NCDOT Final Technical Report

Recommended Mitigation Plan for *Solidago verna* in Craven Co., North Carolina; Havelock Bypass, R-1015

Research Project HWY-0733

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16. Abstract

North Carolina Department of Transportation (NCDOT) project R-1015 is the construction of the U.S. Highway 70 bypass around the town of Havelock, North Carolina. A large portion of the new right-of-way passes through Croatan National Forest (CNF) lands and will directly impact two of the largest known populations of *Solidago verna* M. A. Curtis (Spring-flowering goldenrod), a threatened species in N.C. and a federal species of concern (N.C. Natural Heritage Program 2004). A transplant project will be conducted to mitigate impacts to this population.

A preliminary experimental transplant study was conducted from 2003 to 2005 on various soil types in the vicinity of the threatened population and with different vegetation treatments to inform mitigation transplant site selection and management (Fleming, Stucky, and Brownie, in review). Both soil wetness and plant interactions affected transplant survival and the effect of neighboring vegetation differed significantly between soils. Increase in transplant mass is not critical to establishing a viable population, however, as small individuals can reproduce.

It is recommended that transplants be established in the longleaf pine flatwood along the west side of Wolf Pit Branch Rd.at 34° 53' N, 76° 56' W. The soil at this site is a dry phase of Leaf which was among the more favorable soils for survivorship of *S. verna* transplants during the experimental study. Also, the recommended site supports red-cockaded woodpecker longleaf pine nest trees so it will be prescribed burned to control shrub growth. Reduced shrub growth improved survivorship of *S. verna* transplants during the experimental study.

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Executive Summary

North Carolina Department of Transportation (NCDOT) project R-1015 is the construction of the U.S. Highway 70 bypass around Havelock, North Carolina. A portion of the new 76 m wide right-of-way passes through Croatan National Forest (CNF) lands and will directly impact two of the largest known populations of *Solidago verna* M. A. Curtis (Spring-flowering goldenrod), a threatened species in N.C. and a federal species of concern (N.C. Natural Heritage Program 2004). A transplant project will be conducted to mitigate impacts to the two populations.

A transplant study preliminary to the main mitigation transplant project was conducted from 2003 to 2005 on various soil types in the vicinity of the threatened populations and with different vegetation treatments. The purpose of the preliminary study was to inform mitigation transplant site selection and management (Fleming, Stucky, and Brownie, in review.). Both soil wetness and plant interactions affected transplant survival and the effect of neighboring vegetation differed significantly between soils. Increase in transplant mass is not critical to establishing a viable population, however, as small individuals can reproduce.

Based on results of the preliminary study, the plan for the mitigation transplant project recommends that transplants be established in the southern portion of the longleaf pine flatwood located along the west side of Wolf Pit Branch Rd. at 34° 53' N, 76° 56' W. The dry phase of Leaf soil at this site was among the more favorable soils for the survivorship of *S. verna* transplants during the preliminary study. Also, the site supports red-cockaded woodpecker nest trees so it will be prescribed burned to control shrub growth. During the experimental study, reduced shrub biomass improved survivorship of *S. verna* transplants. The site also supports *Aristida stricta* which, as suggested by results of the preliminary study, may facilitate the survivorship of *S. verna* transplants under wet conditions.

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Introduction

North Carolina Department of Transportation (NCDOT) project R-1015 is the construction of the U.S. Highway 70 bypass around Havelock, North Carolina. A portion of the new 76 m wide right-of-way passes through Croatan National Forest (CNF) lands. One of the proposed alternatives for the bypass will directly impact two of the largest known populations of *Solidago verna* M. A. Curtis (Spring-flowering goldenrod), a threatened species in N.C. and a federal species of concern (N.C. Natural Heritage Program 2004). A transplant project will be conducted to mitigate impacts to the two populations.

Mitigation Goals/Objectives:

The purpose of the planned transplant mitigation is to conserve the genetic material from the two at-risk populations by establishing a new, viable population. Plants will be transplanted to a new site, which will then be managed to maintain habitat conditions suitable for *S. verna*. Long-term maintenance requirements for the new population should be minimal. A period of monitoring will follow to determine if mitigation has been successful.

