How Reproductive Fitness in Introduced Populations Compares to Reproductive Fitness in Natural Populations of *Echinacea tennesseensis* (Beadle) Small [Asteraceae]

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ABSTRACT

HOW REPRODUCTIVE FITNESS IN INTRODUCED POPULATIONS COMPARES TO REPRODUCTIVE FITNESS IN NATURAL POPULATIONS OF *ECHINACEA TENNESSEENSIS* (BEADLE) SMALL [ASTERACEAE]

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The Tennessee purple coneflower, *Echinacea tennesseensis* (Beadle) Small [Asteraceae], is a state (Tennessee) and formerly federal endangered species naturally found in cedar glades in middle Tennessee. A loss of habitat and a naturally restrictive geographic range contributed to this coneflower being listed as endangered. *Echinacea tennesseensis* has recently been delisted from the federal Endangered Species List due to meeting the criteria of its recovery plan. These criteria included conservation efforts and the establishment of new populations of *E. tennesseensis*. Although the species had met the criteria for delistment, it was unknown how the reproductive fitness of the introduced colonies compared with that of the natural colonies.

Statistical analysis of germination rates found a marginally significant interaction between introduced and natural populations, especially at the Couchville site. Statistical analysis of seed set levels found significant differences in seed production between natural and introduced populations at the Vine and Vesta sites, with introduced populations having higher seed production than the natural populations at those sites. Introduced populations at

the Vine site also had higher viable seed set. However, there were no differences at the Couchville site between the natural and introduced populations. In these analyses of seed traits that relate to fitness success, introduced colonies are just as, if not more, successful than natural colonies of *E. tennesseensis.* Seed production and viable seed set are similar or greater in introduced than natural colonies. Thus, introduced colonies appear to have the same regeneration potential as natural colonies and are just as reproductively functional, a key component when evaluating restoration success.

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CHAPTER I

INTRODUCTION

Echinacea tennesseensis (Beadle) Small (Asteraceae) (Tennessee coneflower) is a spring-blooming polycarpic perennial endemic to the cedar limestone glades of central Tennessee (Baskauf et al. 1994). After McGregor was unable to locate any *E. tennesseensis* plants between 1959-1961, the species was considered extinct. However, plants were subsequently found at a site in 1967 (Walck, Hemmerly and Hidayati 2002). *Echinacea tennesseensis* was placed on the Endangered Species List on June 6, 1979 due to the following identified threats: loss of habitat due to development; collection of the species; no Tennessee state law protecting rare plants; and succession of the cedar glade communities in which the plant occurred (Federal Register 2010). Hemmerly (1986) believed that possible factors for *E. tennesseensis* having limited numbers included its specialized habitat and its lack of adequate dispersal mechanisms. On February 14, 1983, the U.S. Fish and Wildlife Service published the Tennessee Coneflower Recovery Plan, which was revised on November 14, 1989. One of the criteria for considering the species recovered was if there were at least five secure wild populations, each with three self-sustaining colonies (Federal Register 2010). The Recovery Plan defined a population as a group of colonies in which the probability of gene exchange, through cross pollination, is high. A colony was then defined as plants found at a single site but separated from other plant groups by unsuitable habitat (USFWS 1989). This criterion entailed the establishment of multiple populations of the species for two critical reasons: one, provide redundancy and two, preserve the genetic structure within the species (Federal

