IMPACT OF LARGE MAMMAL HERBIVORY ON THE FEDERALLY THREATENED PLANT, *SCUTELLARIA MONTANA* CHAPM. (LARGE-FLOWERED SKULLCAP) AT AMILITARY TRAINING SITE, CATOOSA COUNTY, GEORGIA

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ABSTRACT

Scutellaria montana Chapm. (Large-flowered skullcap) is a federally listed species endemic to a few counties in northwestern Georgia and southeastern Tennessee. A large population of this species is housed within the Tennessee Army National Guard Volunteer Training Site (VTS) in Catoosa County, GA. To investigate the impacts of large mammal herbivores on this species at the VTS, an exclosure experiment was conducted in the field during 2011 and 2012. Results indicate that deer are not negatively impacting *S. montana* at the individual or population levels, but and after the second season, it was apparent that the white PVC pipe used to construct the exclosure frames attracted deer to plants that were accessible within one of the treatments. Results indicated that deer may also play a positive, indirect role through thinning by reducing resource competition between *S. montana* and other understory vegetation. During 2012, I investigated the effects of disturbances associated with prescribed burning and canopy thinning on impacts of herbivory to *S. montana*. Results did not indicate a significant effect of these disturbances, either singularly or combined, on the impacts of herbivory to *S. montana*. Results are considered preliminary because this research was conducted only during one study season and there were no replicates of treatments. Regarding management of *S. montana* populations at the VTS, it was concluded that current herbivory levels are not threatening the continued existence of *S. montana* there.

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LIST OF ABBREVIATIONS

ANOVA, analysis of variance

B, burned

C, control

FB, fenced burned

FC, fenced control

FT, fenced thinned

FT + B, fenced thinned + burned

GADNR, Georgia Department of Natural Resources

INRMP, Integrated Natural Resource Management Plan

PVC, polyvinyl chloride

SAIC, Science Applications International Corporation

T, thinned

T + B, thinned + burned

TNARNG, Tennessee Army National Guard

UB, unfenced burned

UC, unfenced control

USFWS, United States Fish and Wildlife Service

USGS, United States Geologic Survey

UT, unfenced thinned

UT + B, unfenced thinned + burned

UTC, University of Tennessee at Chattanooga

VTS, Volunteer Training Site

CHAPTER 1

INTRODUCTION

Taxonomy of *Scutellaria montana*

Scutellaria (Lamiaceae) is a large and wide-ranging plant genus comprised of approximately 360 species (Paton 1990). In the New World, *Scutellaria* ranges from the Arctic Circle south to Tierra del Fuego but is absent from the Amazon Basin (Epling 1942; Paton 1990). This genus is most diverse within temperate zones of North America, possibly due to the dislocation of plants during glaciation which caused more frequent production of allopolyploids (Epling 1942). This genus is also distributed throughout the Old World with the exception of lowland tropical Africa, South Africa, the Pacific Islands, the deserts of Central Asia, and lands north of the Arctic Circle (Paton 1990). The name *Scutellaria* was first used by Cortuso (1591, as cited in Paton 1990) and is derived from the Latin s*cutella* meaning 'dish,' which refers to the dish-like scutellum present on the upper lip of the calyx that characterizes members of this genus (Epling 1942; USFWS 2002). Presently, *Scutellaria* species are characterized by a bilabiate corolla with short unequal lips where the lower lip is larger and rounded, stamens inserted under the upper corolla lip, a bilabiate calyx with entire and round lips that close at the mouth in fruit, ovaries elevated on a post-like gynophore, and nutlets that vary in conformation (Epling 1942; Paton 1990). Members of this genus are mostly perennial, rarely annual (Paton 1990) herbs or half-shrubs of intermediate size with small leaves (Epling 1942). Although *Scutellaria* is a genus in the mint family, plants are non-aromatic (Small 1933; Kral 1983; Kemp 1987; Paton 1990).

Technical descriptions of *Scutellaria montana* (Large-flowered skullcap or Mountain skullcap) may differ slightly among authors, but generally this species is presently described as having solitary, erect, square, hairy stems that are 30 to 60 cm tall (Kral 1983; Patrick et al. 1995; USFWS 2002; GADNR 2008). Plants have opposite phyllotaxis, and leaves are ovate- to elliptic- shaped with crenate to serrate margins; leaf blades are 2 to 10 cm long with glandular and eglandular hairs on both surfaces. Leaf pubescence, in particular, is an important identifying feature for this species because there are congeners, such as *S. pseudoserrata*, *S. ovata* and *S. elliptica*, that overlap in their ranges with *S. montana* (USFWS 1996). Although *S. montana* is most likely to be misidentified as *S. pseudoserrata*, *S. montana* has a very soft pubescence of glandular and non-glandular hairs on both surfaces of the leaf whereas *S. pseudoserrata* has sessile glands on the upper leaf surface only, with hairs confined to the veins and leaf margin (Kral 1983; USFWS 1996). To the touch, the leaves of *S. montana* are very soft whereas leaves of *S. pseudoserrata* are noticeably rougher (personal observation). The flowers are also important to the identification of this species because their corollas are among the largest of the genus (Patrick et al. 1995) at 2.6 to 3.5 cm in length (GADNR 2008; USFWS 2002). In addition, the corolla has an erect white tube (GADNR 2008), a pale blue hood-like upper lip, and a pale blue spreading lower lip that has two longitudinal white lines with dark blue borders (Kral 1983; Patrick et al. 1995; GADNR 2008). The inflorescence is a terminal leafy-bract raceme (Kral 1983; USFWS 2002).

In 1878, Chapman (1809-1899) first described *S. montana* from specimens collected on mountains probably near Rome in Floyd County, Georgia (Collins 1976; Kemp 1987; Patrick et al. 1995). Chapman's (1878) original published description of *S. montana* appears as follows:

> *Scutellaria montana*, n. sp. Perennial? tomentose pubescent; stem simple, erect (1-1½ feet high); leaves of the stem and lowest pair of floral ones ovate, or

> oblongovate, coarsely and sharply serrate, acute at both ends, or the lowest subcordate, petioled, the floral ones small, lanceolate, entire; raceme simple, few-flowered; pedicels opposite, rather longer than the calyx; corolla large (1¼-1½ inches long) blue, the ample lower lip nearly as long as the curved upper one — Dry woods and margins of fields in the mountains of Georgia.

Penland (1924) later reduced this species to varietal status as *Scutellaria serrata* Andr. var *montana* (Chapm.) and described it as similar to *S. serrata* but with glandular-pubescent stems and leaves.

In 1942, Epling restored this taxon to species status and his description of *S. montana* included morphological characters similar to those outlined by Chapman; however, Epling emphasized the pubescence on various plant structures. Specifically, Epling (1942) described *S. montana* as having stems with downward-curved capitate-glandular hairs throughout, ovate median leaves with soft straight hairs on both surfaces, and glandular flowering calyces with straight hairs. Epling also described the corolla of *S. montana* as exannulate. A notable detail of Epling's description is that *S. montana* is distinguishable from most other allied species not only by its large exannulate corolla, but also by the pubescence on its lower leaf surfaces and glandular stems. Additionally, Epling (1942) generalized that most of the temperate *Scutellaria* species have underground perennial rhizomes, but does not address this feature for *S. montana* specifically.

Epling (1942) included *S. montana* with 14 other *Scutellaria* species in the section *Annulatae*, which is exclusively North American and primarily distributed in the southeastern United States, although some species range north to New York and Michigan and west to Texas (Collins 1976). Overall, he described this section as being comprised of herbaceous plants that are about 1 m tall and have blue-violet flowers with a hairy annulus within the tube near the calyx orifice. However, Epling described *S. montana* as the only species of this section that is exannulate (i.e., lacks an annulus within the corolla tube). He also observed that flowers of *Annulatae* are mainly uniform in conformation, color, and especially in size. Consequently, Epling (1942) primarily segregated species within this section by leaf habit and pubescence.

In his revision of the *Annulatae* section, Collins (1976) emphasized that all of its members except for *S. montana* possess a villous annulus within the corolla tube near the orifice with the calyx. But, contrary to Epling, Collins described morphological differences between species that do not seem to be limited to any particular parts of the plants. Collins also noted that biological characteristics, such as anthesis, habitat requirements and geographic distribution, could be used along with morphological characteristics to help distinguish between species of this section. In addition, Collins (1976) asserted that six species of the section *Annulatae* do form rhizomes, but contrary to Epling (1942), he specified that *S. montana* is not one of these species. Members of this section that do not form rhizomes perennate by producing short caudices or elongate rootstocks (Collins 1976). Later, Kral (1983) specified that *S. montana* forms a short erect caudex, which gives rise to simple primary roots.

Life History

Both mature *S. montana* individuals that have perenneated as rootstocks and new *S. montana* individuals that have germinated from nutlets released during the previous year exhibit aboveground growth beginning in late March. Generally, plants continue to increase in stem height throughout April, and anthesis occurs between mid-May and early June (Collins, as cited in USFWS 1996). In this long-lived species, plants usually do not produce flowers until they are several years old (Cruzan 2001; GADNR 2008), and then they will produce two to 20 flowers per stem per year (Cruzan 2001), although robust plants may contain up to 70 flowers (personal observation). If pollination occurs, the corolla will shrivel and fall within one or two days later. If the flower is not pollinated, the corolla may remain intact for about five to six days and then fall without shriveling (Collins 1976). Following pollination, the calyx mouth into which the corolla was secured becomes compressed and encloses around the developing fruit, which develop into brown nutlets (Collins 1976). Fruits usually mature in June and early July (USFWS 2002) and during mid-June to mid-July, the upper lip of the compressed calyx falls away releasing the nutlets (Epling 1942; Collins 1976; Collins, as cited in USFWS 1996).

Given that *S. montana* nectar has a sucrose-hexose (sugar) ratio near 50% and flowers feature long floral tubes, it has been suggested that moths or long-tongued bees are likely the primary pollinator of this species (Cruzan 2001). Potential pollinators that have been observed visiting *S. montana* include Hymenopterans of the superfamily Apoidea, such as carpenter bees (*Xylocopa* spp.) and bumble bees (*Bombus* spp.; Johnson 1991), a medium-sized butterfly of the family Hesperildae (King 1992), and various hummingbirds and wasps (GADNR 2008). However, the limited number of actual observations suggests that *S. montana* pollinators may be rare or even lacking (Cruzan 2001). Shared observations of low rates of fruit and/or seed production by this species (Kemp 1987; Stirling, as cited in Kemp 1987; King 1992; Nix 1993; Hopkins 1999; Cruzan 2001) support the idea that *S. montana* experiences limited pollination. But despite observations that suggest pollination and/or seed set may be low in this species, *S. montana* exhibits higher levels of genetic variation than other similar herbaceous perennials (Cruzan 2001). This genetic diversity could be influenced positively by the relatively long lifespans of *S. montana* individuals, relatively high levels of gene flow among populations, persistence of seed banks, and associations with pollinators capable of long-distance dispersal (Cruzan 2001).

Geographic Range and Habitat

Scutellaria montana is an endemic species (Cruzan 2001; Beck and Van Horn 2007) found in the Cumberland Plateau and Ridge and Valley physiographic provinces (Patrick et al. 1995; Bridges, as cited in USFWS 1996). Specifically, known populations occur in four southeastern Tennessee counties (Bledsoe, Hamilton, Marion, and Sequatchie) and nine northwestern Georgia counties (Bartow, Catoosa, Chattooga, Dade, Floyd, Gordon, Murray, Walker, and Whitfield; USFWS 2012). Although this species has not been officially recorded from Alabama, it has been reported anecdotally that populations also may occur there (Patrick et al. 1995; Bridges, as cited in USFWS 1996).

Chapman (1878) originally described *S. montana* as occurring in dry woods and the margins of fields in the mountains of Georgia. Lipps (1966) later described the area from which this species was originally described by Chapman (in Floyd County, Georgia) as a mid- to late-successional forest with oak (*Quercus* L.), hickory (*Carya* Nutt.), and pine (*Pinus* L.) species as the predominant canopy trees. The most common overstory trees occurring in select eastern Tennessee sites containing *S. montana* populations have also been described as oak and hickory species, specifically white oak (*Quercus alba* L.) and pignut hickory (*Carya glabra* (Miller) Sweet), as well as red maple (*Acer rubrum* L.; Mullhouse et al. 2008). The understories of forests where *S. montana* populations occur have been described as sparse (Patrick et al. 1995) with a deciduous shrub layer and some evergreen species, such as blueberries (*Vaccinium* spp.; Bridges, as cited in USFWS 2002). Light availability dictated by canopy and/or understory coverage has been described as an important environmental factor influencing survival and growth of *S. montana* individuals (Nix 1993). In particular, although this species can tolerate moderate shading, it has been reported that plants tend to prefer open areas that are not heavily shaded by canopy and/or understory vegetation (Johnson 1991). In addition, the presence of *S. montana* has been associated negatively with the percent vertical vegetation cover and positively with the horizontal grass cover of forests (Mulhouse et al. 2008).

The soils in which *S. montana* typically grows are shallow, rocky (USFWS 2002; personal observation), and slightly acidic (Lipps and DeSelm 1969; Johnson 1991; USFWS 2002). These soils overlay bedrock composed of sandstone, chert, limestone and shale (Lipps and DeSelm 1969; USFWS 2002). Specifically, these soils overlay the Upper Mississippian limestone and Lower Pennsylvanian sandstones and shales in Tennessee and Georgia (USFWS 1996).

Protection Status and Management

Between the time of Chapman's discovery of *S. montana* in 1878 and 1973, few additional populations of *S. montana* had been discovered. However, between 1973 and 1982, Collins discovered eight populations, increasing the total number of known populations to ten (USFWS 1986). In 1985, the United States Fish and Wildlife Service (USFWS 1986) proposed listing *S. montana* as endangered due to habitat loss/alteration, possible exploitation for commercial use, inadequate regulatory protection, and the potential of population elimination due to natural fluctuations in numbers or human-induced habitat modifications. At that time, there were less than 7,000 known *S. montana* individuals occurring within ten populations – seven in Georgia and three in Tennessee – located solely within the Ridge and Valley Physiographic Province (USFWS 1985). In 1986, citing additional information specific to habitat destruction, the USFWS formally listed *S. montana* as endangered. Following its federal listing, a recovery plan was completed for this species. The overall goal of the plan was to recover and/or protect *S. montana*; specific actions toward meeting this goal included habitat studies, additional population searches, land management, and translocations to be performed or funded by various government entities (USFWS 2000). One of the main objectives outlined in the recovery plan was to downlist and then eventually delist *S. montana* based on evidencing a number of adequately protected and self-sustaining populations. Specifically, downlisting was to be considered when 25 distinct populations or 10 protected and managed self-sustaining populations of *S. montana* distributed throughout its range were known. A population was to be considered self-sustaining if it contained 100 or more individuals (USFWS 1996).

In 2000, it was proposed that *S. montana* be downlisted from endangered to threatened status because the criteria for downlisting described in its recovery plan were met when the number of known populations was 32 and the number of protected, self-sustaining populations was 11 (USFWS 2000). Following the discovery of additional populations and increased protection through ownership by conservation organizations and federal entities, it was ruled in 2002 that the downlisting criteria outlined in the USFWS recovery plan had been sustained. As a result, *S. montana* was officially downlisted to its current threatened status (USFWS 2002). Recovery and protection actions continue for this species with the ultimate goal of delisting it. Delisting *S. montana* from protected status will be considered when there are 15 managed and protected self-sustaining populations of at least 100 individuals maintained for 10 years and distributed throughout its known range (USFWS 1996).

Threats posed to the survival and persistence of this species include inherently low reproductive rates (USFWS 2002), habitat destruction due to development, logging, wildfire, and grazing (USFWS 1996; 2002), competition from invasive plant species (GADNR 2008), and a lack of management information (USFWS 1996). Although the USFWS (2002) report on the reclassification of *S. montana* from endangered to threatened does not list deer herbivory as a specific threat to this species, deer herbivory has been observed at sites where this species occurs (Boyd et al. 2010; Snyder and Lecher 2010) and has been listed as a possible threat in other documents (e.g., USFWS 1996; GADNR 2008). During the past century, man-made habitat alterations have allowed white-tailed deer population densities to reach historic levels in the eastern United States (Alverson et al. 1988; Smith 1991; Augustine and Frelich 1998; Fletcher et al. 2001a), suggesting that understory plants have experienced and will continue to experience increased browsing pressure over time. Herbivory in general has the potential to directly impact population dynamics and reproduction of plant species (Fletcher et al. 2001b) and eventually change the vegetation structure of forest communities (Miller et al. 1992). Deer herbivory in particular has been shown to halt growth and reduce reproduction during the growing season when herbivory occurs (Augustine and Frelich 1998; Fletcher et al. 2001a, b), reduce growth and reproduction in subsequent years (Augustine and Frelich 1998), and cause specific plant species populations to experience severe declines or even local extinction (Anderson 1994). Increasing knowledge of how browsing by deer and other large mammals could impact *S. montana* at individual and population levels could have important management and conservation implications for this currently threatened species.

In the following chapter, I present the findings of two years of field-based research on the impacts of large mammal herbivory, mainly by white-tailed deer (*Odocoileus virginianus* Zimmerman) and feral hogs (*Sus scrofa* L.), on *S. montana* individuals located at the Tennessee Army National Guard Volunteer Training Site (VTS) in Catoosa County, Georgia. In 2010, Drs. Jennifer Boyd and Joey Shaw (University of Tennessee at Chattanooga) were contracted by the Tennessee Army National Guard to determine if large mammal herbivores are impacting *S.*

montana individuals and populations located within the VTS property. I filled the role of graduate research assistant on this project and was primarily responsible for implementing the experiment and collecting and analyzing the associated field-based data. Specifically, an exclosure experiment designed to allow for the isolation of *S. montana* individuals from various types of herbivores, and the subsequent examination of survival, growth, and reproduction of these individuals was implemented in eight study locations across the VTS in May 2011. Monthly during the 2011 and 2012 growing seasons, we assessed survival and determined the stem height, number of stems, number of branches, number of leaves, number of flowers/fruit, the presence of observable damage (from mammal browsing, insects, fungus) and the life stage (juvenile or adult) of all plants included in this experiment. The primary research objectives were to quantify the effects of herbivory by large mammals on *S. montana* individuals and to evaluate the potential of large mammal herbivores to influence *S. montana* population dynamics through destruction of reproductive structures and/or preferences of various plant life stages.