Description of Impacted Site(s):

Site A - The northernmost occurrence of *Solidago verna* that will be impacted by construction is located east of Greenfield Blvd., near Havelock (see Figure 1of Appendix A). The majority of plants in this population are found in the powerline right-of-way (ROW) north of the Paul property. The population also extends into the adjacent pine flatwood. The site is easily accessible by crossing the powerline ROW from Wolf Pit Branch Road.

All of this area is part of CNF and is managed for mixed use, including timber production and public recreation. Prescribed burning in the flatwood and mowing in the powerline ROW maintain habitat for *S. verna* and facilitate its flowering and producing seeds.

The population of *S. verna* at this site contains up to 10,000 individuals and is the largest population known to science. It is designated as element occurrence 041 in Natural Heritage Program (NHP) records. Road construction may directly impact all or a portion of the population while secondary impacts from the proximity of the highway will impact the entire population. Secondary impacts include altered hydrology and decreased frequency of prescribed burning. The combined effects of primary and secondary impacts threaten the continued viability of this population.

The vegetation in the powerline ROW is primarily herbaceous with widely scattered woody species. The dominant herb is *Aristida stricta* Michaux; the dominant woody species are *Gaylussacia frondosa* (L.) T. & G., *Ilex glabra* (L.) Gray, and saplings of *Liquidambar styraciflua*. Water percolates through the soil at Site A rapidly enough to prevent ponding and the area does not regularly flood. The seasonal high water table is around 4 to 5 inches and the soil is in the Lenoir series (The Catena Group, Inc. 2004).

Site B - The second *S. verna* population that will be impacted is located approximately one mile south of Site A, immediately north of Sunset Drive and east of Forest Route 613 (see Figure 1). The new roadway and overpass that will be constructed here is likely to directly impact all of this population. This area is part of CNF, and is managed for mixed use, including timber production and public recreation. Soil here is the Goldsboro series with a seasonal high water table at 13 inches (The Catena Group, Inc. 2004).

This population is primarily in open-canopied pine flatwood. *Pinus palustris* is the dominant tree species, with some *Pinus taeda* interspersed. This area has many of the same species that were abundant at Site A, including *Liquidambar styraciflua* saplings, *Gaylussacia frondosa*, and *Ilex glabra*, and a few clumps of *Aristida stricta*.

Receptor Site Selection:

The receptor site where the new population is to be established must be chosen carefully for mitigation to be successful. A site close to the impacted populations is more likely to have similar habitat than a more distant location, and close proximity will simplify the logistics of transplanting. The site should also be easily accessible, protected, and managed. Management for the site must include periodic burning, as *S. verna* produces seeds only after it has been burned. Mowing results in somewhat less seed production than does burning (Stucky and Wright 1999). In addition to stimulating reproduction, frequent burning prevents dense shrub growth and the accumulation of deep leaf litter (US Geological Survey 2000), conditions which correlate with increased mortality (Stucky and Wright 1999). Management and protection of the new population will be more likely if the site is owned by a government agency.

In addition to geographic location and management considerations, habitat features including soil wetness and associated vegetation must be considered. *Solidago verna* occurs on soils ranging from the poorly drained Rains to the well drained Vaucluse and the somewhat excessively drained Tarboro. It has been reported on two of the soils used in the experimental transplant study reported here, Leaf and Lenoir

(N.C. Natural Heritage Program EO's). Generally, *S. verna* is most abundant in grass-dominated vegetation under a relatively open longleaf pine canopy.

A preliminary experimental transplant study was conducted from 2003 to 2005 on various soil types in the vicinity of the threatened populations and with different vegetation treatments to inform mitigation transplant site selection and management (Fleming, Stucky, and Brownie, in review; Appendix B). This study concentrated on the effects of variation in soil wetness and ground layer vegetation interactions on *S. verna* transplant survivorship and growth.