Register 2010). After the Recovery Plan was published, it was found by Baskauf et al. (1994), that most of the genetic diversity within *E. tennesseensis* is maintained within, instead of between, each population. This finding meant establishing multiple populations for the purpose of maintaining the genetic structure of the species was not as critical (Federal Register 2010). By 2010, it was determined that the number of existent colonies of *E. tennesseensis* exceeded the number required by the Recovery Plan for delistment, and these colonies were secure and thriving, thus the species could be considered for delistment (Federal Register 2010). In 2011, *E. tennesseensis* was delisted from the Endangered Species Act. At the time of the publishing of the Recovery Plan (1989), there were only five known populations of *E. tennesseensis*, all within 23 kilometers (14 miles) of each other in Davidson, Wilson and Rutherford counties in middle Tennessee. Each population was at least 5 kilometers (3 miles) from any other population and varied in size from 3,700 to about 89,000 plants (USFWS 1989). Each population contained one to three colonies (Federal Register 2010). According to the Recovery Plan (1989), most of the natural colony at Vesta (colony number 2.1), in Wilson County, was owned by the Tennessee Department of Conservation, Division of Forestry, with the remainder privately owned. This site was roughly 100 acres in size with most of the 16,000 *E. tennesseensis* plants on land owned by the State. Prior to state-ownership, most of the site was open farmland. At Vine, natural colony 3.1, in Wilson County, was under both state and private ownership and was roughly six acres in size, with *E. tennesseensis* found in various sites. Natural colony 3.2, on the border of Wilson and Rutherford Counties, was under private ownership and *E. tennesseensis* was found in small groups over an area of 100 acres. The population at Couchville, in Davidson County, was the largest known population and consisted of one colony, natural colony 5.1. Privately owned and covering roughly 150 acres, this colony contained approximately 89,000 *E. tennesseensis* plants, as well as other state-protected species (USFWS 1989). There are now six populations within a 400 square kilometer (154 square mile) area, and each population contains between two and eleven colonies (Federal Register 2010). These colonies are located on federal, state, or private property.

Plant Background

Echinacea tennesseensis is pollinated by generalist insects, such as bumblebees (*Bombus* spp.), honeybees (*Apis mellifera* L.) and various species of butterflies (Walck, Hemmerly and Hidayati 2002). The genus *Echinacea* consists of nine species which are found in eastern and central North America. Three species (*E. augustifolia*, *E. pallida*, and *E. purpurea*) are used in medicinal remedies (Walck, Hemmerly and Hidayati 2002). Since *E. tennesseensis* has been delisted, *E. laevigata* (Smooth Coneflower), another southeast native, is now the only species in the genus still on the Federal Endangered Species List (USFWS Species Profile). The cedar limestone glades to which *E. tennesseensis* is endemic, are unique to the southeastern United States, found primarily in middle Tennessee (Center for Cedar Glades Studies). Along with *E. tennesseensis*, there are eighteen other species endemic to the cedar glades of the United States (Walck, Hemmerly and Hidayati 2002). The tree-less cedar limestone glades have very thin and in some places, absent, soil and a shallow bedrock which contributes to the formation of a harsh micro-climate to which species have specially evolved (Center for Cedar Glades Studies). The plant composition of the areas of the glades where *E. tennesseensis* is found is varied (Walck, Hemmerly and Hidayati 2002). *Echinacea* *tennesseensis* is self-incompatible, does not reproduce vegetatively, and has overall low genetic diversity. It is shade intolerant, grows best in high light conditions, and can tolerate a wide range of soil moisture conditions such as are found in the cedar limestone glades (Walck, Hemmerly and Hidayati 2002).

<u>Other Recovery Efforts</u>

The goal of species recovery is delistment through self-sustaining populations. This goal can be achieved through protection of extant populations and their habitats and/or through (re)introduction of populations. The introduction, or reintroduction, of species into areas with an environment in common with sources is not always successful, nor is it always monitored long-term. Montalvo and Ellstrand (2000) found in common garden experiments, the performance of *Lotus scoparius* (Nutt.) Ottley (Fabaceae) decreased significantly with genetic, and sometimes, environmental distance from the source. Also, populations have crashed within a few years of introduction, such as *Amsinckia grandiflora* (Kleeb. ex Gray) Kleeb. ex Greene (Boraginaceae) (Pavlik 1996), and *Holocarpha macradenia* (DC.) Greene (Asteraceae) (Allen 1994). Some introductions have unknown long term results, such as *Conradina glabra* Shinners (Lamiaceae) (Gordon 1996) and *Hydrastis canadensis* L. (Ranunculaceae) (Sinclair and Catling 2003). Some introductions are successful, such as, *Rutidosis leptorrhynchoides* (Asteraceae) in Australia. Morgan found all reintroductions were as successful as, if not more so, than the natural remnant populations (Morgan 2000). Ritchie and Krauss (2011) found there were no significant differences between restored and natural populations of *Banksia attenuate* (Proteaceae) regarding germination rates and measured performance factors including leaf count and aboveground height. Albrecht et al. (2011), promoting long-term monitoring of reintroduced populations, mention the success of *Potentilla robbinsiana* (Rosaceae), once an endangered species. *Potentilla robbinsiana* has now been delisted after its transplanted populations reached or surpassed the minimum viable population size (Federal Register 2002).