A related objective of the *S. montana* study at the VTS was to investigate the influence of common forest management disturbances associated with prescribed burning and canopy thinning on herbivory by large mammals on *S. montana*. I present the findings of this research designed to address this objective in the third chapter of this thesis. This phase of the research was implemented in March 2012 with the installation of larger exclosures across four previously existing treatment plots designed to test for the main and interactive effects of prescribed burning and canopy thinning on *S. montana* in the VTS. Monthly during the 2012 growing season, I assessed survival and determined the stem height, number of stems, number of branches, number of leaves, number of flowers/fruit, the presence of observable damage (browsed, insect, fungus) and the life stage (juvenile or adult) of all plants included in this experiment.

Finally, in the concluding chapter, I synthesize and evaluate the findings of both research experiments described in this thesis regarding their relevance to the VTS Integrated Natural Resources Management Plan (INRMP). This plan aims to provide guidance on the protection of natural resources at the VTS while allowing for the military to meet their training needs (Snyder and Lecher 2010). In addition to their specific relevance to *S. montana* protection at the VTS, these findings can be applied to overall conservation efforts for *S. montana*. Also in the final chapter of this thesis, I suggest additional research ideas to help further elucidate the impacts of herbivory on *S. montana*, increase general knowledge of this species, and provide guidance for management practices and conservation efforts.

CHAPTER 2

IMPACT OF LARGE MAMMAL HERBIVORY ON FEDERALLY THREATENED *SCUTELLARIA MONTANA* CHAPM. AT THE TENNESSEE ARMY NATIONAL GUARD VOLUNTEER TRAINING SITE, CATOOSA COUNTY, GEORGIA

This chapter will be submitted to *Forest Ecology and Management* for publication and the use of *we* and *our* refers to myself and collaborators J. Shaw and J. Boyd with whom I worked to formulate the project, construct exclosures, identify *S. montana* plants, set up the exclosures and study plots in the field, and communicate with VTS staff. Additionally, I was responsible for data collection, calculations, interpretations, and the writing of this document.

Introduction

White-tailed deer (*Odocoileus virginianus* Zimmerman) are one of the most widely distributed large herbivores in the Western hemisphere, occurring from southern Canada to northern Columbia and Venezuela (Smith 1991; Demarais et al. 2000). Within the United States, this species occurs in all 48 conterminous states (Demarais et al. 2000). White-tailed deer were likely not as abundant historically as they are today due to overhunting (Smith 1991). Specifically, in Georgia, white-tailed deer were at one time nearly eliminated from the state, but ultimately wildlife management efforts have successfully restored this species so that it now numbers more than 1.2 million individuals (GADNR 2004). With the increase of deer populations comes new management concerns, including the impacts that deer may have on plant species and their associated ecosystems (McShea et al. 1997). White-tailed deer allot more time to feeding than to any other activity (Smith 1991), and food selection varies from season to season depending on availability (Crawford 1982; Smith 1991). During the winter, browse from woody plants dominate their diets, but once herbaceous plants emerge in the spring and summer months, deer will feed preferentially on these plants (Crawford 1982; Balgooyen and Waller 1995). It has been estimated that forbs, in particular, make up nearly three-fourths of the deer diet in late spring (Crawford 1982). Deer will forage selectively for preferred plant species (Crawford 1982) and will preferentially consume plant parts that are relatively high in caloric value (Short 1975) and easily digestible (Short 1975; Demarais et al. 2000). In addition, the vision of white-tailed deer is most sensitive to the short and middle wavelengths within the visible portion of the light spectrum (Jacobs et al. 1994), approximately 300 nm to 800 nm, which means they see blue to yellow-green very well (VerCauteren and Pipas 2003). Since the flowers of *S. montana* are blue to purple in color (Chapman 1878; Kral 1983), deer are likely able to see these flowers, allowing them to easily distinguish these plants in the forest understory. Although direct observation of deer browsing plants rarely occurs (Miller et al. 1992), damage caused specifically by deer will leave a rough cut on the main stem of the plant (Balgooyen and Waller 1995; Augustine et al. 1998; Augustine and Frelich 1998; Fletcher et al. 2001b).

A majority of the research on deer herbivory impacts has examined impacts on woody vegetation, and to a lesser degree on herbaceous vegetation (Miller et al. 1992). Research conducted on browsing impacts to common herbaceous plant species has evidenced the negative impacts of deer (e.g. Anderson 1994; Augustine and Frelich 1998; Garcia and Ehrlén 2002**;**

Frankland and Nelson 2003; Knight 2007). Common negative impacts include partial to complete removal of leaf and stem tissues and reproductive structures, as well as decreased overall plant height (Anderson 1994; Balgooyen and Waller 1995; Augustine and Frelich 1998; Garcia and Ehrlén 2002; Frankland and Nelson 2003). Removal of leaves and stems of perennial forbs over time can result in decreased overall plant height and photosynthetic capabilities, and as those photosynthetic capabilities decrease, the ability to assimilate energy and subsequently store energy in below ground perennating structures is reduced (Anderson 1994; Ruhren and Handel 2000; Fletcher et al. 2001a; Frankland and Nelson 2003). Through time, this reduction could negatively affect flowering and associated reproductive activity (Anderson 1994; Fletcher et al. 2001a). Research has also suggested that deer preferentially fed on taller, flowering individuals of a given plant species rather than shorter, non-flowering individuals (Anderson 1994; Frankland and Nelson 2003), which could reduce population size and/or growth (Garcia and Ehrlén 2002). Such declines could lead to the local extirpation of populations that are preferentially browsed (Anderson 1994; Balgooyen and Waller 1995; Augustine and Frelich 1998; Frankland and Nelson 2003). Ultimately, the extirpation of plant species from an area due to persistent, preferential deer browsing could produce an overall reduction in its plant species diversity (Balgooyen and Waller 1995; Fletcher et al. 2001a; Rooney and Waller 2003), which could have profound repercussions for insect pollinators and other herbivores, thereby decreasing overall biotic diversity (Anderson 1994).

Because deer browsing has the potential to greatly impact and possibly extirpate common plant species (Anderson 1994; Balgooyen and Waller 1995; Augustine and Frelich 1998; Frankland and Nelson 2003), it is intuitive that there are even greater implications for impacts on rare plant species. A study of the effects of wildlife, including white-tailed deer, on the rare

Turk's cap lily (*Lilium superbum* L.) in Northern Virginia found that plants exposed to deer herbivory experienced overall reduced stem heights compared to protected plants (Fletcher et al. 2001b). Because deer consumed terminal stems and leaves, plant growth almost always ceased and that year's reproduction was eliminated with just one browsing occurrence (Fletcher et al. 2001b). Kettering et al. (2009) investigated the effects of white-tailed deer herbivory on the endangered scrub blazing star (*Liatris ohlingerae* (S.F. Blake) B.R. Robe) and also found that deer browsing of unprotected plants removed plant biomass and caused plants to experience reduced growth relative to protected plants. Furthermore, browsed individuals had more stems due to release from apical dominance caused by removal of the apical meristem, and were less likely to flower or exhibited delayed flowering. Overall, researchers found that browsing damage at the population level resulted in a 30% reduction in fecundity across all sites, which could compromise the long-term persistence of some *L. ohlingerae* populations (Kettering et al. 2009). This preferential feeding has not only been shown to negatively impact plants that are already rare (Fletcher et al. 2001b; Webster et al. 2005; Kettering et al. 2009; Vitt et al. 2009), but to also cause once common species to become rare in a specific area (Augustine and Frelich 1998; Webster et al. 2005). In the Cades Cove area of Great Smoky Mountains National Park, Tennessee, Webster et al. (2005) found that long-term effects of deer herbivory caused *Trillium* sp. to become rare at this location while remaining common at a reference site that had comparatively lower deer densities. The local rarity of *Trillium* sp. in Cades Cove was probably influenced by persistent herbivory that reduced mean plant height and caused plants to be less reproductive since *Trillium* reproduction is dependent on plant height (Webster et al. 2005). Because deer herbivory may not only prevent plant populations from thriving, but could lead to local extirpation, the negative impacts of deer herbivory should be considered for the management and conservation of rare plants.

Scutellaria montana Chapm. (Large-flowered skullcap or Mountain skullcap) is a perennial forb of the mint family (Lamiaceae) that is endemic to southern portions of the Cumberland Plateau and Ridge and Valley physiographic provinces (Patrick et al. 1995; Bridges, as cited in USFWS 1996; USFWS 2002)**.** Populations of this species are documented in nine northwest Georgia counties and four southeastern Tennessee counties (USFWS 2012), and although to date none have been documented, populations are suspected to exist in adjacent areas of Alabama (Patrick et al. 1995; Bridges, as cited in USFWS 1996). In 1986, *S. montana* was listed as a federally endangered species, and in 1996, the United States Fish and Wildlife Service (USFWS 1986, 1996) officially outlined goals and objectives for downlisting and eventually delisting this species. Downlisting *S. montana* to threatened status was to be considered when 25 distinct populations or 10 protected and managed self-sustaining populations of *S. montana* distributed throughout its range were known. A population was to be considered self-sustaining if it contained 100 or more individuals (USFWS 1996). In 2002, after the documentation of additional populations, *S. montana* was downlisted to its current threatened status (USFWS 2002). When there are at least 15 protected and managed self-sustaining populations distributed throughout its range that have been maintained for at least10 years, delisting will be considered (USFWS 1996).

The Tennessee Army National Guard (TNARNG) Volunteer Training Site (VTS) located in Catoosa County in northwest Georgia (Figure 2.1), houses one of the largest known populations of federally protected *S. montana* within its 1,628 acres (Snyder and Lecher 2010). In 2002, at the suggestion of the USFWS and per Army regulations, the VTS was surveyed to determine the number of individuals of *S. montana* on site. In total, 1,600 individuals were counted (SAIC 2006) and subsequently separated into 26 management groups based on the proximity of plants to one another. To allow for continued monitoring of the VTS *S. montana* population, 46 permanent monitoring plots were established across the site to include all management groups (SAIC 2006). In 2004, as required by law and Army regulations for sites containing federally listed species (SAIC 2006), VTS staff implemented an annual *S. montana* monitoring program, which University of Tennessee at Chattanooga (UTC) faculty and students performed in 2009 (Shaw et al. 2010) and 2010 (Boyd et al. 2010).

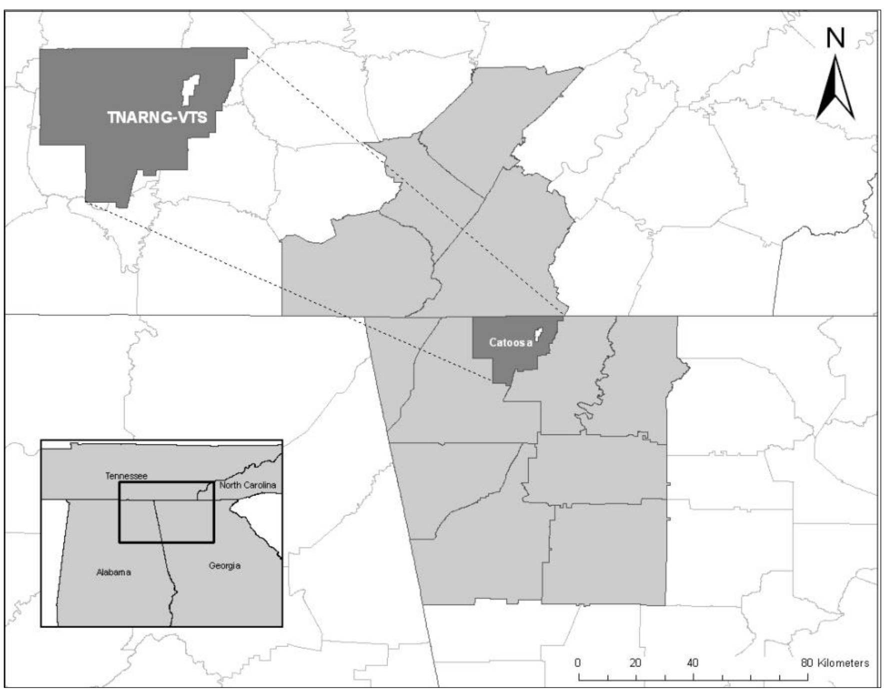

Figure 2.1 Location of Tennessee Army National Guard Volunteer Training Site in Catoosa County, Georgia (dark gray) and other Tennessee and Georgia counties with documented *S. montana* populations (light gray).

The USFWS (2002) reclassification report of *S. montana*, changing its status from endangered to threatened listed habitat loss due to disturbances associated with land-use changes including logging, residential development, clearing of forested areas, and animal grazing and wildfire as threats to the continued existence of *S. montana*. In addition, competition with invasive species such as Japanese honeysuckle (*Lonicera japonica* Thunb.) and privet (*Ligustrum vulgare* L.) for light also threaten *S. montana* in some locations (USFWS 2002). The report does not list deer herbivory as a specific threat to this species. However, deer herbivory has been listed as a possible threat in other documents (e.g. USFWS 1996; GADNR 2008). During these monitoring efforts, evidence of browsing by relatively large herbivores, including the removal of floral structures, has been observed and noted although, not consistently quantified. While not directly observed, this evidence of browsing and the known presence of white-tailed deer at the site has lead VTS staff to suspect that white-tailed deer may be browsing *S. montana* and that such browsing could impact its individual- and population-level performance at the site (Snyder and Lecher 2010). Although neither deer population size nor carrying capacity of the VTS for deer is known (Snyder and Lecher 2010), the presence of white-tailed deer is evidenced by frequent sightings and a vast network of established deer trails throughout the site (personal observation).

Goals and objectives outlined in the TNARNG Integrated Natural Resources Natural Management Plan (INRMP) for the VTS for years 2010-2014 are aimed at meeting the military's training needs while minimizing impacts to the environment and natural resources as well as maintaining a healthy ecosystem (Snyder and Lecher 2010). Our research was designed to determine if controlling deer within the site would provide increased protection for *S. montana* there. To address our goals, we aimed to: (1) quantify the effects of large mammal herbivory on intact, undisturbed *S. montana* individuals within the VTS; and (2) evaluate the potential of large mammal herbivores to influence *S. montana* population dynamics through preferences for various plant life stages. We hypothesize that large mammal herbivores are impacting *S. montana* populations within the VTS, and specifically we predict that they are having a negative impact on these plants through removal of biomass and reproductive structures.

Methods

To begin investigating the impacts of white-tailed deer on federally threatened *S. montana* located within the VTS, we selected eight of the 46 permanent monitoring plots that had a documented presence of both *S. montana* individuals and large mammal visitation (as reported in Boyd et al. 2010) as areas of study in late spring 2011. Herbivory study areas were established at least 10 m away from each of these permanent monitoring plots to ensure that annually monitored individuals were not disturbed by our research. These herbivory study areas were located throughout the VTS property (Figure 2.2) and labeled HS1-8.

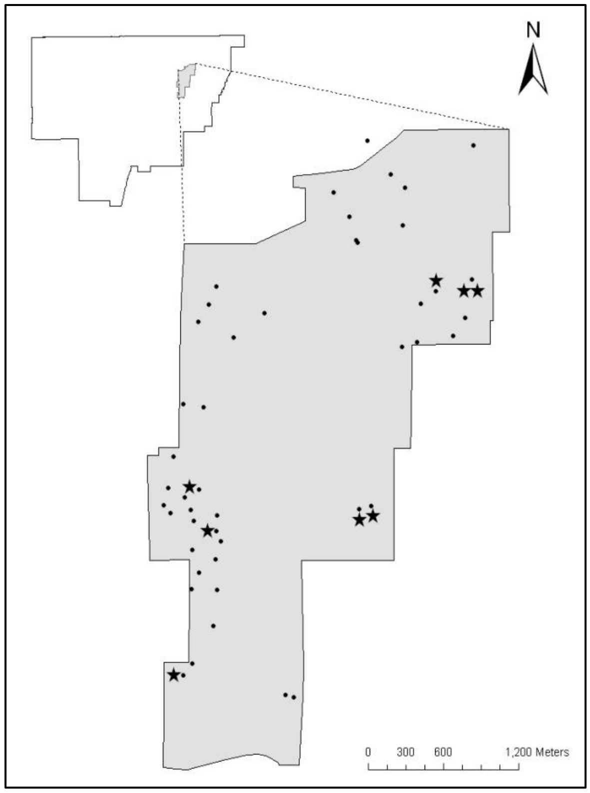

Figure 2.2 Location of *S. montana* permanent monitoring plots (dots) and herbivory study plots (stars) within the Tennessee Army National Guard Volunteer Training Site, Catoosa County, Georgia.

In mid-May 2011, at least 32 individuals located in each of the eight herbivory study areas, with eight individuals to be included in each of the four treatments, were marked with flags. To isolate the effects of large mammals as opposed to small mammals or insects on *S. montana*, we constructed exclosures approximately 1 m^3 in size, using ½ inch diameter PVC pipe connected with PVC corner joints for the frames, with 1 inch aperture hex wire mesh (chicken wire) secured around the frames by cable ties (Figure 2.3). This exclosure design was adapted from Frankland and Nelson (2003). Since the wire mesh would protect plants from not only large mammals such as deer, but also small animals like rabbits and turtles, which we also have observed frequently within the VTS, we cut 4 to 6 inch holes in two opposing sides of the wire mesh of some cages to permit smaller herbivores to access plants in the study (see Fletcher et al. 2001a). To control for any effects of exclosure presence on herbivore attraction or deterrence, we constructed additional PVC frames without wire mesh covering (i.e., ‘blanks’).

Figure 2.3 Example herbivory study exclosure constructed of a PVC pipe frame enclosed with wire mesh secured by cable ties.