Organization of Report

The next three sections of this report, Literature Review, Report Body, Findings and Conclusions, are taken directly from a journal article manuscript describing the experimental transplant study. The Recommendations section is taken from a transplant mitigation project plan. The transplant mitigation plan and journal article manuscript are included in this report as Appendices A and B, respectively.

Literature Review

Competition is one factor that may influence goldenrod transplant success (Howard and Goldberg 2001). Welden and Slauson (1986) defined competition as "the induction of strain in one organism as a result of the use, defense, or sequestering of resource items by another organism." It is commonly thought that species are rare because they are poor competitors, however, this is not so for all rare species (Lloyd et al. 2002). Stucky and Wright (1999) found that *S. verna* seedlings established in plots where herbs and shrubs were cleared mechanically or with fire, but not in uncleared control plots. They also found that goldenrod flowered and produced seeds primarily during the growing season following winter burning. They and others (Brewer and Platt 1994) have attributed these and similar results to competition.

Goldenrod is part of an ecosystem that historically experienced low intensity, ground-level fire every 1-3 years (Frost 1996). Such fires remove plant litter and inhibit the growth of woody species (US Geological Survey 2000). In this way, fire reduces the amount of competition for light, space and other resources, but it may also affect plant mutualisms and facilitation (Callaway 1995, Bertness and Callaway 1994), the spread of pathogens, the depth of plant litter on the ground, water infiltration, and soil surface moisture and temperature. From a management standpoint, then, it is more useful and reasonable to study the effects of competition together with effects of other interactions, rather than attempt to separate these effects. Here the combination of competition and other interactions is referred to as neighbor effects.

Neighbor effects can be manipulated by cutting aboveground portions of neighboring plants and removing plant litter to simulate some of the effects of fire. Fire has additional effects which are not simulated by this method, such as making nutrients available for plant growth and stimulating seed germination, so the total effect of fire is not examined here. Brewer (1998) determined that killing neighboring plants and removing dead biomass were both necessary to increase densities of pink sundew (*Drosera capillaris* Poiret) seedlings. Neighbor effects, though, are not solely responsible for determining the distribution and abundance of species.

Soil factors can influence the abundance and distribution of plant species (Molles 1999, Rice and Rice 1997). Although Brewster (1995) found no significant relationships between goldenrod densities and soil chemical characteristics and proposed that goldenrod can survive in a wide variety of environmental conditions, she suggested that soil moisture may be an important factor affecting *S. verna* distribution. Soil moisture influences the structure of fire-dependent plant communities in the longleaf pine ecosystem of the southeastern Coastal Plain (Kirkman et al. 2001), amount and schedule of litterfall (West et al. 2003), and the effects of litter (Xiong et.al. 2003). Variation in soil moisture is typically accompanied by differences in soil texture, drainage capacity (USDA Soil Conservation Service 1989, West et al. 2003), redoximorphic features (Buolet et al. 2003), microtopography (USDA Soil Conservation Service 1989), distance to drains (Daniels and Gamble 1967), and changes in vegetation (Frost 1996, USDA Soil Conservation Service 1989, USFWS 1988).

Report Body

Study Objectives:

In survivorship and growth studies of the type reported here, it is sensible to measure the soil moisture x neighbor effect because interactions are likely to be more important than single factor effects (Xiong et al 2003). The objectives of this study are to (1) quantitatively describe the importance of neighbor effects, soil moisture, and the neighbor effect x soil moisture interaction on *S. verna* transplant survivorship and growth and (2) recommend a soil type to which *S. verna* should be transplanted as mitigation for impacts to the threatened population.

Field Site Description:

The longleaf pine flatwood study site, N34^{o}53'30"-54'14", W76^{o}56'34-45", was included on the USGS 7.5 min. topographic Havelock quadrangle map. Soil series within the study site included Craven, an Aquic Hapludult; Lenoir, an Aeric Paleaquult; Masontown, a Cumulic Humaquept; and four phases of Leaf, a Typic Albaquult. The northern population of goldenrod that is threatened by road construction was located near the center of the study site on Lenoir soil. Field indicators of soil wetness (USDA Natural Resources Conservation Service 2006) for these soils included accumulated mucky organic matter, depth to low chroma, depth to redoximorphic features (Table 1), and wetland indicator status of dominant plant species present (Table 2). The tree canopy was entirely longleaf pine.