<u>Colony Introductions</u>

Couchville

According to the Federal Register (2010), there were three natural sites. It is unknown if these sites were used as sources for the 1980s introductions of the introduced colonies under study. Plants also came from Middle Tennessee University (TDEC NHIP document).

Vesta and Vine

The introduced colonies under study at Vesta were introduced in the 1980s, and those of Vine in the late 1980s and early 1990s. The sources are unknown, but possibly from the U.S. Forest Service seed storage facility in Macon, Georgia, which received the seeds from the Tennessee Valley Authority nursery, where Dr. Robert Farmer had grown plants from seeds taken from natural colonies 2.1 (Vesta) and 3.1 (Vine) (USFWS 1989).

<u>Purpose of Study</u>

Although *Echinacea tennesseensis* (Figure 1) had met the criteria for delistment, it was unknown how the reproductive fitness of the introduced colonies compared with that of the natural colonies. It is important to know the reproductive fitness of a species in restorations because populations with great reproductive fitness will maintain and even increase their size, through replacement of older plants by younger plants, thus ensuring continued existence of the population. The purpose of this present study was to determine whether the introduced colonies were as reproductively successful as the natural colonies. The reproductive fitnesses of the two types of colonies were compared using seed set and germination data, which are standard measurements of reproductive fitness.

Figure 1. *Echinacea tennesseensis*. Photo by Dr. Matthew Albrecht. Center for Conservation and Sustainable Development.

CHAPTER II

MATERIALS AND METHODS

Study Sites

Thirteen colonies in middle Tennessee, representing natural and introduced populations, were chosen for study. These thirteen colonies were chosen because they were stable and contributed to the delistment of the species, as well as consisting of natural and introduced colonies from each population and over a wide geographic range (Matthew Albrecht, personal communication). Each colony was assigned an Element Occurrence Number (EO Number) by the Tennessee Department of Environment and Conservation (TDEC). In this study, a colony was defined as a distinct patch of plants occurring on a limestone cedar glade, and populations were defined as groups of colonies within a glade-cedar-hardwood forest landscape. These thirteen colonies were spread across four populations: Mount View (1 colony natural [1.1]), Vesta (2 colonies introduced [2.3, 2.6], 1 colony natural [2.1]), Vine (2 introduced [3.8, 3.9], 3 natural [3.1, 3.2, 3.4]) and Couchville (3 introduced [5.3, 5.5, 5.6], 1 natural [5.1]) (Figure 2).