In each of the herbivory study areas during late May 2011, we installed exclosures and frames to include at least eight *S. montana* individuals in each treatment – PVC frames with wire mesh to exclude both large and small herbivores (i.e., ‘all herbivores’), PVC frames with wire mesh with holes to exclude only large herbivores (i.e., ‘large only’), and unmeshed PVC ‘blanks’ to permit browsing by all herbivores. Additionally, we selected at least eight *S. montana* non-exclosed individuals (i.e., ‘controls’) at each herbivory plot for comparative study. In June 2011, a total of 262 individuals were initially tagged: 67 in the ‘all herbivores’ exclosures, 66 in the ‘large only’ exclosures, 65 in the ‘blank’ exclosures and 64 non-exclosed controls. One individual in the ‘blank’ exclosure treatment did not have aboveground growth at any time when data were collected from June to September. Additional individuals that grew within any of the exclosures from June through September were also tagged, bringing the total of tagged individuals with aboveground growth during 2011to 266. Within the herbivory study sites, *S. montana* individuals within 1 m of each other were grouped and groups were assigned randomly to each exclosure treatment. This grouped design minimized equipment costs and simplified the logistics of implementing our experiment. In total, 24 ‘all herbivores’ exclosures, 27 ‘large only’ exclosures and 30 PVC ‘blanks’ were installed within the herbivory study sites. In mid-June 2011, we classified the life stage (juvenile < 10 cm, or adult $\geq$ 10 cm stem height), measured stem height, number of stems, number of leaves, and number of flowers/fruit, and assessed the presence of observable damage (insect, browsed, fungal, none) of each *S. montana* individual included in our herbivory study. During our initial measurements, we noted that some plants exhibited branching, so beginning in July 2011, we also counted the number of branches of each *S. montana* individual in the study. All developmental and health assessments and growth measurements were repeated on a monthly basis through early-mid September 2011, at which time many individuals became senescent.

Between the 2011 and 2012 study periods, exclosures were maintained and checked for damage at least once per month. The 2012 study period began in mid-May 2012, as soon as plants had flowers. Data were again collected once per month through September. An additional treatment consisting of flat, 1-m^2 PVC pipe frames (‘flats’) were installed in 2012 in three of the herbivory study areas with a total of 38 individuals, because preliminary results from the 2011 study period suggested that the PVC blanks were affording *S. montana* some degree of inadvertent protection from large herbivores. Specifically, analysis of variance (ANOVA) suggested that individuals within blanks effectively experienced no change in individual plant stem height while the stem height of individuals in our control treatment was reduced. We hypothesized that the vertical PVC posts of the blanks may have inadvertently provided protection from herbivores because blank exclosures were often applied to individuals that would not fit within the confining mesh of the other exclosure treatments, but would fit within the blank exclosures if situated in the corners of the frame against the vertical posts. An alternative hypothesis is that herbivores did not browse individuals within the blank exclosure because they did not want to lower their heads below the top of the frame and/or herbivores saw the cage frame and did not attempt to browse individuals because they could not browse individuals inside the nearby mesh-covered exclosures. As well as adding individuals in the flat PVC square treatment to the total number of plants, any additional individual that grew within an exclosure was tagged and measured. As a result, one individual was added to the ‘all herbivores’ exclosure treatment, four to the ‘large only’ exclosure treatment and four to the ‘blank’ exclosure treatment and one to the ‘flat’ PVC square exclosure treatment. Of the 267 individuals that were tagged during 2011, 16 did not have aboveground growth during any dates when data were collected during 2012.

Once all data were collected, we calculated the number and proportion of plant individuals that were adult versus juvenile and browsed versus unbrowsed in each exclosure treatment in each study period. Since the USFWS (2002) describes *S. montana* as having one stem per individual, but Cruzan (2001) described that individuals may have one to several stems, the number and proportion of individuals with multiple stems during both 2011 and 2012 for each treatment were recorded. Additionally, *S. montana* does not typically exhibit branching (Collins 1976) unless release of apical dominance due to damage of the apical meristem occurs (King 1992), so we assessed number and proportion of individuals that exhibited branching during 2011 and 2012 for each treatment. The proportion of adult individuals with flowers was assessed for 2012 only. Percent changes in stem height and number of leaves were calculated for each individual plant during each study season as the difference between the variable at the end of the study period (September in both years) and the beginning of the study period (June in 2011, May in 2012) divided by its initial value and then multiplied by 100. We then calculated mean percent changes in plant stem height and number of leaves for each exclosure treatment during each study period. Because the specific date of initial data collection was arbitrary, we only included individuals that exhibited aboveground growth at that time in all calculations. Statistical analyses were performed using IBM SPSS Statistics Version 20 software (IBM Corp., Armonk, NY). Specifically, one-way analysis of variance (ANOVA) was used to determine the main effect of exclosure treatment on mean percent changes in individual stem height and number of leaves for each study period.

An interseasonal analysis comparing monthly results for 2011 and 2012 was performed for four variables measured: stem height, number of leaves, number of stems and number of branches. Also, an overall interseasonal analysis of 2011 and 2012 treatments was performed for mean percent change in stem height and number of leaves per individual. Only months common to the two study seasons (June-September) and individuals present during both study seasons were included in these analyses. One-way analysis of variance (ANOVA) was used to determine the main effect of season on mean values of the stem height, number of leaves, stems and branches per individual and the mean percent changes in individual stem height and number of leaves for each study period.

Results

2011 Study Season

We analyzed mean percent change in number of leaves per individual and mean percent change in individual plant stem height to examine impacts that large mammal herbivores may have on *S. montana* aboveground biomass throughout the 2011 study period (see Table2.1). Results indicated that throughout the study period, number of leaves per plant decreased (Figure 2.4). The greatest reduction was observed for individuals to which herbivores had access, specifically non-exclosed control individuals (38.4%) and individuals that received the blank exclosure treatment (37.6%). Plants protected from all herbivores experienced the least reduction in number of leaves (20.6%) followed by plants protected from large herbivores only (25.4%). The mean percent change in number of leaves per individual for plants protected from all herbivores was significantly different from non-exclosed control individuals and individuals in the 'blank' exclosure treatment ($P \leq 0.05$) suggesting that large herbivores negatively impacted the number of leaves per individual.

Table 2.1 Summary of one-way ANOVA results for mean percent change in the numbers of leaves of *Scutellaria montana* individuals within each of the four herbivory treatments (both large and small herbivores excluded, *All Herbivores*; only large herbivores excluded, *Large Only*; no herbivores excluded, *Blank*; and non-exclosed individuals, *Control*) at the VTS. Mean percent change was calculated for the period from June to September 2011, where exclosure treatment was considered the fixed independent variable.

	Sum of squares	df	Mean square	F	P
Treatment	1.548	3	0.516	3.228	0.23
Error	40.926	256	0.160		
Total	66.363	260			

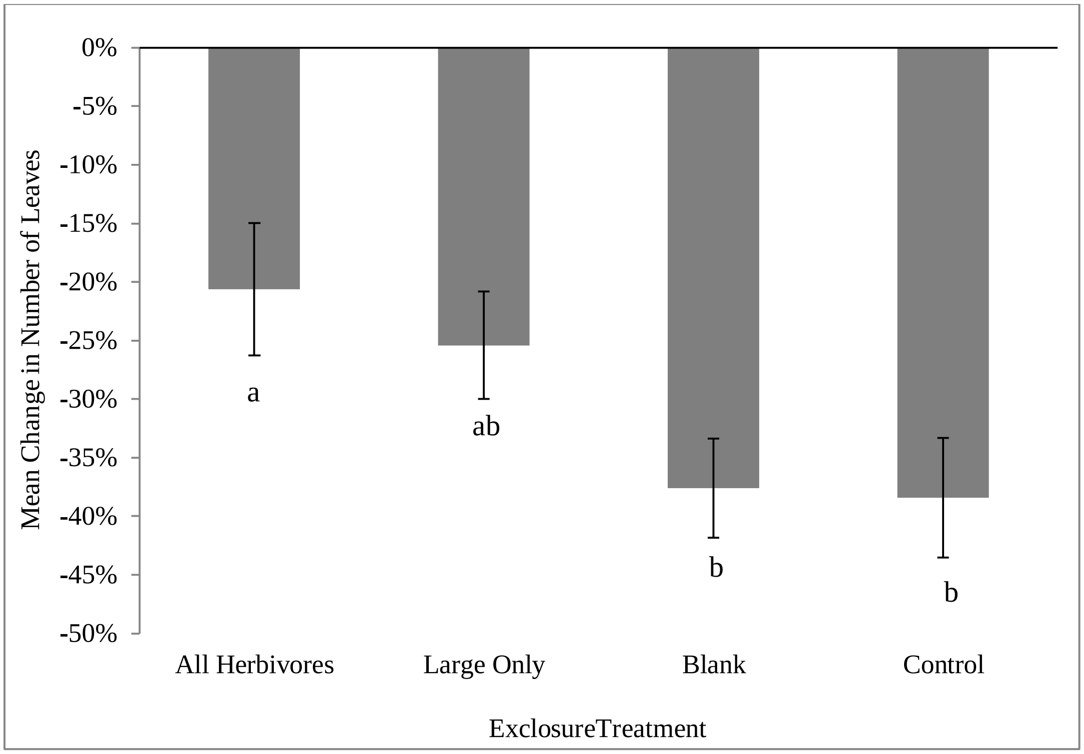

Figure 2.4 Mean percent change in the numbers of leaves of *Scutellaria montana* individuals within each of the four herbivory treatments (both large and small herbivores excluded, *All Herbivores*; only large herbivores excluded, *Large Only*; no herbivores excluded, *Blank*; and non-exclosed individuals, *Control*) at the VTS. Mean percent change was calculated for the period from June to September 2011. Bars shown are means ± 1 SE. Values shown below the same letter are not statistically different at the $P \leq 0.05$ level of significance.

Results for mean percent change in steam height (see Table 2.2) indicated that plants protected from all herbivores experienced a negligible change in this variable (2.2%), whereas plants protected from large herbivores only experienced an increase in stem height (7.3%) throughout the study period (Figure 2.5). Plants that served as non-exclosed control individuals experienced a stem height decreased (-8.6%) indicating that large herbivores negatively impacted stem heights of *S. montana* individuals. However, individuals that received the blank exclosure treatment had a negligible change in stem height (-0.8%) throughout the study period, which we hypothesized was the result of the PVC pipe frames inadvertently providing some type of protection from herbivores. To test this additional hypothesis, when data were first collected for 2012 field season in May, we installed an additional PVC pipe treatment ('flat') consisting of flat, 1-m x 1-m squares on the ground around additional *S. montana* individuals.

Table 2.2 Summary of one-way ANOVA results for mean percent change in stem height of *Scutellaria montana* individuals within each of the four herbivory treatments (both large and small herbivores excluded, *All Herbivores*; only large herbivores excluded, *Large Only*; no herbivores excluded, *Blank*; and unframed non-exclosed individuals, *Control*) at the VTS. Mean percent change was calculated for the period from June to September 2011, where exclosure treatment was considered the fixed independent variable.

	Sum of squares	df	Mean square	F	P
Treatment	0.864	3	0.288	3.087	0.28
Error	23.886	256	0.093		
Total	24.75	260			

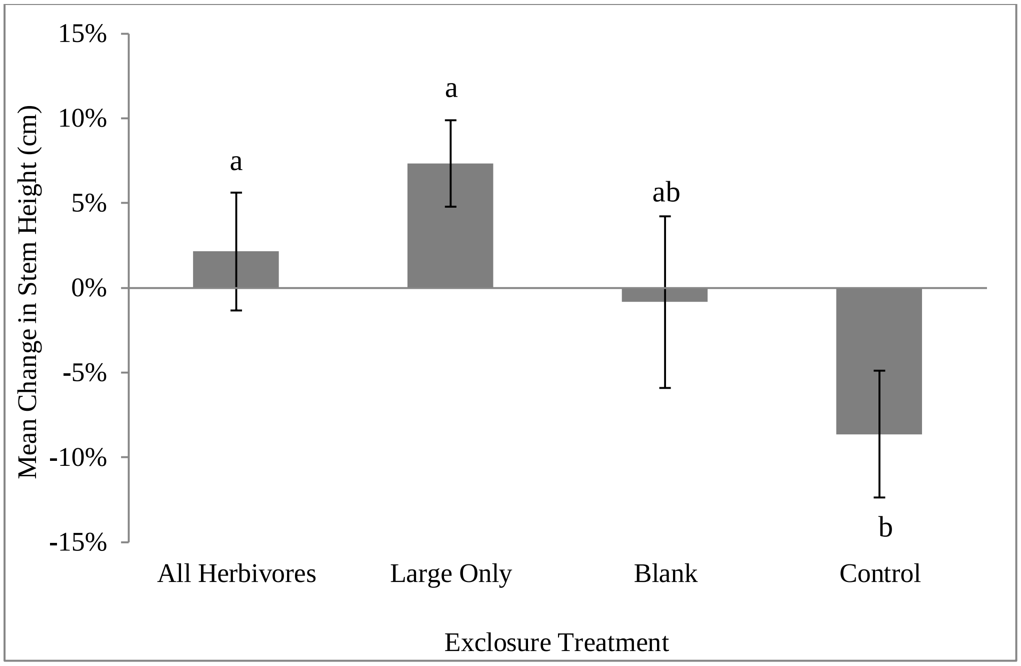

Figure 2.5 Mean percent change in stem height of *Scutellaria montana* individuals within each of the four herbivory treatments (both large and small herbivores excluded, *All Herbivores*; only large herbivores excluded, *Large Only*; no herbivores excluded, *Blank*; and unframed non-exclosed individuals, *Control*) at the VTS. Mean percent change was calculated for the period from June to September 2011. Bars shown are means ± 1 SE. Values shown below the same letter are not statistically different at the $P \leq 0.05$ level of significance.

There was a greater proportion of adult than juvenile individuals within each of the four treatments (Table 2.3). Individuals protected from herbivores in the all herbivores exclosure treatment were characterized by a greater proportion of adult than juvenile plants, and a greater proportion of unbrowsed plants than in other exclosure treatments. In this exclosure treatment (n=68), 72% of individuals were adults, and as expected since both large and small mammal herbivores were exclosed, zero individuals were browsed. Individuals in the large only exclosure treatment (n=65) had the highest proportion of adults with 83.1%, and had the second highest proportion of browsed individuals with 32.2%. Individuals exposed to herbivory in the blank exclosure (n=63) and non-exclosed control (n=64) treatments had a higher proportion of adult than juvenile individuals with 82.5% and 68.7%, respectively. Non-exclosed control individuals had the greatest proportion of individuals browsed (35.9%), while plants in the blank exclosure treatment had the second lowest proportion of individuals browsed (22.2%).

We observed a low proportion of total individuals in this study that had more than one stem (Table 2.3). Individuals in the non-exclosed control treatment were characterized by having the greatest proportion (19%) of individuals with multiple stems compared to individuals that received the other treatments. Individuals exclosed from large herbivores only had the second highest proportion (18%) of individuals with multiple stems. Individuals exposed to herbivores in the blank exclosure treatment had the lowest proportion (13%) of individuals with multiple stems, while individuals protected from all mammal herbivores had the second lowest proportion (16%) of individuals with multiple stems.

Approximately a quarter of individuals in each of the four treatments experienced branching (Table 2.3), and individuals exposed to herbivores in the non-exclosed control treatment were characterized as having the highest proportion of plants that exhibited branching with 31.3% of individuals. Individuals exposed to herbivores in the blank exclosure treatment were characterized as having the lowest proportion of individuals with branching (20.6%). Plants that were protected from large mammal herbivores in the all herbivores and large only exclosure treatments had a very similar proportion of individuals that exhibited branching with 25% of plants in the all herbivores exclosure treatment and 24.6% of plants in the large only exclosure treatment exhibiting branching.

Table 2.3 Total number of adult and juvenile individuals with aboveground biomass during initial data collection (June), and total number of adult and juvenile individuals that were browsed, exhibited branching (July-Sept only), were multiple-stemmed in each exclosure treatment for data collected during June to September 2011.

Exclosure Treatment	Adults	Juveniles	Individuals Browsed		Individuals with > 1 stem		Individuals with Branches	
			Adults	Juveniles	Adults	Juveniles	Adults	Juveniles
All Herbivores (n=68)	49	19	0	0	11	0	15	2
Large Only (n=65)	54	11	17	6	9	3	13	3
Blank (n=63)	52	11	13	1	8	0	13	0
Control (n=64)	44	10	23	0	9	3	20	0

2012 Study Season

Similar to data analysis during 2011, we analyzed mean percent change in number of leaves per individual and mean percent change in individual plant stem height to examine impacts that large mammal herbivores may have to *S. montana* aboveground biomass throughout the 2012 study period (see Table 2.4). Results again indicated that throughout the study period, number of leaves per plant decreased (Figure 2.6). The greatest reduction was observed for individuals exposed to herbivory in the flat PVC square treatment (49.5%). Plants protected from all herbivores experienced the second greatest reduction in number of leaves (40.4%) followed by individuals that received the blank exclosure treatment (38.9%). Non-exclosed control individuals (27%) followed by plants protected from large herbivores only (27.1%) had the two least reduction in this variable. The mean percent change in number of leaves per individual was not significantly ($P \leq 0.05$) different between any of the exclosure treatments suggesting that large and small herbivores are not drastically impacting the number of leaves per individual.

Table 2.4 Summary of one-way ANOVA results for mean percent change in the numbers of leaves of *Scutellaria montana* individuals within each of the five herbivory treatments (both large and small herbivores excluded, *All Herbivores*; only large herbivores excluded, *Large Only*; no herbivores excluded, *Blank*; Flat PVC squares; no herbivores excluded, *Flat*; and non-exclosed individuals, *Control*) at the VTS. Mean percent change was calculated for the period from May to September 2012, where exclosure treatment was considered the fixed independent variable.