Table 1. Morphological field indicators of wetness for the soils at study site.

Soil	Wetness Indicators
Craven	Redoximorphic concentrations at 22"
Lenoir	Redox. concentrations at 14"
Leaf A	Redox. concentrations at 8"
Leaf D	Redox. concentrations at 9"
Leaf C	Chroma 2 at 6", high % fine organic matter at surface
Leaf B	Chroma 1 at surface, mucky organic surface 2" thick
	Firm clay at 6" causing observed ponding
Masontown	Chroma 1 at surface, mucky surface 9" thick. flooding observed

Table 2. Dominant plant species on each soil type and their region 2 wetland indicators (USFWS 1988). Nomenclature follows Radford et al. (1968). Data collected June 2004.

Soil	Dominant Species	Region 2 Indicator	Aerial Cover %	Total Aerial Cover % (all species)	Mean Shrub Canopy Height (cm)
Craven	*Gaylussacia frondosa* (L.) T. & G.	FAC	40	113	65.5
	Ilex glabra (L.) Gray	FACW	40		
	Pteridium aquilinum (L.) Kuhn	FACU	30		
Lenoir	*Gaylussacia frondosa*	FAC	63	128	70.5
	Pteridium aquilinum	FACU	46		
	Liquidambar styraciflua L.	FAC+	10		
Leaf A	*Ilex glabra*	FACW	35	149	80
	Arundinaria gigantea (Walt.) Muhl.	FACW	35		
	Gaylussacia frondosa	FAC	30		
	Pteridium aquilinum	FACU	28		
Leaf D	*Gaylussacia frondosa*	FAC	53	155	98
	Arundinaria gigantea	FACW	33		
	Osmunda cinnamomea L.	FAC+	30		
	Ilex glabra	FACW	23		
Leaf C	*Arundinaria gigantea*	FACW	70	84	45
	Ilex glabra	FACW	5		
	Aristida stricta Michaux	FAC-	5		
Leaf B	*Arundinaria gigantea*	FACW	85	99	58
	Liquidambar styracifluafa	FAC+	7		
	Ilex glabra	FACW	3		
Masontown	*Arundinaria gigantea*	FACW	60	63	62
	Liquidambar styraciflua	FAC+	3		

Methods:

A preliminary linear regression using SAS PROC GLM (SAS Institute 2001) of transplant dry weight (dependent variable) on fresh weight determined that fresh weight was strongly correlated with dry weight {Dry Wt. = 0.0304 + 0.3451 (Fresh Wt., R^2 = 0.97)}. Fresh weight was used for all subsequent growth analyses.

Pairs of experimental plots were established on Masontown, Lenoir, Craven, and on four phases of the Leaf series (USDA Soil Conservation Service 1989). One plot of each pair was designated full neighbor and the other reduced neighbor. Vegetation was cut at ground level and removed from each reduced neighbor plot in mid-May 2003. Full neighbor plots were unmanipulated. On May 23 and 24, 615 goldenrod plants were collected from the threatened population. Soil was carefully washed from the roots/rhizomes before the plants were weighed, and allocated to eight size classes. (Although removing and washing soil from transplants was necessary to determine transplant weights for this experimental study, we recommend that only excess soil be removed from rhizomes/roots for transplant mitigation.) Leaves and stems of transplants were left intact. One plant from each class was transplanted into each study plot. Each transplant was assigned an individual identification number. Periodically during 2003, survivorship of individual transplants was determined.

On May 19, 2004, we again cut and removed vegetation from the reduced neighbor plots. On this same day, PAR (Photosynthetically Active Radiation) was measured in each experimental plot at both chest height and ground level. In reduced neighbor plots, PAR was measured immediately before and after clipping. PAR was measured again on July 29, 2004 and Nov. 19, 2004.