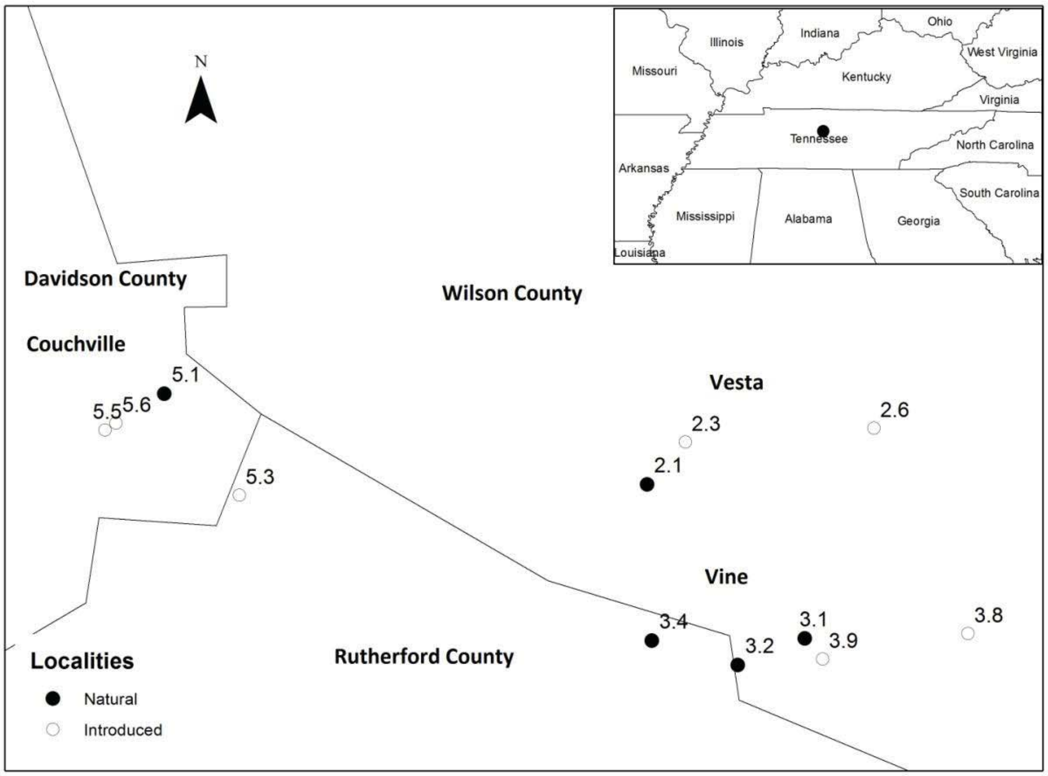

Figure 2. Map of study sites. Numbers are colony identifiers: Vesta 2.1, 2.3, 2.6; Vine 3.1, 3.2, 3.4, 3.8, 3.9; Couchville 5.1, 5.3, 5.5, 5.6. Mount View 1.1 is not located on the map because it was not included in the study, as explained in the text. Not to scale. Map courtesy of the Missouri Botanical Garden.

<u>Method of Collection</u>

Twenty maternal plants were chosen for seed collection at each of the thirteen colonies. The plants were selected by two people who walked transects through each population and collected seed heads from plants spaced at least two meters apart. In September 2010, one seed head was collected from each plant, and the site identification information was recorded on the collection envelopes.

Seed Set

Methods

Each collected seed head was taken apart and the pieces sorted into four piles: viable achenes, inviable achenes, flower parts, and other. Achenes were squeezed with tweezers to determine if they were filled (viable) or not. Flower parts included the short flowers that were sometimes still attached to the achenes. Each pile of achenes and the flower parts were then numbered and placed into separate labeled envelopes.

Statistical analysis

Conservation and Sustainable Development (CCSD), performed the statistical analysis on seed set using R (2013). Differences in seed production were analyzed via a generalized linear model (GLM) with a negative binomial error distribution and log link function. The error and link functions provided a better fit to the seed count data than log-transformed linear regression or Poisson regressions. Differences in the fraction of viable seeds per head were compared using GLM with a binomial error distribution and logit link function to account for the fact that the data were proportional. In cases where data were overdispersed compared to the expected binomial distribution, a quasibinomial error distribution was used to correct the P-values. Data from Mount View were excluded because there was only one colony represented and thus no comparison could be made to other colonies in that population.

<u>Germination Rates</u>

Methods

Viable seeds processed from the seed set analysis were used to conduct the germination study. In the interest of time, the study took place at two different sites. Roughly, half the seeds were tested at Southern Illinois University at Edwardsville (SIUE) and half at the and Sustainable Development (CCSD). At SIUE, germination tests were conducted in batches of approximately 200 seeds per batch. Four to six seeds from each colony were placed in a damp sand-filled 100mm x 15mm polystyrene petri dish (Fisherbrand), and then placed in a 10 degree Celsius refrigerator for 10-12 weeks of cold stratification. The seeds were then planted in a potting mix (Pro-Mix) in plastic 6-packs in a greenhouse with fertilized watering on a regular basis, or as needed, and natural daylight, and heat lamps (70 degrees Fahrenheit) for those seeds germinating in the winter. At the CCSD, ten seeds from each colony were cold stratified at 5 degrees Celsius for 12 weeks and then transferred to a growth chamber with 20/10 degrees Celsius diurnal temperature cycles (14-hour photoperiod) as per Baskin et al. (Baskin, Baskin, and Leck 1993). The date of germination and number of plants germinated were noted when the cotyledons appeared.

