stratification plus eight weeks of cold stratification to reach its maximum germination rate in this study. The majority of *Lindernia monticola* seeds ripened approximately four weeks later and it was observed that *L. monticola* continued to produce fruit sporadically throughout the rest of the summer. This species reached its maximum germination level at both the eight and twelve week warm (plus eight weeks cold) stratification levels. The ability to lose dormancy after two months of warm treatment (plus cold stratification) could allow the later seeds to germinate the following spring.

The germination patterns for *Hypericum gentianoides* were affected by the addition of water during the warm stratification periods. Without water, roughly half of the *H. gentianoides* seeds germinated in the laboratory after four and eight weeks of warm stratification. However, no seedlings of this species were ever observed in the field during the fall. Seeds that received water during warm stratification germinated at significantly lower rates. The presence of water at some point or points during the summer seems to inhibit seeds from germinating in the fall.

In the warm plus cold stratification categories, the addition of water during warm treatment increased germination at both the four and eight week levels. Germination began during the cold treatments for every trial for both the “watered” and the “unwatered” seeds. However, no seedlings were observed in the field during the winter or early spring. Some other factor must be involved that keeps *H. gentianoides* dormant during the winter months. Further investigation is needed to clarify what is controlling dormancy in *H. gentianoides*.

Like *Lindernia monticola, Crotonopsis elliptica* did not exhibit a discreet period of fruit set. Seeds ripened slowly over the course of five to six weeks in the late summer and early fall. The later seeds would not have received any warm stratification, only cold stratification during the upcoming winter. Seeds that received only a cold stratification period in this study germinated at a much lower rate than those that were exposed to warm plus cold stratification.

Both *Viguiera porteri* and *Aster avitus* appear to be dormant upon maturity and this dormancy can be relieved with cold stratification. Cold treatment seemed to gradually wear away dormancy in *V. porteri* but it seems to disappear abruptly in *A. avitus*. *Aster avitus* began to germinate in the last cold stratification period. As with *Hypericum gentianoides*, another factor could be at work controlling dormancy in *A. avitus*.

Habitat Garden Study

Plain sand of either type (granite or river) was not as effective as either the 75 or 50 % sand mixes. *Diamorpha smallii* and *Arenaria uniflora* seemed to prefer the river sand mixes while the other species generally preferred the granite sand mixes. A good compromise for both the spring flowering species and the summer flowering species could be to use an equal amount of both sand types. Although organic matter is an important component of outcrop soil, commercial potting soil should not be used. Another source such as sterilized top soil should be used instead. A good soil mixture based on these observations would be to use one third river sand, one third granite sand and one third sterilized top soil.

A liner should be used for weed and pest control and should be large enough to extend at least two feet beyond the edges of the garden. It should be made of heavier (> 6 mil) plastic and covered with mulch and rocks to hold it in place. Provisions should be made for watering the garden during particularly dry seasons.

The construction of the test gardens was relatively easy and the cost remained under twenty dollars per garden. Seeds were easily collected from local outcrops and all the materials needed to build the garden were obtained easily from local hardware stores. The annual species appeared to produce enough seeds this year to produce plants next year.