In June 2004, ground layer vegetation was characterized in 2m x 2m plots randomly located in each soil unit, close to, but not overlapping, transplant study plots. In late Nov. and early Dec. 2004, at the end of the second growing season, the dry weight of each surviving transplant was determined.

SAS PROC GLM (SAS Inc. 2001) was used to perform a type of split plot analysis of variance to determine if soil and/or neighbors significantly affected survival, per plot, of the transplants and to determine if neighbor effects varied by soil series. Soil type was treated as a whole plot factor and neighbors as a sub plot factor. Because growth data were unbalanced, SAS PROC MIXED (SAS Inc. 2001) was used to perform the mixed model analysis of variance to estimate the effects of soil, neighbors, and their interaction on transplant growth. The DDFM = Kenward option was used to compute denominator degrees of freedom. The effect of initial mass on survival was tested by a mixed model analysis of covariance on the outcome for individual plants. SAS PROC MIXED (SAS Inc. 2001) was also used to perform a random effects analysis of variance to estimate the components of variance and, thereby, determine the relative importance of soil, neighbors, their interaction, and all other unspecified factors in the survival and growth of *S. verna*.

Results:

Clipping vegetation in reduced neighbor plots increased the amount of PAR available to transplants (Fig.1), and the effect continued throughout the growing season (Fig. 2). The increase was less pronounced on the three wettest soils (Leaf C, Leaf B and Masontown), indicating that shrub layer vegetation on these soils was not initially as dense as on the relatively drier soils (Fig.1). PAR reaching ground level tended to decrease over the growing season in both clipped and unclipped plots, and then increase slightly during the Fall (Fig.2).

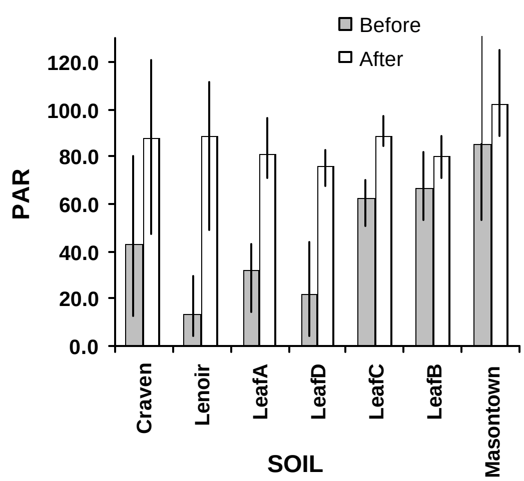

Figure 1. Mean PAR at ground level (expressed as % of PAR at chest level) for reduced neighbor plots (n=5) before and after removing vegetation on May 14, 2004. Error bars are ranges.

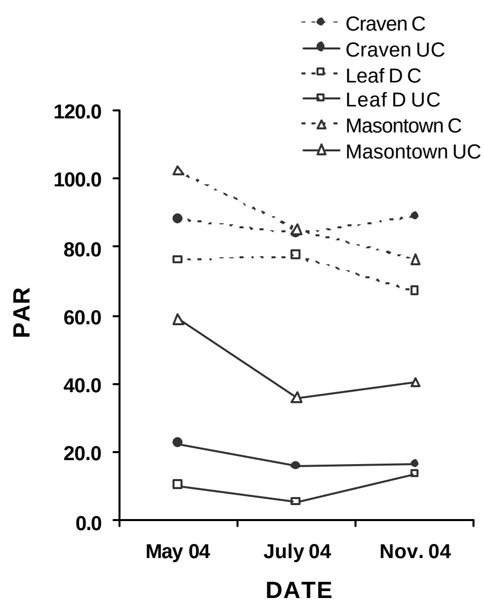

Figure 2. Change in light reaching ground level (expressed as % of PAR at chest level) over time in clipped (C) and unclipped (UC) plots.