	Sum of squares	df	Mean square	F	P
Treatment	1.798	4	0.45	1.070	0.372
Error	109.611	261	0.42		
Total	144.712	266			

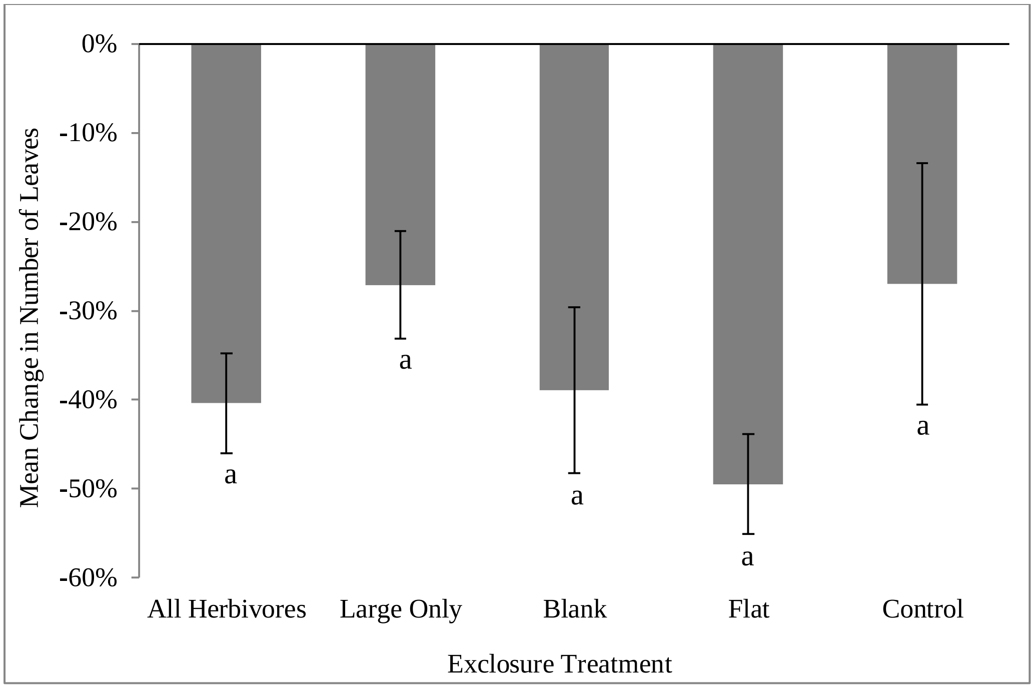

Figure 2.6 Mean percent change in the numbers of leaves of *Scutellaria montana* individuals within each of the five herbivory treatments (both large and small herbivores excluded, *All Herbivores*; only large herbivores excluded, *Large Only*; no herbivores excluded, *Blank*; Flat PVC squares; no herbivores excluded, *Flat*; and non-exclosed individuals, *Control*) at the VTS. Mean percent change was calculated for the period from May to September 2012. Bars shown are means ± 1 SE. Values shown below the same letter are not statistically different at the $P \leq 0.05$ level of significance.

Mean percent change in individual stem height was also analyzed for the 2012 study period (see Table 2.5). Results for mean percent change in steam height (Figure 2.7) indicated that plants protected from all herbivores and non-exclosed control individuals exposed to herbivores experienced a negligible change in this variable (-0.7% and 0.86%, respectively). Plants that were protected from large herbivores only experienced a slight decrease in stem height (-3.1%) throughout the study period. Plants exposed to herbivores in the blank exclosure (-23.2%) and flat PVC square (-14.5%) treatments experienced the greatest reduction in this variable. The mean percent change in stem height for individuals in the blank exclosure treatment was significantly different from the non-exclosed control treatment ($P \leq 0.05$) indicating that the PVC pipe attracted large animal herbivores resulting in a negative impact on stem height of *S. montana* individuals.

Table 2.5 Summary of one-way ANOVA results for mean percent change in stem height of *Scutellaria montana* individuals within each of the five herbivory treatments (both large and small herbivores excluded, *All Herbivores*; only large herbivores excluded, *Large Only*; no herbivores excluded, *Blank*; Flat PVC squares; no herbivores excluded, *Flat*; and non-exclosed individuals, *Control*) at the VTS. Mean percent change was calculated for the period from May to September 2012, where exclosure treatment was considered the fixed independent variable.

	Sum of squares	df	Mean square	F	P
Treatment	2.223	4	0.556	4.060	0.003
Error	35.728	261	0.137		
Total	39.338	266			

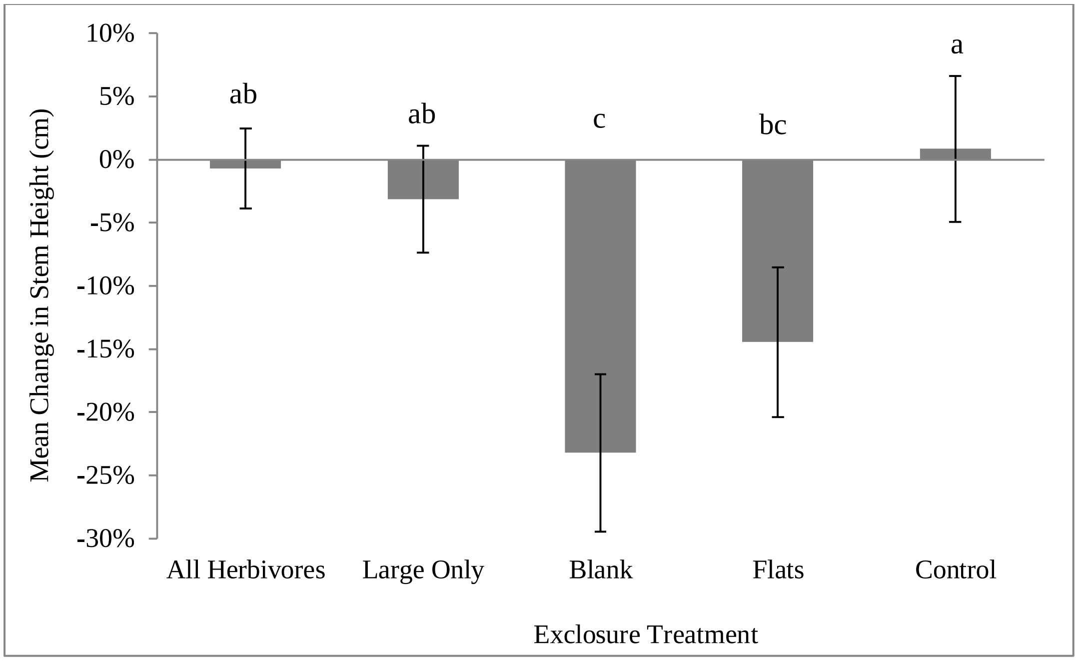

Figure 2.7 Mean percent change in stem height of *Scutellaria montana* individuals within each of the five herbivory treatments (both large and small herbivores excluded, *All Herbivores*; only large herbivores excluded, *Large Only*; no herbivores excluded, *Blank*; Flat PVC squares; no herbivores excluded, *Flat*; and non-exclosed individuals, *Control*) at the VTS. Mean percent change was calculated for the period from May to September 2012. Bars shown are means ± 1 SE. Values shown below the same letter are not statistically different at the $P \leq 0.05$ level of significance.

There was a greater proportion of adult individuals than juvenile individuals within each of the five treatments (Table 2.6). Individuals protected from herbivores in the all herbivores exclosure treatment (n=57) were characterized by a greater proportion of adult than juvenile plants, and a greater proportion of unbrowsed plants than in other exclosure treatments. In this exclosure treatment, 70% of individuals were adults, and as expected since both large and small mammal herbivores were exclosed, zero individuals were browsed. Individuals in the large only exclosure treatment (n=63) had a higher proportion of adults than juveniles (61.9%) and had the second lowest proportion of browsed individuals (9.5%). Individuals in the flat PVC square exclosure treatment (n=38) had the highest proportion of adults with 68.4%, and had the second highest proportion of browsed individuals with 28.9%. Individuals exposed to herbivory in the non-exclosed control (n=57) treatment also had a higher proportion of adult than juvenile individuals (66.7%) and had the highest proportion of browsed individuals at 38.6%. Plants with the blank exclosure treatment (n=51) were characterized as having the lowest proportion of adult individuals (58.8%) but had the third highest proportion of browsed individuals (23.5%).

We observed a low proportion of total individuals in this study that had more than one stem (Table 2.6). Plants in the large only exclosure treatment were characterized by a greater proportion (33.3%) of individuals with multiple stems compared to individuals that received the other treatments. Individuals exclosed from all herbivores had the lowest proportion (12.3%) of individuals with multiple stems. Individuals exposed to herbivores in the control treatment had the second lowest proportion of multiple-stemmed individuals (14%). Plants exposed to herbivory in the blank exclosure treatment had the second highest proportion of individuals with multiple stems while individuals in the flat PVC square treatment had the third highest proportion at 21.6%.

A proportion of individuals in each of the five treatments experienced branching at some time during the study period (Table 2.6). Plants exposed to herbivores in the non-exclosed control treatment were characterized by the greatest proportion of plants that exhibited branching with 33.3% of individuals. Individuals exposed to herbivores in the blank exclosure and flat PVC square treatments had similar proportions of individuals that exhibited branching at 23.7% and 23.5%, respectively. Plants that were protected from large mammal herbivores in the all herbivores and large only exclosure treatments had the lowest proportion of individuals that exhibited branching with 7% and 15%, respectively.

During 2012, a number of adult individuals in each treatment had flowers (Table 2.6), and adult plants in the all herbivores exclosure treatment were characterized by the greatest proportion of adults with flowers (75%) compared to the other treatments. Plants in the blank exclosure treatment had the second greatest proportion of adult individuals with flowers (63.2%) followed by individuals in the large only exclosure treatment (56.4%). Plants in the flat PVC square treatment were characterized by the least proportion of adult individuals with flowers (37.3%) while plants in the blank exclosure treatment were characterized by the second least proportion of flowering adult individuals (46.2%).

Table 2.6 Total number of adult and juvenile individuals with aboveground biomass during initial data collection (May), and total number of adult and juvenile individuals that were browsed, exhibited branching, were multiple-stemmed, and had flowers (May only; adults only) in each exclosure treatment for data collected during May to September 2012.

Exclosure Treatment	Adults	Juveniles	Individuals Browsed		Individuals with > 1 stem		Individuals with Branches		Flowering Adults
			Adults	Juveniles	Adults	Juveniles	Adults	Juveniles	
All Herbivores (n = 57)	40	16	0	0	4	3	2	2	30
Large Only (n = 63)	39	24	2	4	13	8	5	5	22
Blank (n = 51)	30	21	5	7	4	7	6	6	19
Flat (n=38)	26	12	7	4	4	2	5	4	12
Control (n = 57)	38	19	13	9	2	6	11	8	24

Interseasonal Analysis: 2011 vs. 2012

We conducted an interseasonal analysis to evaluate the effects of protection from herbivores as well as related phenological differences between the two study periods. Overall, plants exhibited higher values of all measured variables in 2011 than in 2012 when compared within the same exclosure treatments during the same months with the exception of the mean number of branches per individual. Across all months, individuals in all exclosure treatments were observably taller in 2011 than in 2012 (Figure 2.8). However, only in the blank treatment was the difference significant where plants were taller in 2011 than in 2012 across all months ($P \leq 0.05$). Also across all months, plants in the 2011 blank treatment were observably taller than in any other treatment, whereas plants in the 2012 blank treatment were observably shorter than in any other treatment.

During 2011, individuals in all exclosure treatments had an observably greater number of leaves than in 2012 (Figure 2.9). Across all months in 2011, plants in all treatments had significantly greater number of leaves compared to 2012 with the exception of the large only treatment for which 2011 and 2012 differences were significantly different only during July and August ($P \leq 0.05$). During June, July and August, the 2011 blank treatment had the greatest number of leaves while during September plants in the 2011 all herbivores treatment had the greatest number of leaves. Across all months, the 2012 blank exclosure treatment had the least number of leaves.

Across all months during 2011, individuals in all exclosure treatments had an observably greater number of stems than during 2012 (Figure 2.10). Also, across all months, the 2011 blank treatment had a significantly greater number of stems than during 2012. Number of stems was not significantly different for any of the other three treatments in 2011 and 2012. During June, the 2011 control treatment had the greatest number of stems while during July through September, the 2011 large only treatment had the greatest number of leaves. Across all months, the 2012 blank treatment had the least number of stems.

Mean number of branches per individual was assessed for July through September (Figure 2.11) and across all months, plants in the 2011 all herbivores and 2011 large only treatments had significantly greater number of branches than during 2012. Also during July, plants in the 2011 control treatment had significantly greater branches than during 2012. Overall, plants in the 2011 control treatment had the greatest number of branches and plants in the 2012 all herbivores treatment had the least number of branches. This was the only variable for which all 2011 treatments did not have an observably greater number than during 2012. During August and September, the 2012 blank treatment had an observably greater number of branches than in 2011.

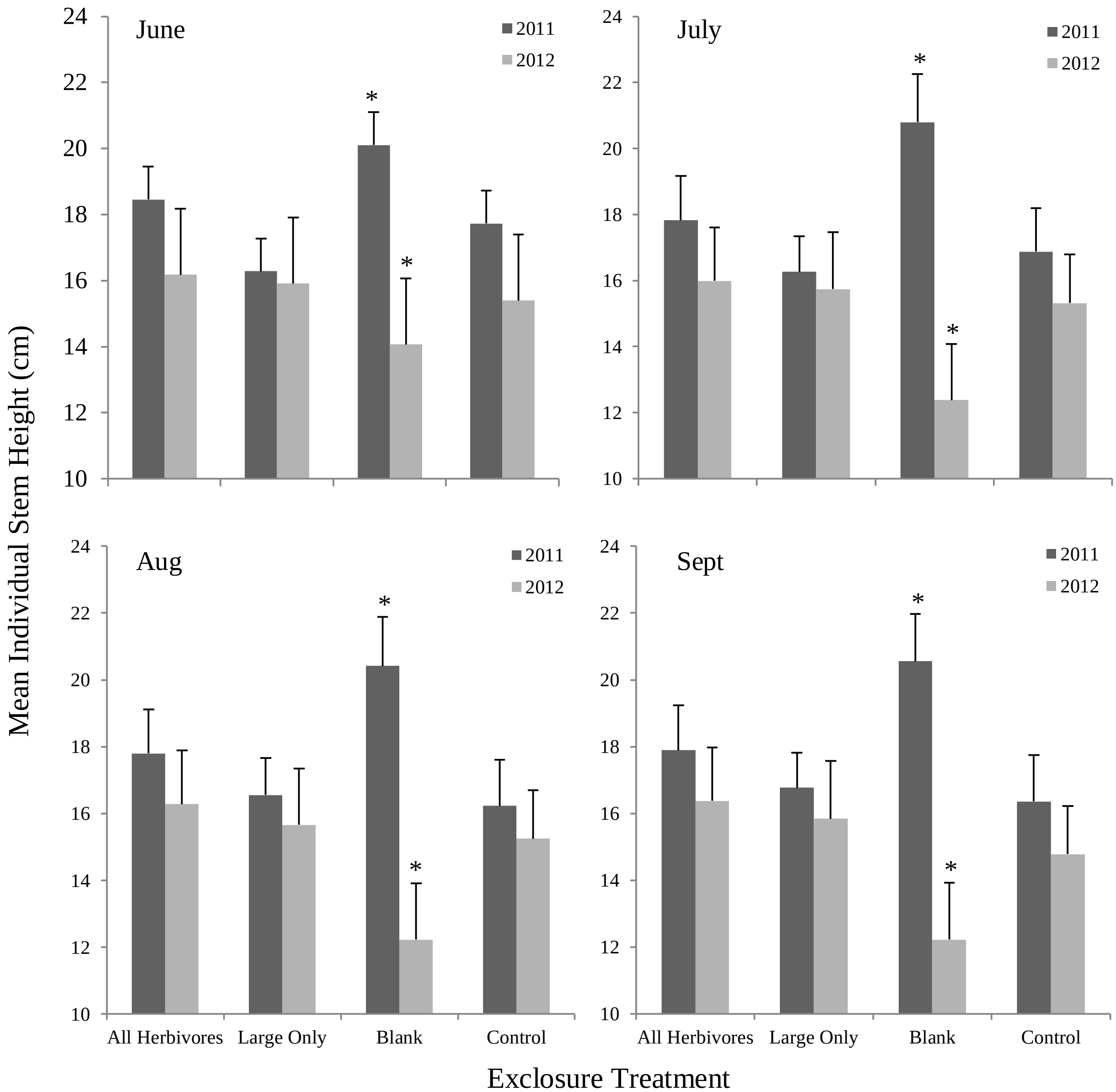

Figure 2.8 Interseasonal comparison of mean individual stem height for *Scutellaria montana* individuals at the VTS for June (top left), July (top right), August (lower left) and September (lower right) for each treatment during 2011 (dark gray) and 2012 (light gray). Bars shown are means ± 1 SE.

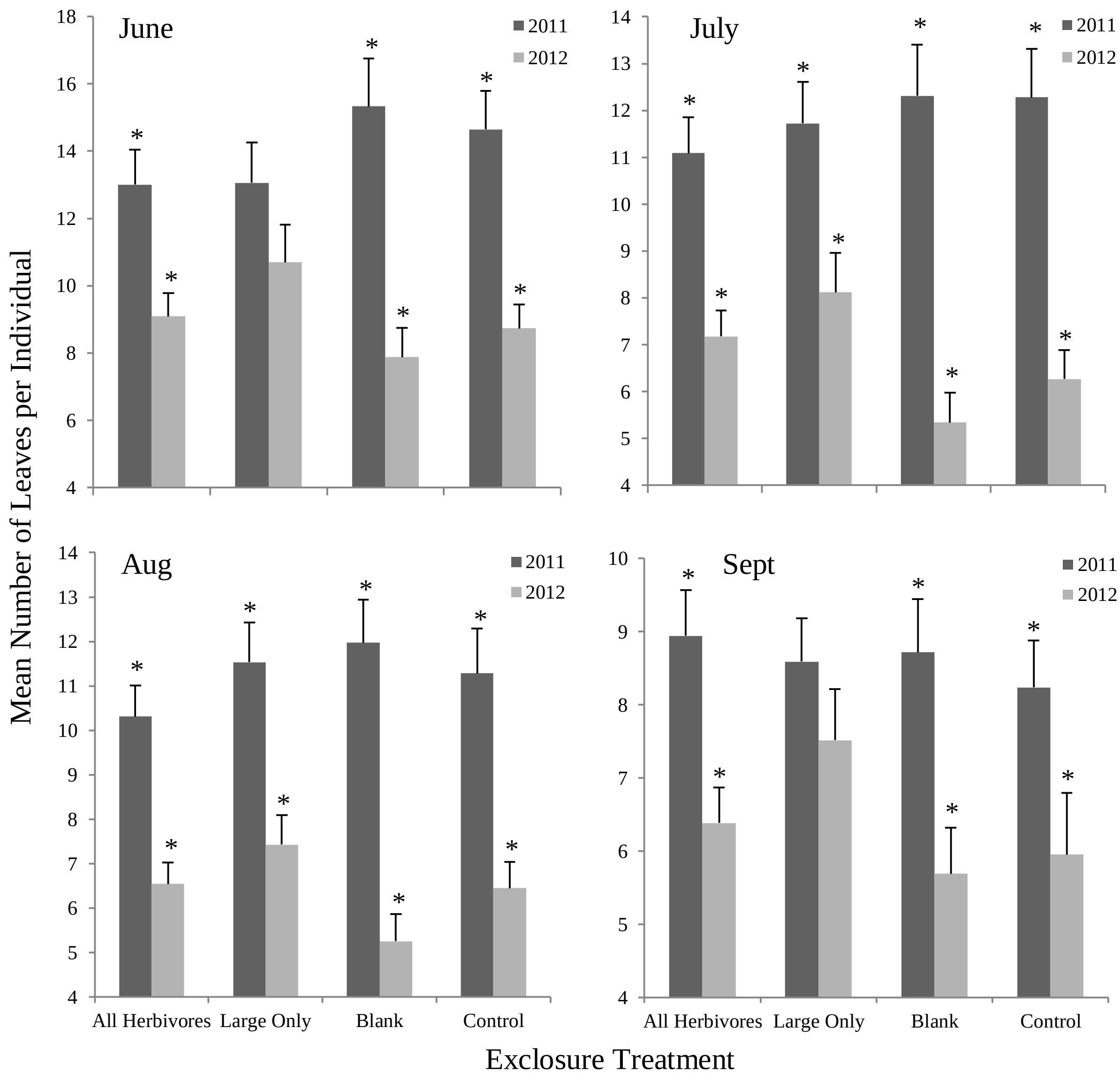

Figure 2.9 Interseasonal comparison of mean number of leaves per individual for *Scutellaria montana* individuals at the VTS for June (top left), July (top right), August (lower left) and September (lower right) for each treatment during 2011 (dark gray) and 2012 (light gray). Bars shown are means ± 1 SE.