Statistical analysis

Differences in seed germination were analyzed using a multi-factor ANOVA (Systat 13). A multi-factor ANOVA was also used to evaluate the interaction between the source (introduced, natural) and the population (Couchville, Vesta, Vine), and between the source and where the seeds were grown (growth chamber, greenhouse). The germination rates were arcsine square root transformed. A Least Square Means test was conducted, and the data were backtransformed. Data from Mount View were excluded because there was only one colony represented, thus no comparison could be made to other colonies in that population. The effect of stratification period length was not evaluated because stratification periods were not the same for all seeds.

CHAPTER III

RESULTS

Seed Set

Results

Seeds from 100 plants from five natural colonies were counted. Out of a total of 10,240 seeds, 3613 seeds, or 35%, were viable. Seeds from 140 plants from seven introduced colonies were counted. Out of a total of 16,285 seeds, 6471 seeds, or 40%, were viable.

Statistical analysis

There were no differences in seed production ($P = 0.44$) or viable seed set ($P = 0.65$) among colonies (3 introduced, 1 natural) at Couchville (Table 1). At Vesta, however, the two introduced colonies exhibited significantly greater (both P-values < 0.05) seed production than the natural colony, but there were no differences among the colonies in viable seed set ($P = 0.28$). There were significant ($P < 0.01$) differences in seed production among the colonies at Vine (2 introduced, 3 natural), with introduced colony 3.8 exhibiting greater seed production than other natural and introduced colonies. Similarly, both introduced colonies at Vine exhibited significantly greater viable seed set than the natural colonies ($P < 0.01$).

Table 1. Results showing total and viable seed counts. N = natural, I = introduced.

Site	Colony	N/I	Total	Viable	% Viable
Couchville	5.1	N	2332	875	38
Couchville	5.3	I	2131	785	37
Couchville	5.5	I	2150	779	36
Couchville	5.6	I	2339	950	41
Vesta	2.1	N	2090	755	36
Vesta	2.3	I	2455	971	40
Vesta	2.6	I	2593	1008	39
Vine	3.1	N	1655	564	34
Vine	3.2	N	1958	673	34
Vine	3.4	N	2205	746	34
Vine	3.8	I	2823	1207	43
Vine	3.9	I	1794	771	43
Total			**26525**	**10084**	

<u>Germination Rates</u>

Results

The total number of seeds planted was 3667(Table 2). Of these, 1539 seeds came from natural populations, and 2128 seeds came from introduced populations. A total of 1305 seeds were started in the SIUE Greenhouse, and 2362 seeds were started in the growth chamber at CCSD. The average rate of germination for natural populations ranged from

Table 2. Results of Germination Tests. N = natural, I = introduced, Grn = Greenhouse, Gr = Growth Chamber. Continued on next page.

Site	Colony	N/I	Grn/Gr	Total # of Seeds	% Germination Average
Couchville	5.1	N	Grn	117	25
			Gr	200	65.5
Couchville	5.3	I	Grn	103	39
			Gr	192	54
Couchville	5.5	I	Grn	114	41
			Gr	199	66.2
Couchville	5.6	I	Grn	110	56
			Gr	200	76.5
Vesta	2.1	N	Grn	104	28
			Gr	200	51.5
Vesta	2.3	I	Grn	109	28
			Gr	200	14.5
Vesta	2.6	I	Grn	112	62
			Gr	200	53.5

Table 2

continued.