Transplant survival was lowest on the three wettest soil series (Fig.3; soil main effect $F_{6,28} = 33.29$, $P < 0.001$). Survival was greater when neighboring vegetation was removed (Fig.3; neighbor main effect $F_{1,28} = 10.29$, $P = 0.003$); and neighbor effects differed significantly between soil series. Among soils in the drier to mid range of the wetness gradient, the intensity of neighbor effects increased as soil wetness increased.

(Fig.3; neighbor X soil interaction $F_{6,28} = 4.64$, $P = 0.002$). Initial mass of transplants did not significantly affect survival (covariate effect $F_{1,351} = 0.49$, $P = 0.485$).

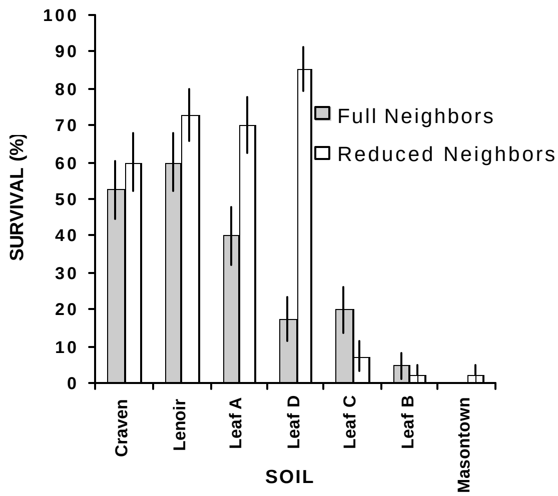

Figure 3. Effects of soil series and neighbor treatments on transplant survival (mean % surviving in each plot). Soils are ordered from driest to wettest. Error bars are ± 1 SE.

Soil was the most important factor affecting transplant survival (Table 3; accounting for 47.44% of the variance in survival). Neighbor vegetation was of little importance when examined outside the context of soil (Table 3; neighbor main effect importance was 4.89 %). The importance of the interaction between soil and neighbors was similar to the importance of all other unspecified factors (Table 3; explaining 23.26 % and 24.40 % of the variance in survival respectively).

Table 3. Importance of experimental and other factors in the survival and growth of transplants. Figures are the relative percent of variance attributable to each factor.

Factor	Importance	
	Survival	Growth
Soil	47.44	6.43
Neighbors	4.89	9.13
Soil X Neighbors	23.26	0.00
Other	24.40	84.44

Most transplants decreased in mass during this study. Because survival was extremely low on the Leaf C, Leaf B, and Masontown soils, data from plots on those soils were excluded from analyses of growth data. Transplants grown with full neighboring vegetation lost significantly more mass than transplants in plots with reduced neighboring vegetation (Fig.4; neighbor main effect $F_{1,175} = 8.76$, $P = 0.0035$). Transplants lost more mass as soil wetness increased (Fig.4; soil main effect $F_{3,18.2} = 3.24$, $P = 0.0463$). The effects of neighboring vegetation did not differ significantly among soils (Fig.4; neighbor X soil interaction $F_{3,174} = 0.24$, $P = 0.8667$).

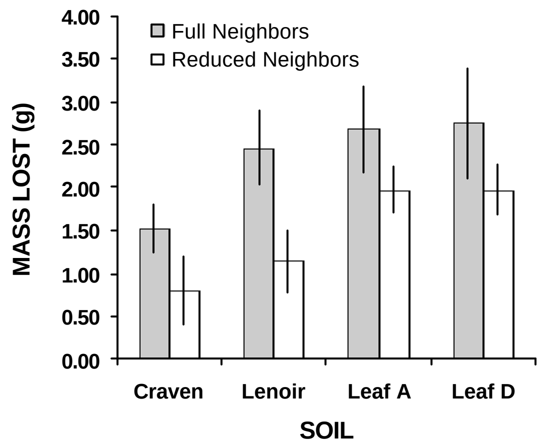

Figure 4. Effects of soil series and neighbors on transplant growth (mean individual mass (g) lost). Error bars are $\pm$ 1 SE.