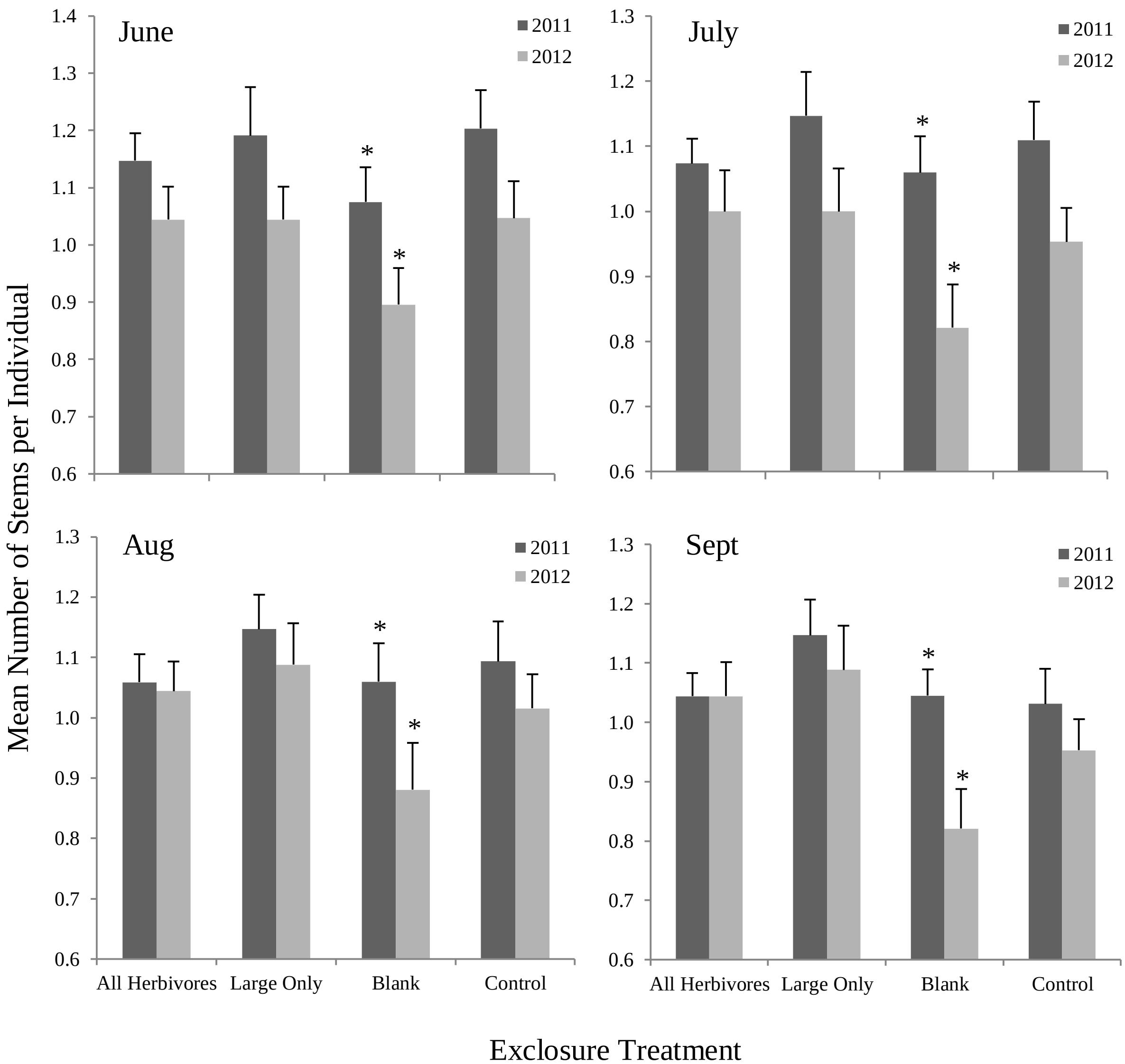

Figure 2.10 Interseasonal comparison of mean number of stems per individual for *Scutellaria montana* individuals at the VTS for June (top left), July (top right), August (lower left) and September (lower right) for each treatment during 2011 (dark gray) and 2012 (light gray). Bars shown are means ± 1 SE.

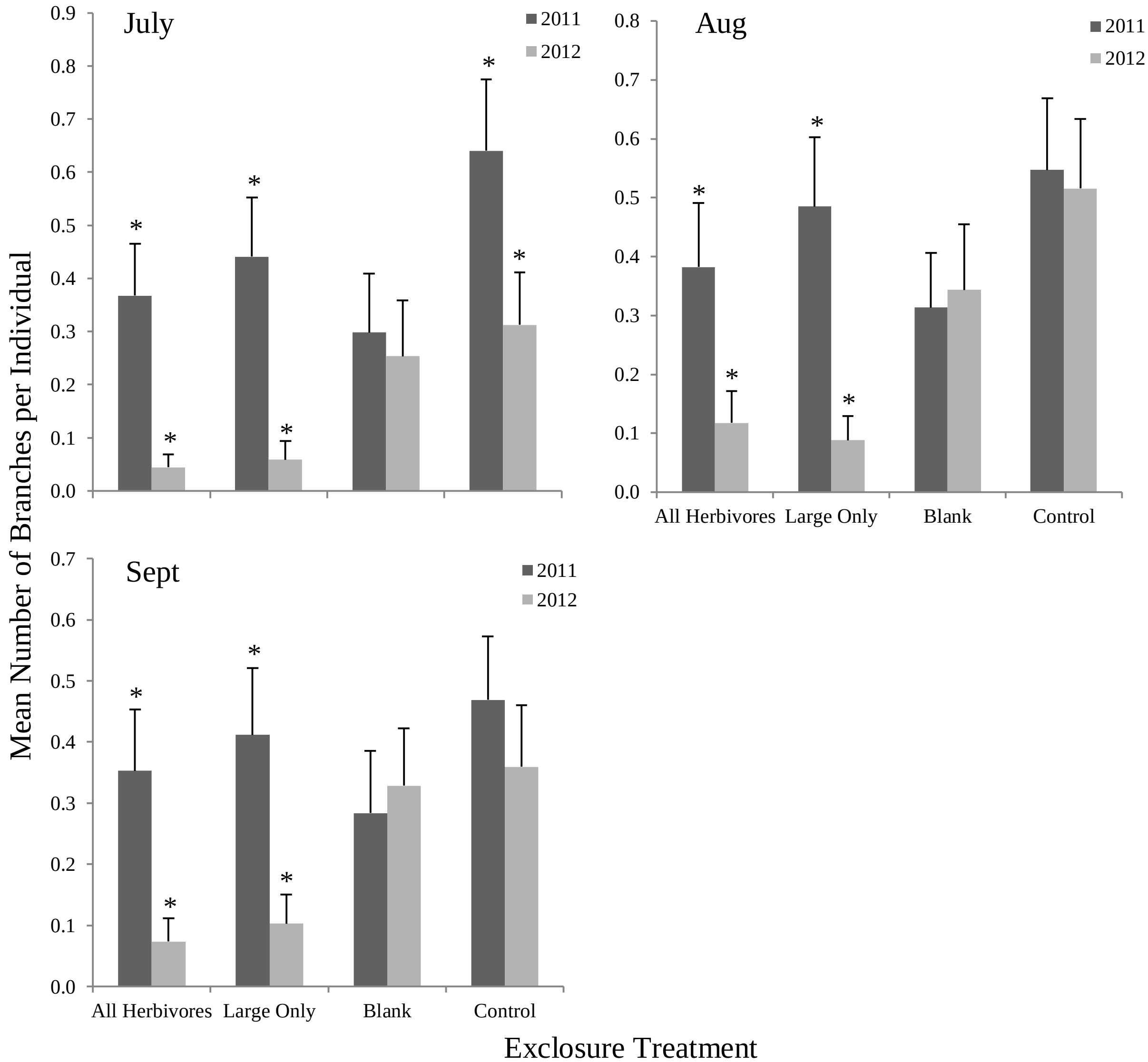

Figure 2.11 Interseasonal comparison of mean number of branches per individual for *Scutellaria montana* individuals at the VTS for July (top left), August (top right), and September (lower left) for each treatment during 2011 (dark gray) and 2012 (light gray). Bars shown are means ± 1 SE.

We also conducted an interseasonal analysis to evaluate the effects of protection from herbivores between the two study periods (see Table 2.7). Results indicated that during both study periods, number of leaves per plant decreased (Figure 2.12). Overall, individuals with the all herbivores exclosure treatment had a significantly greater decrease ($P \leq 0.05$) in number of leaves per individual during 2012 (40.4%) compared to 2011 (20.6%). All herbivores exclosure treatment for both 2011 and 2012 were not significantly different from any other treatment/year. Individuals exposed to herbivores in the blank exclosure treatment had an observably very similar decrease in number of leaves during 2011 (37.6%) and 2012 (38.9%). Individuals exposed to large herbivores only also had an observably similar decrease in this variable during 2011 (25.4%) and 2012 (27.1%). Observably, individuals exposed to herbivory in the non-exclosed control treatment lost a lower proportion of leaves than during 2012 (27%) than during 2011 (38.4%). During 2012, the large only exclosure treatment had a slightly greater decrease (27.1%) in number of leaves than during 2011 (25.4%).

Table 2.7 Summary of one-way ANOVA results for mean percent change in the numbers of leaves of *Scutellaria montana* individuals within each of the four herbivory exclosure treatments (large and small herbivores exclosed, *All Herbivores*; only large herbivores exclosed, *Large Only*; PVC frame only and no herbivores exclosed, *Blank*; and unframed non-exclosed individuals, *Control*) at the VTS for 2011, where exclosure treatment was considered the fixed independent variable.

	Sum of squares	df	Mean square	F	P
Treatment	2.553	7	0.365	1.198	0.302
Error	146.097	480	0.304		
Total	197.324	488			

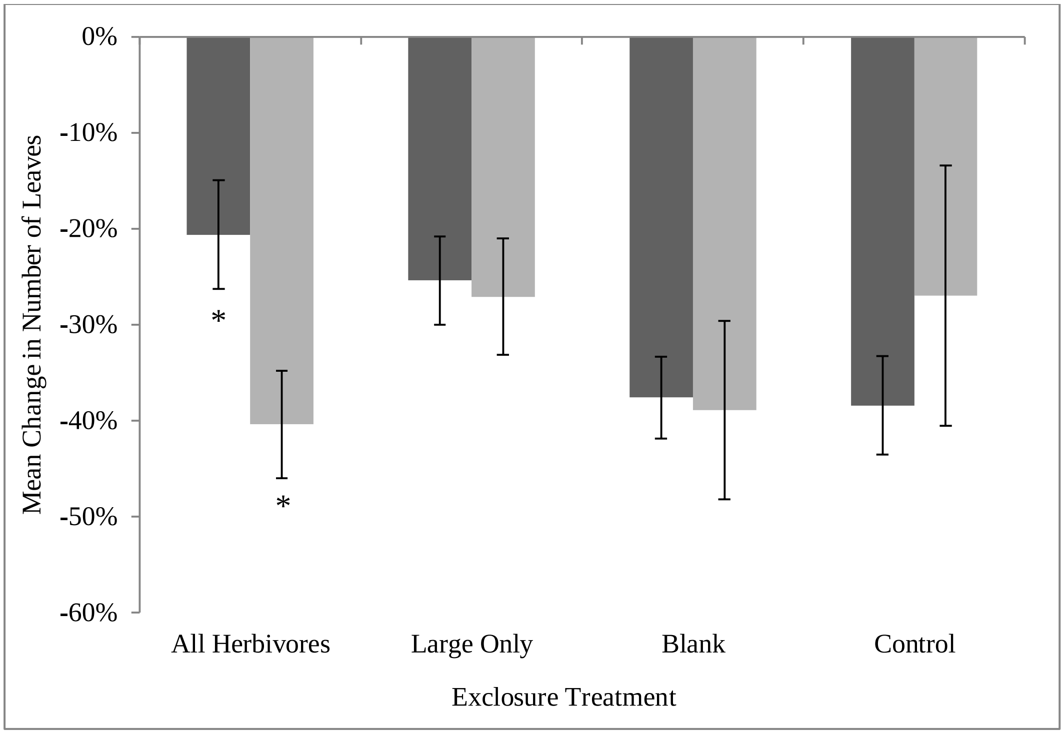

Figure 2.12 Mean percent change in number of leaves of *Scutellaria montana* individuals in each of four herbivory exclosure treatments (large and small herbivores exclosed, *All Herbivores*; only large herbivores exclosed, *Large Only*; PVC frame only and no herbivores exclosed, *Blank*; and unframed non-exclosed individuals, *Control*) at the VTS for 2011 (dark gray) and 2012 (light gray). Bars shown are means $\pm$ 1 SE. Values shown below the same letter are not statistically different at the P $\leq$ 0.05 level of significance.

An interseasonal analysis of mean percent change in stem height between the two study periods was also conducted (see Table 2.8). A comparison of results for mean percent change in steam height (Figure 2.13) for 2011 and 2012 indicate that plants protected from all herbivores experienced a negligible change in this variable during both 2011 (2.2%) and 2012 (-0.7%). Plants that were protected from large herbivores only experienced an increase in stem height during 2011 (7.3%), and during 2012 experienced a decrease (-3.1%). Plants that served as non-exclosed control individuals experienced a stem height decreased during 2011 (-8.6%). However, during 2012, there was a negligible change in this variable for individuals in the blank exclosure treatment (-0.9%) indicating a decreased browsing pressure during that study period for these individuals. Plants that received the blank exclosure treatment saw a negligible change in stem height (-0.8%) throughout the 2011 study period, but during 2012, individuals in the blank exclosure treatment experienced a decrease in stem height (-23.2%) that was significantly different from results during 2011.

Table 2.8 Summary of one-way ANOVA results for mean percent change in stem height of *Scutellaria montana* individuals within each of the four herbivory exclosure treatments (large and small herbivores exclosed, *All Herbivores*; only large herbivores exclosed, *Large Only*; PVC frame only and no herbivores exclosed, *Blank*; and unframed non-exclosed individuals, *Control*) at the VTS for 2011, where exclosure treatment was considered the fixed independent variable.

	Sum of squares	df	Mean square	F	P
Treatment	3.306	7	0.472	4.146	0.000
Error	54.669	480	0.114		
Total	58.350	488			

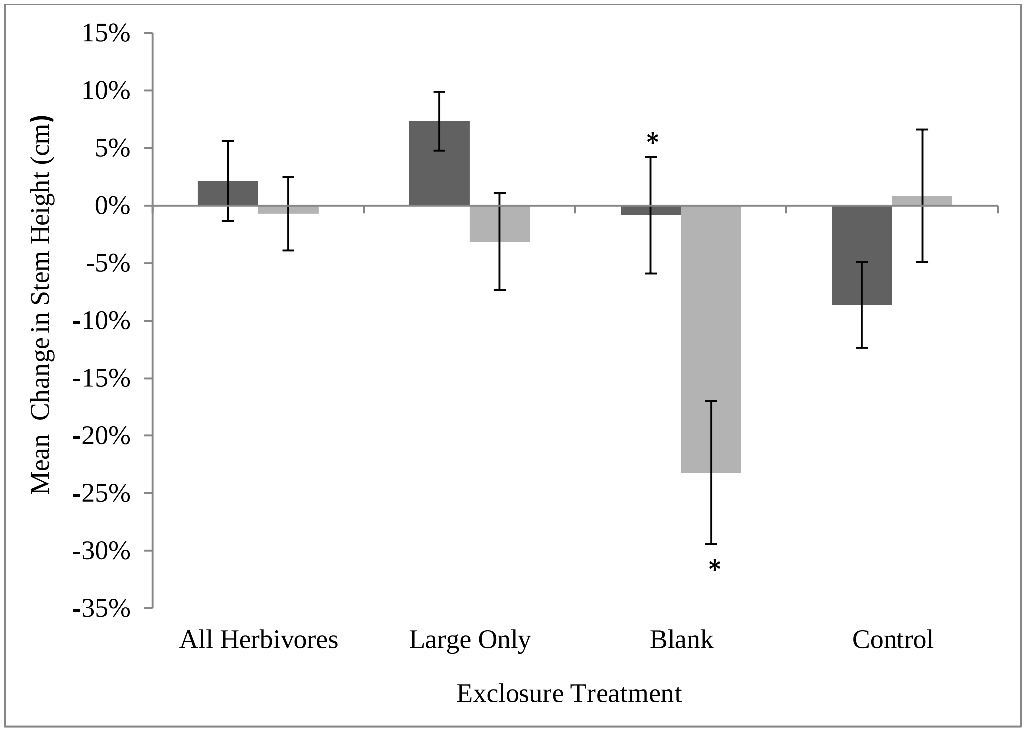

Figure 2.13 Mean percent change in stem height for *Scutellaria montana* individuals for each of the four exclosure treatments (both large and small herbivores exclosed, *All Herbivores*; only large herbivores exclosed, *Large Only*; PVC frame only and no herbivores exclosed, *Blank*; and unframed non-exclosed individuals, *Control*) at the VTS for 2011 (dark gray) and 2012 (light gray). Bars shown are means $\pm$ 1 SE. Values shown below the same letter are not statistically different at the $P \leq 0.05$ level of significance.