Site	**Colony**	**N/I**	**Grn/Gr**	**Total # of Seeds**	**% Germination Average**
Vine	3.1	N	Grn	106	21
			Gr	188	46.1
Vine	3.2	N	Grn	110	30
			Gr	200	27
Vine	3.4	N	Grn	114	20
			Gr	200	49
Vine	3.8	I	Grn	102	37
			Gr	192	34
Vine	3.9	I	Grn	104	46
			Gr	191	46
			Total	**3667**	

20-65.5%. The average rate of germination for introduced populations ranged from 14.5-76.5%. The average rate of germination for seeds started in the SIUE Greenhouse ranged from 20-62%. The average rate of germination for seeds started in the growth chamber at CCSD ranged from 14.5-76.5%.

Statistical analysis

An ANOVA (Table 3) resulted in a marginally significant effect of source (natural, introduced)(P=0.0591), and a significant effect of population (Couchville, Vesta, Vine)(P=0.001). There was a significant effect of where (greenhouse, growth chamber)(P< 0.0001) the seeds were started. An ANOVA to discover interactions showed there was no significant interaction of source x population (P=0.5505), and a significant interaction of source x where (P<0.005).

Table 3. Results of analysis of variance to detect effects of source (natural, introduced), population (Couchville, Vesta, Vine), where (greenhouse, growth chamber), and interactive effects of source and population, and source and where. *** P < 0.001, ** P < 0.01, * P < 0.05, ns: nonsignificant.

SOURCE	df	MS	F	
Source	1	0.7245	3.5792	*
Population	2	1.4296	7.0628	***
Where	1	4.3516	21.4986	***
Source x Population	2	0.121	0.5977	ns
Source x Where	1	1.6431	8.1177	**
Error	470	0.2024		

CHAPTER IV

DISCUSSION

Seed Set

It appears the introductions of *Echinacea tennesseensis* have been successful. The introduced colonies either have the same or greater seed set and viable seed production as the natural colonies. The reasons why the introduced populations produce more viable seed than the native populations could not be determined by this work. The design of this study was only to detect patterns and not to determine mechanisms. However, plausible explanations include incompatibility mechanisms and numbers of pollinators. *Echinacea tennesseensis* has a sporophytic self-incompatibility (SI) system. *Echinacea purpurea* (Stephens 2008) and *E. augustifolia* (Wagenius 2006) both have sporophytic SI systems, as do all *Echinacea*, and it is common in Asteraceae (Les, Reinartz and Esselman 1991).

A way to overcome a lack of mating compatibility is to increase the population size with new plants which have a variety of mating types. A greater variety of types overcomes the pollen limitation caused by a lack of compatible mates (Wagenius 2006). This use of varied types as plant sources could have been what happened when new colonies of *E. tennesseensis* were created, possibly through the accidental artificial selection of seeds from plants that were producing viable seeds (Dr. Jeffrey Walck, personal communication). By this artificial selection, seeds were collected from plants that had overcome the sporophytic self-incompatibility system by producing viable seeds. A greater number of pollinators at the introduced sites could also have played a role (Dr. Matthew Albrecht, personal communication). Of course, seed set alone does not determine if a species will have continued success. Continued reproduction and genetic diversity ensures that a species can replace itself and adapt to conditions.

Germination Rates

Increasing the sample size and sampling from more sites could better differentiate the effects of source (natural, introduced) and population, which an ANOVA showed had marginally significant or significant effects, respectively. The significant effect of where the seeds were germinated, either a greenhouse or a growth chamber, needs additional study. Perhaps by germinating seeds from one colony, whether natural or introduced does not seem to matter, in both a greenhouse and growth chamber, it can be determined how great an influence these sites had on the growth conditions and, thus, germination rates, of the seeds. The marginally significant interaction between source and where could also be explained by there being more consistent conditions for seeds in the growth chamber. The lack of significant interaction between source and population could be because seeds from natural and introduced colonies, at all sites, share the same required or minimal conditions for germination, and these conditions were met.

Colony Introductions

Overall, natural populations had higher numbers of individual plants, thus larger colonies. However, seed set, whether total or viable, did not seem to depend on the size of the colony.