Other factors, possibly environmental factors not specifically examined in this study or genetic differences between transplants, accounted for a larger percentage of the variation in the amount of mass lost than did experimental factors (Table 3; other 84.44 %). Among experimental factors, neighbor effects were most important, explaining 9.13 % of variance in transplant mass loss, while soil differences accounted for 6.43 %, differences among plants (replicates) explained 2.96 %, and the interaction between soil and neighbors was of no importance (Table 3).

Findings and Conclusions

Despite being an obligate wetland species (U. S. Fish and Wildlife Service, 1988), *Solidago verna* is not suited for survival in soils that are inundated or saturated for extended durations, such as Masontown and Leaf B.

Among soils where overall survival was greater than 50% (Craven, Lenoir, Leaf A and Leaf D), the intensity of neighbor effects increased as soil wetness increased (Fig.3). Since the amount of PAR blocked by the shrub layer did not show a corresponding increase (Fig.1), competition for light does not adequately explain the neighbor effect trend. The explanation for the observed trend may involve litter. A thick layer of woody fibers and shrub leaves formed dense mulch covering the ground on the Leaf A and Leaf D soils, with Leaf D having the deepest litter layer. Transplants were rooted in this material in reduced neighbor plots, where the litter formed a moist but well drained soil surface horizon, but they were buried under it in the full neighbor plots.

Underground plant interactions were not specifically addressed in this study but could have affected transplant survival (Casper and Jackson 1997). Increasing soil wetness was accompanied by increasing dominance of cane (*Arundinaria gigantea* (Walter) Muhl.) (Table 2), a species with very large and extensive rhizomes.

Overall survival was low (< 15%) on the Leaf C soil but survival on full neighbor plots was more than twice that on reduced neighbor plots (Fig.3). In this case, soil wetness likely was the limiting factor but neighboring vegetation may have reduced soil wetness by taking up water from the soil through transpiration. Leaf C, the only soil in the study where facilitation was apparent, was also the only soil with wiregrass (*Aristida stricta)* (Table 2). Wiregrass may have facilitated goldenrod by creating relatively dry microsites. However; the assumption should not be made that wiregrass is always beneficial to goldenrod. It may interfere with goldenrod, rather than facilitate it, when soil wetness does not produce abiotic stress.

Soil and neighbor effects were responsible for a significant portion of the decrease in transplant mass; however, combined, they explain only 15 % of the data variation. Some other factor or factors were the primary cause. Stress from the transplanting process might explain loss of mass. Another possible explanation is shading from the tree canopy. Transplants were taken from a powerline right-of-way with no tree canopy, while the study site had a canopy of longleaf pine, so all plants were grown in lower light conditions during the study than prior to the study.

Recommendations

A transplant receptor site close to the impacted populations is more likely to have similar habitat than a more distant location, and close proximity will simplify the logistics of transplanting. The site should also be easily accessible, protected, and managed. Management for the site must include periodic burning, as *S. verna* requires fire or mowing in order to sexually reproduce. Frequent burning prevents dense shrub growth and the accumulation of litter, conditions which correlate to increasing *S. verna* mortality. Management and protection of the new population will be more likely if the site is owned by a government agency.

Transplant survival was excellent on a Leaf variant with evidence of saturated conditions at 9 inches, when neighboring vegetation was cleared and litter removed, but survival was greatly diminished when existing vegetation was left intact. Survival was good on Lenoir with evidence of saturation at 14 inches, both with and without neighboring vegetation. Soil similar to either of these would be suitable, but one like this phase of Lenoir is preferred because a short lapse in management is not likely to devastate the population. Vegetation should include an open longleaf pine canopy and a low herbaceous layer with a species composition similar to Sites A and B. Wiregrass appears to alleviate abiotic stress when soil wetness limits *S. verna* survival. For this reason, and because wiregrass is beneficial for maintaining the appropriate fire regime in this ecosystem, receptor sites with *Aristida stricta* are preferred. The presence of *A. stricta* is essential if the seasonal high water table at the receptor site is within 6 inches of the soil surface, or where the soil surface is saturated for long durations.