Conclusions and Discussion

In this study, we examined the impacts of large mammal herbivory, specifically that by white-tailed deer, on *S. montana* individuals at the VTS-Catoosa. Research was conducted over the course of two study periods to determine if large mammal herbivores are impacting *S. montana* at the individual and population levels and to assist VTS staff in determining if controlling deer within the site would provide increased protection for *S. montana*. Although another large mammalian herbivore, feral hog (*Sus scrofa* L.), is present at the VTS, and indications of rooting have been noted near *S. montana* groups (Snyder and Lecher 2010), no feral hog hoof prints or rooting evidence were observed at any of our herbivory study plots during this study. In contrast, we made many observations of deer presence at our study plots, including deer sightings, a rough cut characteristic of deer browse to browsed individuals, presence of deer pellets at multiple sites, hoof prints and trails. Therefore, damage from large mammal herbivores to *S. montana* within our study plots is assumed to result from white-tailed deer browsing.

To address our goals, the impact of herbivory on *S. montana* at the individual level was assessed by examining herbivory impacts to stem height and number of leaves per individual. Results indicated that deer caused a mean percent decrease in number of leaves for *S. montana* individuals during 2011, because plants exposed to herbivory had a significantly greater decrease in this variable compared to plants protected from large and small herbivores. A decrease in leaves can be detrimental to a plant because it results in decreased photosynthetic capabilities (Anderson 1994; Fletcher et al. 2001a; Frankland and Nelson 2003). Over the long-term, this reduction could negatively affect flowering and associated reproductive activity (Anderson 1994; Fletcher et al. 2001a). During 2012, the decrease in this variable was not significantly different between any of the herbivory treatments, suggesting that there was year-to-year variability in the impact of herbivores on leaf number, but perhaps no long-term impact of herbivory on leaf loss throughout the growing season.

The interseasonal monthly comparison of mean percent change in number of leaves suggested that over the two study periods, there was variability in this for *S. montana* individuals which was not solely due to deer herbivory. Only plants that were protected from both large and small mammal herbivores by exclosures had a significantly different mean percent loss in number of leaves suggesting effects from a factor other than direct browsing by mammal herbivores, such as abiotic factors necessary for plant growth, like as soil nutrients, soil moisture, light availability, etc. It has also been observed during annual monitoring efforts that leaf number per individual tends to vary widely from year-to-year (Shaw, personal communication) and from plot to plot (Boyd et al. 2010). It is noteworthy to mention that some degree of insect-caused leaf damage was observed for all individuals at some point during each of the two study periods, which can also cause leaf loss (Fletcher et al. 2001b). It has been shown that the number of invertebrates (including insects) within plots protected from large mammal herbivores specifically moose, was greater than in plots exposed to herbivory (Suominen et al. 1999). Leaf damage by deer could similarly influence insect pressure on *S. montana* in our study sites, although this link was not investigated. As with the monthly interseasonal comparison, a yearly interseasonal comparison showed that none of the treatments with plants exposed to herbivores of any size (i.e. large only, blank and non-exclosed controls) had a significantly different percent change in number of leaves between seasons. The difference in this variable however was significant between 2011 and 2012 for the all herbivores exclosure treatment, indicating that again, a factor other than deer herbivory influenced this variable.

We also examined mean percent change in stem height per individual and predicted that deer would have a negative effect on this variable. However, this prediction was not supported by our findings. Given the varying levels of protection from herbivory, we expected that individuals that were completely protected from small and large mammal herbivores would have experienced the greatest overall percent increase in stem height during the study period and that plants protected from large herbivores only would have experienced the second greatest percent increase in plant stem height. However, results showed that in 2011, plants that were protected from large herbivores only showed the greatest overall percent increase in stem height. We suggest that for this treatment, small herbivores may have played a positive role through thinning of competing plants within the exclosures (see van der Wal et al. 2000). While we cannot speculate on specific resource competition between *S. montana* and other understory plants, it has been documented that although *S. montana* does not prefer direct sunlight exposure (Johnson 1991), it does appear to be negatively affected by heavy shading (Johnson 1991; King 1992; Nix 1993; USFWS 2002). Additionally, we expected to see a comparable decrease in this variable for plants that were exposed to herbivory in the blank exclosure and non-exclosed control treatments, but instead saw that individuals with the blank exclosure treatments experienced a negligible percent change in stem height while non-exclosed control individuals experienced a decrease. We suggest the vertical posts of the blank exclosure may have inadvertently provided protection from herbivory because blank exclosures were often applied to individuals that would not fit within the confining mesh of the other exclosure treatments, but would fit within the blank exclosures if situated in the corner of the cage against the vertical posts. Another hypothesis was that herbivores did not browse individuals within the blank exclosure because they did not want to lower their head below the top of the frame and/or herbivores saw the cage frame and did not attempt to browse individuals because they could not browse individuals inside the other exclosures.

Results for the 2012 study period also showed that large mammal herbivores did not impact percent change in stem height of *S. montana* individuals. The significantly greater percent reduction in stem height during 2012 for individuals in the blank exclosure and flat PVC square treatments compared to non-exclosed controls indicated that white-tailed deer not only discerned that plants inside these two treatments could be browsed, but they browsed these individuals more heavily. It appeared that the white PVC pipe may have attracted deer once they learned that they could access plants inside the blank exclosure and flat treatments. It has been shown that through classical conditioning, white-tailed deer can be trained to respond to a stimulus when there is a food reward (Henke 1997). In our experiment, deer may have responded to the white PVC pipe as a stimulus that signaled food including *S. montana* was within that area.

A monthly interseasonal comparison of mean individual stem height for each treatment/year for June through September showed that protection from deer had a similar effect on this variable during the two study periods, except for plants in the blank exclosure treatment. Specifically, mean individual stem height was significantly different only for individuals in the blank exclosure treatment for all months between the 2011 and 2012 seasons. In addition, non-exclosed control individuals experienced a shift in this variable from a decrease in 2011 to a negligible change during 2012 when deer seemed possibly to focus on individuals in the blank exclosure treatment. This comparison of mean percent change in stem height during 2011 and 2012 study periods also reinforced our hypothesis that after the first study period, the PVC pipe served to attract deer to *S. montana* plants, thereby increasing browsing pressure on these individuals and resulting in a decrease in stem height. For individuals protected from large mammal herbivores in the all herbivores and large only exclosure treatments, the shift from having a slight increase in this variable during 2011 to having a slight decrease over the 2012 study period indicated that a variable other than deer impacted these plants. This further supported that over the long-term, the absence of herbivore thinning of competing plants may have negatively impacted stem height of *S. montana* through resource competition. Again, we cannot speculate on specific resource competition between *S. montana* and other understory plants but do believe that this interaction warrants further investigated with an experiment involving various degrees of thinning of understory vegetation growing proximally to *S. montana* individuals.

The impact of herbivory on the number of stems per individual was determined through examining the proportion of multiple-stemmed individuals during the 2011 and 2012 study periods. Herbivory has been shown to cause an increase in the number of stems per individual in the endangered *Liatris ohlingerae* (S.F. Blake) B.R. Robe (scrub blazing star; Kettering et al. 2009), and presumably, a plant with more stems will have more leaves, and therefore more photosynthetic capabilities. If herbivory did result in an increased number of stems in *S. montana* individuals, we would have expected to see treatments with plants exposed to herbivores exhibited the greatest proportion of multiple-stemmed individuals. However, individuals exposed to deer during 2011 and 2012 did not have the greatest proportion of individuals that were multiple-stemmed suggesting that having more than one stem cannot be directly attributed to herbivory.

The proportion of individuals that exhibited branching during the study periods was also examined. Branching following herbivory damage has also been documented for *S. montana* (King 1992). Therefore we expected to see treatments with individuals exposed to herbivory exhibit the greatest proportion of branched individuals. Individuals protected from deer were characterized by more branches during 2011 than 2012 when considered across entire seasons. These findings were not unexpected because these individuals showed evidence of browsing prior to installation of the exclosures in May 2011. Plants exposed to both deer and small mammal herbivores in 2012 had higher proportions of individuals browsed, as well as greater proportions of individuals that exhibited branching when compared to individuals protected from herbivores. Therefore, results for 2012 suggested that deer herbivory can be correlated to branching in *S. montana* individuals. Although deer damage plants and remove biomass when they browse plants, resultant branching is a positive response for the plant because, as King (1992) reports, branching as a consequence of apical damage early in the growing season is likely to result in more flowers per plant, and the more flowers per plant, the greater the reproductive potential.

Also to address our goals, the impact of large mammal herbivory on *S. montana* at the population level was assessed by evaluating the potential of large mammal herbivores to influence *S. montana* population dynamics. We hypothesized that since white-tailed deer are most sensitive to shorter wavelengths of the visible spectrum (Jacobs et al. 1994) and the blue/purple color of *S. montana* flowers is within this range of wavelengths, deer may target *S. montana* adults during anthesis and browse reproductive structures, thereby negatively affecting reproductive rates. Research has suggested that deer feed preferentially on taller, flowering individuals rather than shorter, non-flowering individuals of a given plant species (Anderson 1994; Frankland and Nelson 2003), which has the potential to reduce population growth and/or size (Garcia and Ehrlén 2002). Since preferential browsing may lead to a decline in population growth and ultimately to the local extirpation of populations (Anderson 1994; Balgooyen and

Waller 1995; Augustine and Frelich 1998; Frankland and Nelson 2003), it was important to assess the impact that deer are having on this rare species. Results for 2011 did not indicate that herbivores were preferentially browsing a specific plant life stage, but results for the 2012 study period indicated that herbivores preferentially browsed juvenile individuals.

Overall, this research demonstrated that large mammal browsing did not directly affected *S. montana* individuals in a negative way at the VTS. However, when possibly attracted by the white PVC pipe to plants inside the blank exclosure and flat PVC square treatments during 2012, browsing by large mammal herbivores caused a stem height decrease to plants. Results also showed that deer may have positive, indirect impacts on *S. montana* at the VTS by consuming competing understory vegetation and inducing branching. The positive impact of thinning is consistent with observations of *S. montana* in the Marshall Forest where areas with dense canopy coverage or understory vegetation was found to contain few or no plants (Nix 1993). Impacts of resource competition on *S. montana* from other understory vegetation warrant further investigation, and we recommend an artificial thinning experiment with varying degrees of thinning (no thinning, intermediate thinning to simulate herbivore thinning, and complete removal of competing plants) be conducted on plants protected from herbivory. This will allow for the effects of resource competition on *S. montana* to be evaluated apart from herbivory impacts.

In regards to management of white-tailed deer populations at the VTS, it does not appear that culling the current deer population would positively impact *S. montana* individuals there to any major degree. In contrast, we suggest that decreased browsing of competing understory plants by deer could negatively impact *S. montana* individuals if the deer population at the VTS were thinned. Continuing this exclosure experiment could help to help solidify our conclusions on how large mammal herbivores are impacting *S. montana* individuals at the VTS. If this research continues, we suggest disguising the white PVC pipe of treatments by painting it so that deer are not attracted inadvertently to individuals inside certain treatments. If this research is not going to continue, since the white PVC pipe seems to attract deer to *S. montana* individuals and individuals that are protected from deer browse may be negatively impacted by resource competition of other understory plants also not browsed, that all exclosures will be removed from the site so that deer are allowed to feed on all vegetation as they would naturally.

CHAPTER 3

EFFECT OF DISTURBANCES ON LARGE MAMMAL HERBIVORY OF *SCUTELLARIA MONTANA* CHAPM. AT A MILITARY TRAINING SITE, CATOOSA COUNTY, GEORGIA

Introduction

Historically, natural fire played an important role in shaping ecosystems throughout North America (USGS 2000). However, fire has been largely suppressed in natural areas since European settlement to protect public and private interests and to prevent its perceived destruction of certain ecosystems such as grasslands and forests (USGS 2000). Today, fire is used in many areas as a management tool to restore and maintain the ecological structure of natural plant and animal communities (USGS 2000), as well as to reduce fuel loads (Certini 2005; Gurevitch et al. 2006). The effects of fire on herbaceous vegetation include both positive and negative impacts. Among its positive effects, fire has been associated with increased soil nutrient availability, germination rates, and species richness (Christensen and Muller 1975; Delzare et al. 1992; Harrod et al. 2000; Glasgow and Matlack 2007). For example, the nutrient content of upper soil layers increased significantly in recently burned *Adenostoma* chaparral, while release from shrub cover following fire stimulated increased germination for herbaceous plants in this ecosystem (Christensen and Muller 1975). In a temperate deciduous forest of Ohio, cool fires that removed leaf litter also have been shown to increase germination rates for certain species including American burnweed (*Erechtites hieracifolia* (L.) Raf. ex DC) and tulip poplar

(*Liriodendron tulipiferia* L.), whereas hot fires facilitated germination of blueberry (*Vitis* spp.), smooth sumac (*Rhus glabra*, L.) and American pokeweed (*Phytolacca americana* L.; Glasgow and Matlack 2007). At the ecosystem level, positive effects include increase in species richness soon after fire occurs (Delzare et al. 1992; Harrod et al. 2003). In forests of southern Switzerland, Delzare et al. (1992) saw that in areas of frequent burn, there was an increase in species richness especially for ruderal species such as brittlestem hemp nettle (*Galeopsis tetrahit* L.) and maidens tears (*Silene vulgaris* (Moench) Garcke) following fire. An obvious negative effect to plants immediately following fire is death, but other negative effects of fire include post-fire increase in invasive species (e.g., Keeley et al. 2003; Jacquemy et al. 2005). Additionally, Martin and Moody (2001) found that at two sites in New Mexico and Colorado, soil infiltration rates of water decreased following a severe fire, and which would mean less soil moisture for plants in that area. Despite concerns about the negative impact of fire on species of conservation concern, a synthesis of the effects of fire on rare plants showed that 25% of all plant species listed and proposed for protection under the U.S. Endangered Species Act required fire to maintain populations, 35% tolerated fire without long-term effects, and 38% were not affected by fire, while only 2% were adversely affected by fire (Owen and Brown 2005). Tree thinning to reduce fuel loads is also used as a proactive tool in fire management (Ducrey and Toth 1992; Keeley 2006). In species such as *S. montana* that may be negatively affected by lack of light availability (Johnson 1991, King 1992, Nix 1993), thinning may increase habitat quality (Mullhouse et al. 2008).

Like fire, herbivory also comprises a natural disturbance to herbaceous vegetation that has been associated with both positive and negative impacts. White-tailed deer (*Odocoileus virginianus* Zimmerman) have been shown to negatively impact common herbaceous plant species through their removal of vegetative and reproductive tissues (e.g. Anderson 1994; Augustine and Frelich 1998; Garcia and Ehrlén 2002**;** Frankland and Nelson 2003; Knight 2007). Specifically, a study by Anderson (1994) showed that chronic herbivory of large-flowered trillium (*Trillium grandiflorum* (Michx.) Salisb.) resulted in smaller individuals and a decrease in the number of individuals that flowered. A study by Fletcher et al. (2001a) similarly found that herbivory resulted in decreased plant size and lower reproductive activity in common forest forbs such as bellwort (*Uvularia* L. spp.) and lily (*Smilacina* Desf. spp.). Through time, a reduction in photosynthetic and reproductive structures could negatively affect flowering and associated reproductive activity (Anderson 1994; Fletcher et al. 2001a), and possibly even lead to the extirpation of populations that are preferentially browsed (Anderson 1994; Balgooyen and Waller 1995; Augustine and Frelich 1998; Frankland and Nelson 2003). Ultimately, the extirpation of plant species from an area could reduce overall plant species diversity (Balgooyen and Waller 1995; Fletcher et al. 2001a; Rooney and Waller 2003), which could negatively impact insect pollinators and other herbivores, thereby decreasing overall biotic diversity (Anderson 1994).

Other research has suggested that herbivory can positively impact plants by improving their ability to expand into new habitats and increasing their productivity (Velland et al. 2003; Boulanger et al. 2011). Velland et al. (2003) found that white-tailed deer herbivory of large-flowered trillium (*Trillium grandoflorum* (Michx.) Salisb.) in an eastern U.S. forest increased dispersal of viable seeds with the potential of resulting in long-distance dispersal and subsequent colonization of plants. Boulanger et al (2011) also found that deer mediated the dispersal of the rare green hound’s-tongue (*Cynoglossum germanicum* Jacq.) through consumption of flowers/seeds. Another positive effect seen in the Serengeti included increased plant biomass.

Specifically, McNaughton (1976) showed that grazing by ungulates (wildebeest, *Connochaetes taurinus albojubatus* Burchell) in a *Themeda-Pennisetum* grassland of the Serengeti converted a senescent plant community into a productive one by stimulating overall growth resulting in increased net primary productivity, which prepared the plant community for subsequent dry season exploitation by Thomson's gazelle (*Gazella thomsonii* Günther).

Investigations of the impacts of prescribed burning with and without associated thinning via herbivory have yielded different results for different experiments. For example, Fullbright et al. (2011) found that for three shrub species, white-tail deer herbivory did not reduce vigor of new growth production or increase mortality one year following a fire. Another study by D'Antonio et al. (1993) found that fire did not alter the intensity of herbivory in burned and unburned plots, and deer herbivory limited seedling establishment of an invasive succulent. For seedlings that were able to escape herbivory, the post-burn environment promoted establishment. Another study by Moreno and Oeche (1991) found that for chamise (*Adenostoma fasciculatum* Hook. & Arn.) in a chaparral ecosystem, increased fire intensity not only decreased plant survivorship (resprouting) but also produced a displacement in the time of resprouting which increased herbivory, sometimes resulting in the death of the plant. In another study, when yet another disturbance, tree canopy thinning, is combined with the impacts of fire, the effects on herbivory were not substantial (Apsley and McCarthy 2004). Specifically, this study of the effects of white-tailed deer browsing on the height, density, and composition of woody regeneration in oak hickory forests following thinning and prescribed fire treatments, found that although total basal area was lower on thinned and thinned/burned than on unthinned (control and burned only) plots, deer did not impact the composition of the community. Furthermore, there was no interactive effect between any of the treatments.