In Couchville, introduced colonies 5.3 and 5.5 showed an increase in plants from the time the plants were transplanted to the site until the site was surveyed in 2005. Introduced colony 5.6 showed a decrease in the number of flowering stems from their introduction to the 2005 census. It is unknown if colony 5.6 showed a decrease in plant number (Appendix A). The natural site, 5.1, was larger in size than any of the introduced colonies (Appendix B). However, there was no statistical difference in either total seed set or viable seed set between the natural and introduced colonies. At Vesta, introduced colony 2.6 showed an increase in plant numbers from its introduction. It is unknown if introduced colony 2.3 increased or decreased in plant number from its introduction (TDEC NHIP document, Federal Register 2010) (Appendix A). Again, though, the natural colony, 2.1 here, was larger in size than either of the introduced colonies (Appendix B). In this case, however, the introduced sites had significantly greater total seed set than the natural colony, but no differences in viable seed set. At Vine, both introduced colonies showed an increase in plant numbers from their introduction (TDEC NHIP document, Federal Register 2010) (Appendix A). The natural colonies were all much larger in size (Appendix B). However the smallest colony, introduced colony 3.8, had greater seed production than both the natural and other introduced colonies. The introduced colonies also had greater viable seed set. These results could suggest that the introduced colonies had more varied mating types than the larger natural colonies.

Concluding Remarks

The successful introduction of new colonies of *Echinacea tennesseensis* meant that this species, the second plant species placed on the Endangered Species List, could be delisted in 2011. However, more work remains to determine what, if any, genetic differences there may be between the natural and introduced colonies and between the different populations. Determining if any genetic differences exist is important because Baskauf et al. (1994) found that most of the genetic diversity of *E. tennesseensis* is maintained within, instead of between, each population (Federal Register 2010). What genetic diversity is there? How could genetic diversity affect the future continuation of the populations? Could this knowledge illuminate the evolutionary history of *E. tennesseensis*? These questions and more need to be answered, and they could be answered through molecular analyses. Some analyses have already been done on *E. tennesseensis* (see Mechanda, Baum, Johnson and Arnason 2004a,b). However, no molecular analyses have been done to determine whether there is genetic diversity between natural and introduced colonies of populations. Answering these questions for *E. tennesseensis* could contribute to knowledge needed in the conservation of other endangered species.

It is also important that monitoring of *E. tennesseensis* populations be continued. As referred to previously, populations of other introduced plants of various species have suffered population crashes, so continued monitoring is important in order to solve potential problems as early as possible. Continued monitoring is included in the recovery plan for *Echinacea tennesseensis*, as well as in the recovery plans of other endangered species.

The recovery and delistment of *Echinacea tennesseensis* can serve as a model for other endangered glade species. However, no one model will fit every species. Instead, best practices specific to each species should be developed and followed, as was the case with *E. tennesseensis* and its population dynamics (Dr. Jeffrey Walck, personal communication). Where *Echinacea tennesseensis* can serve as a model, however, is in the cooperation of the many agencies involved in its protection. In the 1980s, the Missouri Botanical Garden, along with various nurseries and state universities, participated in the collection and propagation of *E. tennesseensis* seeds. While most of the sites were on private land, The Nature Conservancy, and then the state of Tennessee, began to purchase these sites. Aerial photography was successfully used in the 1989-1991 search for new populations (Andrea Bishop, personal communication). There is continued cooperation from various federal and state agencies, universities and botanic gardens, to preserve and study this species.
Having suitable habitat nearby, as was the case with *E. tennesseensis*, is very helpful. As was the case with this species, the land on which glade species are found is undesirable for farming and not really attractive for building. Indeed, ceda
contributing to the relative ease of purchasing such land for protection (Dr. Jeffrey Walck, personal communication).
The effects of climate change on endangered species will, in the near future, need to be considered in recovery plans. According to Dr. Matthew Albrecht of the Missouri Botanical
Conservation and Sustainable Development, there are currently two possible hypotheses for how *E. tennesseensis* could be affected by climate change. First, the hotter and drier conditions could help reduce the encroachment of woody plants and other

plant competitors with *E. tennesseensis*. Second, reproduction conditions, such as seed and pollen viability and availability of pollinators, could be adversely affected (Dr. Matthew Albrecht, personal communication). Pollinator studies could shed light both on pollinator behavior now and possibilities for the future. Perhaps the knowledge gained from the delistment process of *Echinacea tennesseensis* will aid in the removal of other plant species from the Endangered Species List.