Scutellaria montana Chapm. (Large-flowered skullcap or Mountain skullcap) is a federally listed, perennial forb of the mint family (Lamiaceae) that is endemic to southern portions of the Cumberland Plateau and Ridge and Valley physiographic provinces (Patrick et al. 1995; Bridges, as cited in USFWS 1996; USFWS 2002). Populations of this species are documented in nine northwest Georgia counties and four southeastern Tennessee counties (USFWS 2012), and populations are suspected to exist in adjacent Alabama although none have been documented to date (Patrick et al. 1995; Bridges, as cited in USFWS 1996). Historically, natural fires occurred in known *S. montana* habitat, including the Marshall Forest, Rome, Georgia, where natural fires occurred every few years (Johnson 1991), and in a site in Marion County, Tennessee (USFWS 1996). The impact that fire may have on *S. montana* is not precisely known, but different effects have been suggested. Fail and Sommers (1993) suggested that disturbance of natural fire regimes through human controlled suppression of fires in the Marshall Forest have altered the successional sequence of native plant communities, affecting species composition. They asserted that fire suppression caused chestnut oak (*Quercus montana* Willd.) to increase in importance as a canopy species, and that this species may suppress growth of *S. montana* through allelopathy. Therefore, they recommended that the use of fire to reduce dominance of chestnut oak in the canopy might be necessary for the long-term survival of *S. montana* in their study area. Conversely, Johnson (1991) speculated that fires could devastate *S. montana* populations, but alternatively he stated that low-intensity surface fires could benefit the species and increase productivity. Additionally, he stated that the thinner canopy and understory provided by these fires opened areas for light to penetrate, which may be required for *S. montana*. Faulkner (as cited in USFWS 1996) observed *S. montana* persisting in a location in Marion County, Tennessee where plants had been subjected to logging activities and low-intensity ground fires, and he concluded that while plants which were established before the disturbance have a chance of survival, recruitment into those disturbed sites was unlikely.

The Tennessee Army National Guard (TNARNG) Volunteer Training Site (VTS) located in Catoosa County in northwest Georgia (Figure 3.1), houses one of the largest known occurrences of federally protected *S. montana* within its 1,628 acres (Snyder and Lecher 2010). As part of the training and ecosystem management needs at the VTS, prescribed burning and thinning does take place. However, its influence on *S. montana* at this site is unknown (Girard 2010). In addition to investigating and quantifying the effects of large mammal herbivory on *S. montana* individuals at the VTS (Chapter 2), a second goal of my thesis was to investigate the influence of disturbances associated with prescribed burning on large animal herbivory of *S. montana* individuals. I hypothesize that abiotic disturbances will not affect impacts of herbivory on *S. montana* because this study was conducted during only one study period and there were no replicates, and another short-term study of the impacts of canopy thinning and prescribed burning showed no effects on herbivory (Apsley and McCarthy 2004).

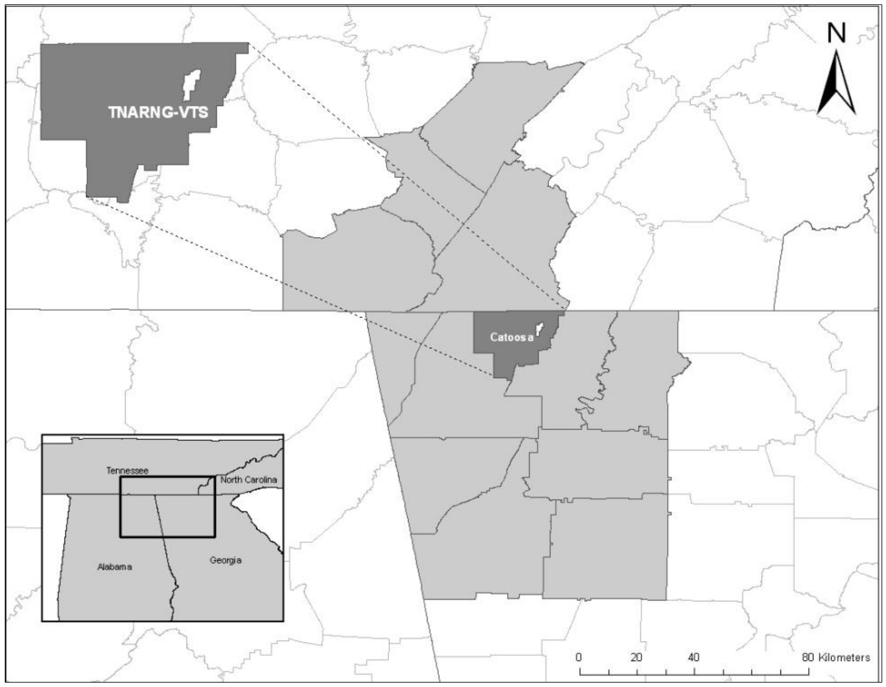

Figure 3.1 Location of Tennessee Army National Guard Volunteer Training Site in Catoosa County, Georgia (dark gray) and other Tennessee and Georgia counties with documented *S. montana* populations (light gray).

Methods

Due to unavoidable land clearing of a buffer zone along the perimeter of the VTS that would potentially disturb a few groups of existing *S. montana* individuals and their habitat, it was necessary to relocate individuals to another area with suitable habitat. In April 2010, UTC faculty and students (Boyd, personal communication) transplanted 100 *S. montana* individuals from two VTS property perimeter locations to an interior area within an existing management group of known *S. montana* habitat (Figure 3.2). This activity was organized by Mae Kile, a former graduate student in the Department of biological and Environmental Sciences at UTC, as part of her thesis research (Kile 2011). Within this interior area, transplanted individuals were randomly assigned to one of four 40 m^2 plots, with each plot receiving 25 plants. In March 2011, a low-grade prescribed burning treatment which consumed only the leaf litter was applied to two of the plots. Additionally, in one of each of the burned and unburned plots, woody stems less than 15-cm diameter at breast height were cleared while larger woody stems were girdled. These burning and thinning treatments are typical of those used at the VTS to control artillery training-induced fire hazards that exist on site (Girard 2010). The resultant plot treatments included a control (C), canopy thinned only (T), burned only (B), and combined canopy thinned and burned (T + B) plots. The burned area was located approximately 100 m from the unburned area, and the plots within each of those areas were spaced approximately 5 m apart (Kile 2011).

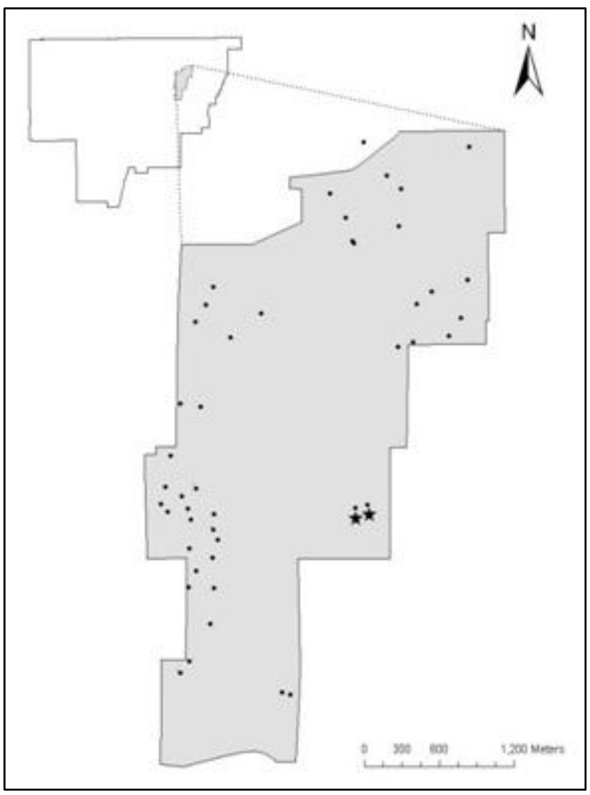

Figure 3.2 Location of *S. montana* permanent monitoring plots (dots) and disturbance study plots (stars) within the Tennessee Army National Guard Volunteer Training Site, Catoosa County, Georgia.

Research on the success of this transplantation was conducted by UTC graduate student Mae Kile (2011) as part of her thesis, and results showed that transplantation of *S. montana* was successful across thinning and burning treatments in terms of early fitness indicators including high survivability, continued maturation in the second year with increases in both growth and development, and higher flower production. However, it was reported that plants transplanted to the thinned and burned plot experienced significantly greater browsing pressure than plants in the control plot, suggesting that the T + B treatment attracted herbivores.

To investigate the effects of burning and canopy thinning on herbivory of *S. montana* individuals at the VTS, I designed and implemented an exclosure treatment in the field across the four plots in which individuals were transplanted in Kile's (2011) study. Since there were only four plots into which plants were relocated, and a different treatment was applied to each plot, replicates were not possible in this experiment. For this disturbance study I conducted, at each of the relocation plots, I fenced in *S. montana* individuals within half of the plot, an upper quarter and a diagonal lower quarter, using 7-ft tall black plastic deer fencing secured to 7-ft tall metal posts with cable ties. Fencing was secured to the ground with 4 inch garden staples, four per side, for a total of 16 per fenced off area, and blue survey tape was wrapped around the top of the fencing to help increase its visibility not only to deer but also to military personnel. There were a total of eight fenced areas and eight unfenced areas. I installed in early March before any of the *S. montana* individuals within the plots had aboveground growth. This fencing design was adapted from Apsley and McCarthy (2004), and the resultant treatments for this study were: fenced control (FC), unfenced control (UC), fenced canopy thinned only (FT), unfenced canopy thinned only (UT), fenced leaf litter burned only (FB), unfenced leaf litter burned only (UB), fenced canopy thinned and leaf litter burned (FT + B), unfenced canopy thinned and leaf litter burned (UT + B).

Once per month the following variables were measured for *S. montana* individuals included in this phase of my study: individual plant stem height (cm), number of stems, number of branches, number of leaves, number of flowers, observable damage (browsed, insect, fungal, none), and life stage (either juvenile or adult with adults having $\geq$ 10 cm stem height). Measurements were first collected in mid-May 2012 when many plants had aboveground growth and subsequent data were collected once per month through early September 2012. During 2012, there were a total of 102 plants that had aboveground growth at sometime during the study season. Three additional original metal tags were found with no aboveground biomass at any time during data collection. Of these three tags, one was in a UC, one was in a UB plot and the third was in an FB plot. These individuals were not included in data analyses. Because the specific date of initial data collection was arbitrary, I only included individuals that exhibited aboveground growth during initial data collection in May in all calculations. As a result, there were a total of 73 plants included in these analyses.

Once all data were collected, I calculated the number and proportion of plant individuals that were adult versus juvenile and browsed versus unbrowsed in each disturbance treatment. Since the USFWS (2002) describes *S. montana* as having one stem per individual, but Cruzan (2001) describes individuals that have one to several stems, the number and proportion of individuals with multiple stems each treatment were also reported. Additionally, *S. montana* typically does not exhibit branching (Collins 1976) unless release of apical dominance due to damage of the apical meristem occurs (King 1992), so I assessed number and proportion of individuals that exhibited branching for each treatment. The proportion of adult individuals with flowers was also assessed. Percent changes in stem height and number of leaves were calculated for each individual plant during each study season as the difference between the variable at the end of the growing season (September) and the beginning of the growing season (May) divided by its initial value and then multiplied by 100. I then calculated mean percent changes in plant stem height and number of leaves for each exclosure treatment during the growing season. Again, because the specific date of initial data collection was arbitrary, I only included individuals that exhibited aboveground growth at that time in all calculations. Statistical analyses were performed using IBM SPSS Statistics Version 20 software (IBM Corp., Armonk, NY). Two-way analysis of variance (ANOVA) was used to determine the fixed effects of fencing or burning and thinning and any interactive effect of mean percent change in stem height and number of leaves per individual.

Results and Discussion

I analyzed mean percent change in number of leaves per individual and mean percent change in individual plant stem height to examine effects that each of the four disturbance treatments had on impacts of herbivory by large mammals on *S. montana* aboveground biomass throughout the 2012 growing season. There were no significant effects of either fixed effect (fencing; $P = 0.344$; $F_{1, 65} = 0.908$; disturbance; $P = 0.674$; $F_{3, 65} = 0.514$) and no interactive effect between fixed effects ($P = 0. 934$; $F_{3, 65} = 0.142$) on the mean number of leaves per individual (Table 3.1). However, results indicated that the number of leaves per plant decreased for all treatments throughout the growing season (Figure 3.3). Observably, reductions in number of leaves were similar for fenced versus unfenced plots for all disturbance types, however, it appeard that there was a greater variation (as denoted by the standard error bars) in mean percent change in number of leaves for individuals exposed to herbivory for all disturbance treatments. Plants exposed to herbivory in the UB and UT + B treatments experienced the lowest decrease, at 7.3% and 11.1%, respectively. Plants protected from herbivores in the FT treatment experienced the greatest reduction (54.4%), and standard error bars indicate that plants in the UC treatment showed the greatest variation.

Similar to the leaf number results, there were no significant effects of either fixed effect (fencing; $P = 0.71$; $F_{1, 65} = 3.377$; disturbance; $P = 0.226$; $F_{3, 65} = 1.490$) and no interactive effect between fixed effects ($P = 0.388$; $F_{3, 65} = 1.023$) on stem height (Table 3.2). However, results indicated that throughout the growing season, stem height decreased for all treatments (Figure 3.4). Observably, plants in the UC treatment experienced the greatest change in this variable over the growing season with a reduction of 46.7%, whereas individuals in the FC treatment experienced the least change, showing a stem height reduction of 0.3%. It is important to note that high variation (as denoted by the standard error bars) was evident in this variable for all disturbance treatments except the FT + B treatment.

This study on the impacts of herbivory to *S. montana* individuals (Chapter 2) suggests that deer directly and negatively impacted stem height of these plants by preferentially feeding on individuals, and indirectly and positively impacted plant stem height through thinning of competing understory vegetation. In this disturbance study, however, those same conclusions could not be reached, as neither the abiotic disturbance treatments nor their possible combinations significantly affected (increased or decreased) deer browsing on *S. montana* within those plots. Results also indicated that number of leaves per *S. montana* individual decreased over the study season and no significant differences due to fencing, disturbance treatment or interactive effects were found. Since both stem height and number of leaves decreased during this study and it could not be attributed to any of the fencing/disturbance treatments, this suggests that another factor such as abiotic factors (e.g., soil nutrients, soil moisture, light availability, etc). In regard to change in stem height, I observed that around mid-July (after anthesis), plants that did produce flowers seemed to abort the top portion of the stem that held the inflorescence. Collins (1976) noted that after fruiting, *S. montana* plants dry rapidly, lose leaves and usually topple dying back to the rootstock. Although rapid dying back was not observed in this study, plants did appear decline in health (such as evidenced by wilting and loss of leaves) following fruiting. Insect damage which was observed for all but two individuals include in the study may have impacted number of leaves, as has been observed by Fletcher et al. (2001b).

Table 3.1 Summary of two-way ANOVA results for mean percent change in the numbers of leaves of *Scutellaria montana* individuals within each of the four fenced or unfenced disturbance treatments (unburned, unthinned, *Control*; canopy thinned only, *Thinned*; leaf litter burned only, *Burned*; canopy thinned and leaf litter burned, *Thinned + Burned*) at the VTS. Mean percent change was calculated for the period from May to September 2012, where fencing and disturbance treatment were considered the fixed independent variables.

	Sum of squares	df	Mean square	F	P
Fenced	0.350	1	0.350	0.908	0.344
Disturbance	0.595	2	0.198	0.514	0.674
Interaction	0.165	3	0.055	0.142	0.934
Error	25.096	65	0.386		
Total	33.487	73			

Table 3.2 Summary of two-way ANOVA results for mean percent change in stem height of *Scutellaria montana* individuals within each of the four fenced or unfenced disturbance treatments (unburned, unthinned, *Control*; canopy thinned only, *Thinned*; leaf litter burned only, *Burned*; canopy thinned and leaf litter burned, *Thinned + Burned*) at the VTS. Mean percent change was calculated for the period from May to September 2012, where fencing and disturbance treatment were considered the fixed independent variables.

	Sum of squares	df	Mean square	F	P
Fenced	0.424	1	0.424	3.377	0.071
Disturbance	0.562	3	0.187	1.490	0.226
Interaction	0.386	3	0.129	1.023	0.388
Error	8.169	65	0.126		
Total	10.077	73			

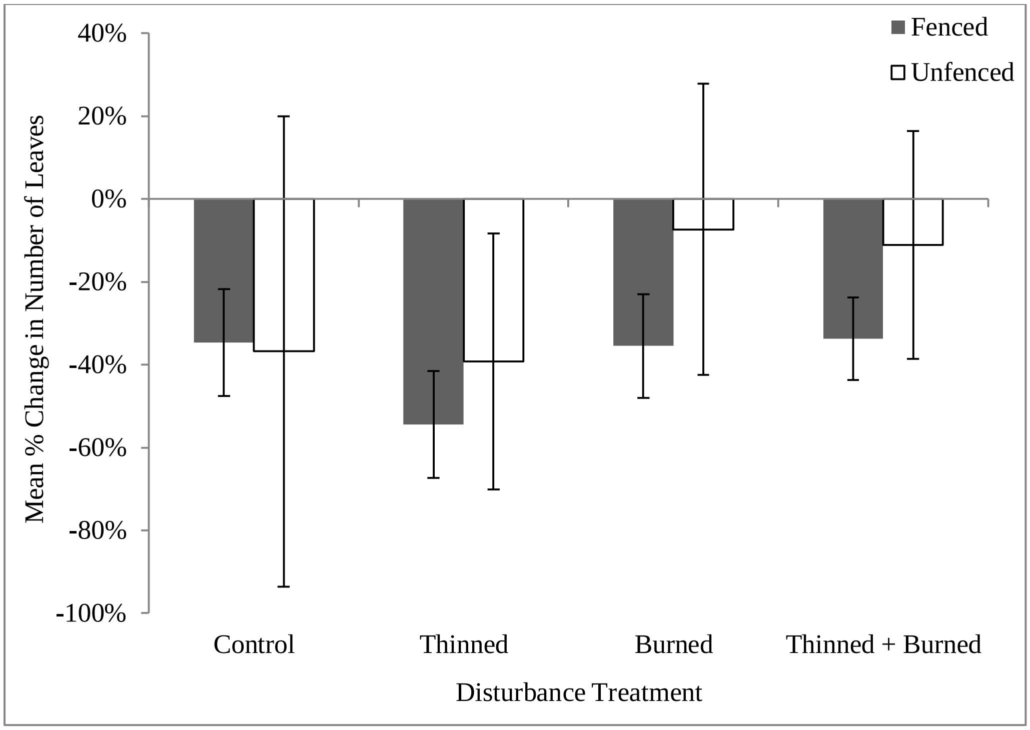

Figure 3.3 Mean percent change in the numbers of leaves of *Scutellaria montana* individuals within each of the four fenced or unfenced disturbance treatments (unburned, unthinned, *Control*; canopy thinned only, *Thinned*; leaf litter burned only, *Burned*; canopy thinned and leaf litter burned, *Thinned + Burned*) at the VTS. Mean percent change was calculated for the period from May to September 2012. Bars shown are means ± 1 SE. Values shown below the same letter are not statistically different at the $P \leq 0.05$ level of significance.