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APPENDIX A

INTRODUCED COLONY HISTORIES

INFORMATION TAKEN FROM TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION NATURAL HERITAGE INVENTORY PROGRAM (TDEC NHIP) UNPUBLISHED DATA AND FEDERAL REGISTER 2010 TABLE I DATA

Vesta

Colony 2.3 North of Cedar Forest Road

Introduced in 1983

Monitored in 1996

2005 Survey: Self-sustaining 139 flowering stems 79 estimated adults

1191 estimated individuals (Federal Register 2010)

Colony 2.6 Entrance

Introduced in 1982

Monitored in 2001 several 100 plants in 2001 (TDEC NHIP)

2005 Survey: Self-sustaining 252 flowering stems 144 estimated adults

2160 estimated individuals (Federal Register 2010)

<u>Vine</u>

Colony 3.8 Warf Nelson Glade

Introduced in 1990

Monitored in February 1990 colony transplanted

Monitored in 1998 606 heads (TDEC NHIP)

2005 Survey: Self-sustaining 1863 flowering stems 1065 estimated adults

15969 estimated individuals (Federal Register 2010)

Colony 3.9 Simmon Bluff Road (south of Cedars of Lebanon SP)

Introduced in 1989

Monitored in 2003 more than 100 plants (TDEC NHIP)

2005 Survey: Self-sustaining 2744 flowering stalks 1568 estimated adults

23520 estimated individuals (Federal Register 2010)

<u>Couchville</u>

Colony 5.3 Long Hunter SP Glade Site/Grove Entrance

Introduced in 1985

Monitored in 1985 transplanted 9 plants from Middle Tennessee State University

Monitored in June 1989 transplanted 6 plants from Couchville

Monitored in 1990 winter seeded

Monitored in 1991 winter seeded

Monitored in July 1998 1344 heads (TDEC NHIP)

2005 Survey: Self-sustaining 1607 flowering stems 918 estimated adults

13774 estimated individuals (Federal Register 2010)

Colony 5.5 Long Hunter SP Site/West of Couchville Lake

Introduced in 1987

Monitored in February 1989 planted 39 (heads) from Couchville

Monitored in May 1989 61 plants (1987 planting)

Monitored in June 1989 100 seedlings (1989 planting)

Monitored in November 1989 transplanted 1 year old plants from Couchville;

35 plants (1987 Planting); 140 seedlings (February 1989)

Monitored in 1993 more than 200 plants (TDEC NHIP)

2005 Survey: Self-sustaining 1300 flowering stems 743 estimated adults

11143 estimated individuals (Federal Register 2010)

Colony 5.6 Long Hunter SP Glade Site/Hill by Picnic Area, Nature Loop Trail #2

Introduced in July 1989

Monitored in 1998 2894 heads (TDEC NHIP)

2005 Survey: Self-sustaining 846 flowering stems 483 estimated adults

7251 estimated individuals (Federal Register 2010)

APPENDIX B

INFORMATION FROM 2005 SURVEY OF *E. TENNESSEENSIS* SITES

Table 4. Adapted from "Summary of *Echinacea tennesseensis* Populations and Colonies" from Table 1 of Federal Register 2010.

POPULATION	POPULATION NAME	COLONY NUMBER	EO NUMBER	ORIGIN	ESTIMATED INDIVIDUALS
2	**Vesta**	2.1	006	Natural	42600
		2.3	038	Introduced	1191
		2.6	040	Introduced	2160
3	**Vine**	3.1	005	Natural	64757
		3.2	016	Natural	106774
		3.4	021	Natural	111249
		3.8	030	Introduced	15969
		3.9	036	Introduced	23520
5	**Couchville**	5.1	010	Natural	63026
		5.3	024	Introduced	13774
		5.5	025	Introduced	11143
		5.6	032	Introduced	7251

EO Number: Element Occurrence Number assigned and tracked by Tennessee Natural Heritage Program