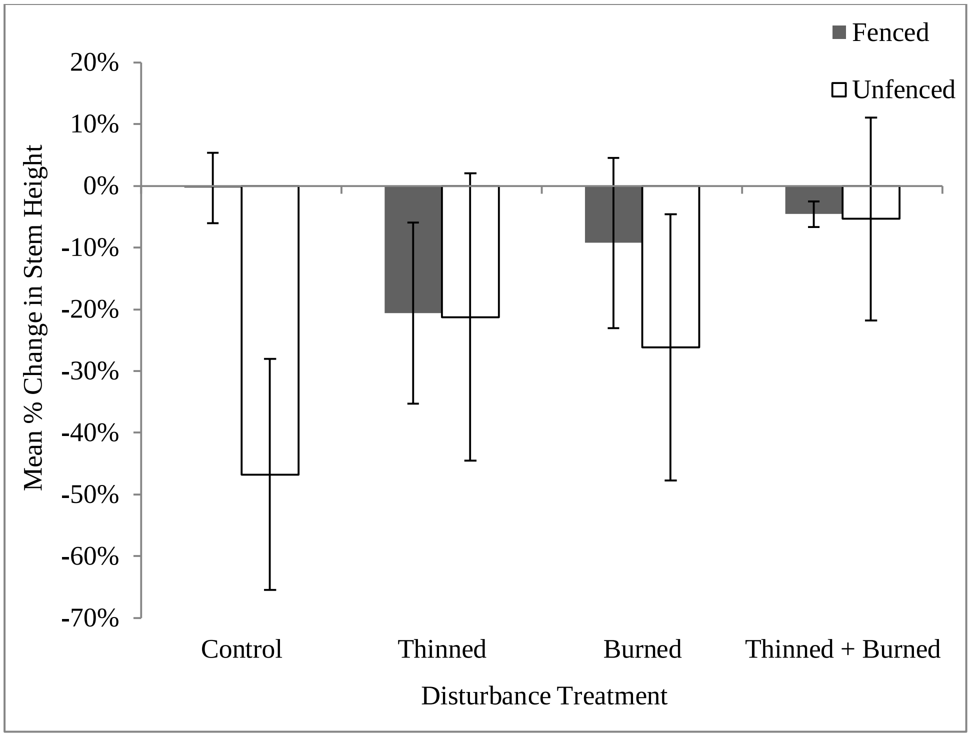

Figure 3.4 Mean percent change in stem height of *Scutellaria montana* individuals within each of the four fenced or unfenced disturbance treatments (unburned, unthinned, *Control*; canopy thinned only, *Thinned*; leaf litter burned only, *Burned*; canopy thinned and leaf litter burned, *Thinned + Burned*) at the VTS. Mean percent change was calculated for the period from May to September 2012. Bars shown are means $\pm$ 1 SE. Values shown below the same letter are not statistically different at the P $\leq$ 0.05 level of significance.

There were a greater proportion of adult individuals than juvenile individuals within each of the fencing/disturbance treatments (Table 3.3). Individuals in thinned only treatment areas (UT, n = 4; FT, n = 8) were characterized by only adult plants regardless of fencing application. Both the fenced and unfenced thinned + burned treatments had the next greatest proportion of adult plants with 95.6% in the FT + B (n=23) and 91% in the UT + B (n=11) treatments. Individuals in the FC (n=9) and UB (n=6) treatments were characterized by a lower proportion of adults than the other fencing/disturbance treatments (56% and 50%, respectively). The UC (n=4) treatment had the third lowest proportion of adult individuals with 75%. Plants in the FB treatment (n=8) were characterized by 87.5% adults.

All except one fencing/disturbance treatment had a proportion of plants that were multi-stemmed (Table 3.3). Plants in the UT treatment were characterized by zero plants with more than one stem. Individuals in the UT + B treatment were characterized by the greatest proportion of multi-stemmed individuals (63.6%) compared to plants in the other disturbance treatments. Within the other two unfenced disturbance treatments, UC and UT treatments, plants were characterized by a low proportion of multi-stemmed individuals (25% and 16.7%, respectively). Within areas that were fenced, individuals in the FB treatment had the greatest proportion of individuals with more than one stem (50%) compared to plants in the other disturbance treatments. Individuals in the FB and FC were characterized by a minority of plants with more than one stem (37.5% and 22.2%, respectively).

A proportion of individuals in each of the fencing/disturbance treatments experienced branching at some time during the growing season (Table 3.3). Overall, plants in the UT + B treatment were characterized by a high proportion of individuals that exhibited branching (72.7%), and had a greater proportion than any of the other fencing/disturbance treatments.

Plants in each the UC and UT treatments were characterized by half of individuals exhibiting branching. The remaining treatments each were characterized by a minority of individuals exhibiting branching with the FT + B treatment having 39.1% branched individuals, FT, FB and UT each with a quarter of individuals exhibiting branching, and the FC treatment with the lowest proportion of individuals exhibiting branching (22.2%).

A high proportion of adults within all fencing/disturbance treatments except the UT + B treatment had flowers (Table 3.3). Plants in the FC treatment were characterized by the greatest proportion of flowering adult individuals where 80% of adults had flowers. Of the treatments that had flowering adult individuals, the FT treatment had the lowest proportion with 37.5%. In both the UC and UB treatments a majority (66.7%) of adult individuals flowered. In each the FB, FT + B and UT treatments about half of adult plants produced flowers (57.1%, 54.5% and 50%, respectively).

Results indicated that, since all unfenced disturbance treatments had 50% or more of individuals browsed, deer do not appear to preferentially browse individuals in one disturbance treatment over another. Conclusions could not be drawn in regards to preferences for a particular life stage (adult or juvenile) because with the exception of the UB treatment which had an even number of adults and juveniles, a majority of individuals in each of the disturbance treatments were adults. Therefore, a higher probability of adults being browsed existed inherently. Neither number of stems nor branching could be directly correlated to browse pressure for any of the disturbance treatments because individuals in all fencing/disturbance treatments had a proportion of individuals with multiple stems and/or plants that exhibited branching.

Table 3.3 Total number of adult and juvenile individuals with aboveground biomass during initial data collection (May), and total number of adult and juvenile individuals that were browsed, exhibited branching, were multi-stemmed in each fencing/disturbance treatment for data collected during May to September 2012.

Fencing/Disturbance Treatment			Individuals Browsed		Individuals with > 1 stem		Individuals with Branches		Flowering Adults
	Adults	Juveniles	Adults	Juveniles	Adults	Juveniles	Adults	Juveniles	
Fenced Control (FC) (n=9)	5	4	0	0	2	0	2	0	4
Fenced Thinned (FT) (n=8)	8	0	0	0	4	0	2	0	3
Fenced Burned (FB) (n=8)	7	1	0	0	2	1	2	0	4
Fenced Thinned + Burned (FT + B) (n=23)	22	1	0	0	9	1	9	0	12
Unfenced Control (UC) (n=4)	3	1	2	1	0	1	1	1	2
Unfenced Thinned (UT) (n=4)	4	0	2	0	0	0	1	0	2
Unfenced Burned (UB) (n=6)	3	3	2	1	0	1	1	2	2
Unfenced Thinned + Burned (UT + B) (n=11)	10	1	8	0	7	0	8	0	0

In this study, I examined the influence of abiotic disturbances associated with canopy thinning and prescribed burning on large mammal herbivory, specifically that by white-tailed deer, on *S. montana* individuals at the VTS during May through September 2012. It was important to study these effects because prescribed burning and associated canopy thinning does take place at the VTS as part of the training and ecosystem management needs, but its influence on *S. montana* individuals there is unknown (Girard 2010). Although another large mammal herbivore, feral hogs (*Sus scrofa* L.), is present at the VTS and indications of rooting have been noted near *S. montana* groups (Snyder and Lecher 2010), no feral hog hoof prints or rooting evidence were observed at any of the disturbance plots during the study. In contrast, I made many observations of deer presence at disturbance plots, including deer sightings, a rough cut characteristic of deer browse to browsed individuals, presence of deer pellets at or near plots, deer hoof prints and deer trails. Therefore, damage from large herbivores to *S. montana* within my disturbance plots is assumed to result from white-tailed deer browsing.

It was important to evaluate if any of the abiotic disturbance regimes related to fire management at the VTS affected deer herbivory on *S. montana* individuals, because of common use of prescribed burning at the site (Girard 2010; Snyder and Lecher 2010). If it was found that prescribed burning and/or canopy thinning affected herbivory on *S. montana* either negatively or positively, then this knowledge could help guide VTS staff in their burning and canopy thinning activities. These results are only preliminary because this research was only conducted over the course of one study season and there were no replicates of treatments. In moving forward, I recommend that replicates of the four fencing/disturbance treatments are established within *S. montana* habitat at the VTS, and that this study is carried out over a longer period to provide more conclusive results. I also recommend that alterations are made to the fencing because the plastic mesh used in this study led to the entanglement and subsequent death of a few snakes, as well as the entanglement of a turtle that I rescued.

CHAPTER 4

SYNTHESIS OF MANAGEMENT AND CONSERVATION IMPLICATIONS

The research presented here was focused on efforts to aid in the management and conservation of a large population of the locally endemic and federally listed *Scutellaria montana* Chapm. (Large-flowered skullcap or Mountain skullcap) contained within the Tennessee Army National Guard Volunteer Training Site (VTS) in Catoosa County, Georgia. Studying the effects of management and disturbance regimes is one of the goals listed in the USFWS (1996) Large-flowered skullcap Recovery Plan aimed towards delisting of this species. Specific to the VTS, the Integrated Natural Resource Management Plan (INRMP) outlines specific goals aimed towards management of this *S. montana* population, including quantifying and monitoring S. *montana* groups, protecting those groups, and investigating management alternatives and impacts (Snyder and Lecher 2012). Examining management alternatives and impacts include the specific goals of investigating the impacts of herbivory and the impacts of prescribed burning on *S. montana* (Snyder and Lecher 2012). Although investigating the direct impacts of prescribed burning on *S. montana* was not addressed in this study, I did investigate the indirect impacts of fire management (i.e., prescribed burning and canopy thinning) on herbivory of *S. montana*.

Research presented here addressed the goal of investigating herbivory impacts to *S. montana* individuals by conducting an exclosure experiment in the field over two seasons (2011 and 2012; see Chapter 2). Results showed that during the 2011 study period, large mammalian herbivores, specifically white-tailed deer, negatively impacted stem height of *S. montana* individuals, but browsed individuals sometimes exhibited branching due to release of apical dominance. Branching following herbivory was a positive result because branches often had leaves and sometimes flowers if they were browsed early in the season, which means that herbivory did not necessarily decrease net photosynthetic tissue in these plants. Branching seems to be a mechanism by which *S. montana* is able to compensate for herbivory damage. It was also found that herbivory may have had positive, indirect impacts through thinning of competing understory vegetation (see van der Wal et al. 2000). Specific to *S. montana*, there is anecdotal evidence of this from personal observations of Boyd and Shaw at Enterprise South Nature Park, Chattanooga, Tennessee (Shaw, personal communication). After the second year of study, results showed that deer did not impact stem height of *S. montana* individuals except when the PVC pipe of the blank exclosure and flat PVC square treatments acted to attract deer to plants. Results indicated that during the first study season, the presence of the white PVC pipe frame may have acted in some way to protect individuals within treatments. However, with the presence of these frames over a longer period, deer were able to learn that within these white PVC pipe frames were palatable plants. As a result, deer actually seemed to target *S. montana* individuals within these open PVC pipe frames during the second study season. After two years of conducting research, results also supported the hypothesis that deer herbivory may have an indirect and positive effect on *S. montana* through thinning of competing understory vegetation, because plants that were protected from deer herbivory for two study seasons did not show an overall increase in stem height as was expected. Further research of this possible positive role of herbivore thinning is warranted, and I recommend an artificial thinning experiment with varying degrees of thinning (no thinning, intermediate thinning to simulate herbivore thinning, and complete removal of competing plants) be conducted on *S. montana* plants protected from herbivory. This will allow for the effects of resource competition on *S. montana* to be evaluated in the absence of herbivory impacts directly to *S. montana* individuals.

Although it was suggested in a previous study by former UTC graduate student, Mae Kile (2011) that vertebrate herbivory may be a factor negatively affecting long-term fitness of *S. montana*, my results suggested that the current level at which deer are browsing *S. montana* at the VTS will probably not have long-term negative impacts to these individuals. Research has shown, however, that high levels of chronic herbivory has the potential to cause a decline in reproductive ability of herbaceous perennials (Anderson 1994; Augustine et al. 1998; Fletcher et al. 2001a; Frankland and Nelson 2003) and possibly lead to the extirpation of populations that are preferentially browsed (Anderson 1994; Balgooyen and Waller 1995; Augustine and Frelich 1998; Frankland and Nelson 2003). As a result, it is suggested that an increase in browsing pressure resulting from an increase in deer population at the VTS could have long-term negative impacts on *S. montana*. Therefore, since the current deer population within the VTS is not known (Lecher, personal communication), it is recommended that population counts are conducted. I also recommend that if this exclosure experiment is continued, the white PVC pipe of treatments should be disguised by painting it so that deer are not attracted inadvertently to individuals inside certain treatments. However, if this exclosure experiment is not going to continue, I recommend that all exclosure treatments are removed so that the open PVC frames are no longer acting to increase browse pressure on plants by attracting deer and so that deer are allowed to browse all understory vegetation as they do naturally. Overall, it appears that the positive effects of herbivore thinning of competing understory plants outweigh any negative direct impacts that herbivores may have on *S. montana* individuals at the VTS.

Research on the effects of disturbances associated with prescribed burning and canopy thinning on impacts of herbivory to *S.* montana at the VTS (see Chapter 3) was conducted because weapons training takes place on site, making it necessary to manage fuel loads (Girard 2010). A study by Apsley and McCarthy (2004) of the effects of white-tailed deer browsing on the height, density, and composition of woody regeneration in oak hickory forests following thinning and prescribed fire treatments, found that although total basal area was lower on thinned and thinned/burned than on unthinned (control and burned only) plots, deer did not impact the composition of the community. Furthermore, there was no interactive effect between any of the treatments. Results of my study were not significant and further research is warranted because these disturbances are a part of fuel load management at the VTS (Girard 2010). Results of this study are considered to be preliminary because it was conducted over the course of a single study season and there were no replicates of treatments. Therefore I suggested that replicate treatments are established in comparable *S. montana* habitat at the VTS so that this research can continue with the goal of providing more conclusive results. The prescribed burning that took place within disturbance plots was a low level burn of leaf litter. It is suggested that to establish replicate treatments within *S. montana* habitat at the VTS, prescribed burning and thinning take place prior to March, since that is when individuals germinate (Collins, as cited in USFWS 1996). The establishment of replicate disturbance plots in areas of the VTS where *S. montana* currently exist, as opposed to in an area to where individuals were transplanted as was the case with this study, will also help the VTS in realizing another management goal, that of investigating the effects of fire on *S. montana* individuals as outlined in the INRMP (Snyder and Lecher 2012).

Although the USFWS (2002) reclassification report of *S. montana* from endangered to threatened did not list deer herbivory as a threat to this species, deer herbivory has been listed as a possible threat in other documents (e.g., USFWS 1996; GADNR 2008). This research suggests that when managing a threatened or endangered plant population, not only should direct impacts of a potential threat, in this case deer herbivory, be taken into account, but that other indirect impacts need to be considered. In this case although deer have the potential to negatively impact *S. montana* individuals, these data do not suggest that deer herbivory is a threat to the continued persistence of this species. Findings suggest that *S. montana* are able to compensate, at least in part, for deer herbivory through branching, and it appears that deer may actually play an important indirect, positive role in *S. montana* habitat because they consume other competing understory vegetation thereby alleviating some resource competition.

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VITA

Andrea R. Benson was born in Princeton, Kentucky, to Edward McAuliff, Jr. and Renee Dunbar McAuliff, and grew up in Powder Springs, Georgia. After graduating from Carl Harrison High School in Kennesaw, Georgia, she attended college at Oglethorpe University in Atlanta, Georgia. After 1.5 years there, she transferred to Kennesaw State University, Kennesaw, Georgia, from which she graduated *cum laude* with a Bachelor of Science in Biology. Following graduation, she worked as a quality assurance technician at Anheuser Busch, Inc., Cartersville, Georgia, as a Scientist I at Post, Buckley, Schuh, and Jernigan (PBS&J), Marietta, Georgia, and as a stormwater inspector in the engineering department of Cherokee County, Georgia. After a few years with Cherokee County, Andrea decided to pursue a master's degree at the University of Tennessee at Chattanooga (UTC). After being offered a graduate research assistantship under Dr. Jennifer Boyd and Dr. Joey Shaw, she decided accept and left her position as a stormwater inspector. Andrea graduated from UTC with a Master of Science in Environmental Science in December 2012. She enjoys conducting scientific research, is passionate about plant ecology, and would like to continue working in the area of environmental management and conservation.