An area of longleaf pine flatwood along the west side of Wolf Pit Branch Rd. at 34° 53' N, 76° 56' W has many characteristics that make it a suitable receptor site for the *S. verna* transplants (see Figure 1 of Appendix A). The land is CNF property and has several trees with active nest cavities of red cockaded woodpeckers (RCW). Management and protection strategies for RCW's will be beneficial for *S. verna* as well. An added benefit is the buffer created by the CNF lands surrounding this site. This provides a buffer against future impacts, such as encroaching residential development, which would make prescribed burning very difficult. The site is burned at least every 3 years (U.S. Forest Service 2001) and has a low, open shrub layer consisting of small woody plants similar to those found at the threatened sites. Wiregrass and varied other grasses are present. The open canopy is entirely longleaf pine. This area is not subject to flooding or ponding. While the entire area is on the Leaf soil, the depth to the seasonal high water table varies, ranging from 12 inches in the southern part of the site to 3 inches in the northern part (The Catena Group, Inc. 2004). The drier soil in the southern area is suitable, but transplants should not be placed in the northern area. Seven mature *S. verna* rosettes were found at this site and one was encircled by 20-30 seedlings, which is strong evidence that the species can survive and reproduce in this habitat.

Implementation and Technology Transfer Plan

Research products are Miranda Fleming's M.S. thesis, a journal article manuscript (submitted for publication review to Southeastern Naturalist), and a transplant mitigation project plan. The thesis and journal article manuscript could provide NCDOT biologists guidance in conducting preliminary studies designed to inform mitigation site selection. The transplant mitigation project plan outlines the project rationale and field methods. A team of NCDOT biologists could implement the project by following the plan.

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Appendix A

Recommended Mitigation Plan for *Solidago verna* in Craven Co., North Carolina; Havelock Bypass, R-1015

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Introduction

North Carolina Department of Transportation (NCDOT) project R-1015 is the construction of the U.S. Highway 70 bypass around the town of Havelock, North Carolina. The project area is included on the USGS 7.5 min. topographic Havelock quadrangle map.

A large portion of the new 76 m wide right-of-way passes through Croatan National Forest (CNF) lands and will directly impact two of the largest known populations of Solidago verna M. A. Curtis (Spring-flowering goldenrod). *Solidago verna* is listed as a threatened species in the State of N.C. and is a federal species of concern (N.C. Natural Heritage Program 2004).

A field study was conducted from 2003 to 2005 to describe the growth and survival of S. verna transplants on various soil types and with different treatments of neighboring vegetation in order to provide information to guide mitigation transplant site selection and management (Fleming, Stucky, and Brownie, in review.). Both soil and vegetation were determined to be important for transplant survival, and the effect of neighboring vegetation differed significantly between soils. Shading from the tree canopy was not specifically examined in the study, but it was believed to negatively affect transplant growth. Increase in transplant mass is not critical to establishing a viable population, however, as small individuals can reproduce.

Goals/Objectives

The purpose of mitigation is to conserve the genetic material from the two at-risk populations by establishing a new, viable population. Plants will be transplanted to a new site, which will then be managed to maintain suitable habitat conditions for *S. verna*. Long-term maintenance requirements for the new population should be minimal. A period of monitoring will follow to determine if mitigation has been successful.

Description of Impacted Site(s)

Site A

The northernmost occurrence of *S. verna* that will be impacted by construction is located east of Greenfield Blvd., near Havelock (see Figure 1). The majority of plants in this population are found in the powerline right-of-way (ROW) north of the Paul property. The population also extends into the adjacent pine flatwood. The site is easily accessible by crossing the powerline ROW from Wolf Pit Branch Road.

All of this area is part of CNF, and is managed for mixed use, including timber production and public recreation. Prescribed burning in the flatwood and mowing in the powerline ROW maintain habitat for *S. verna* and allow it to flower and reproduce.

This is the largest known population of *S. verna*, with as many as 10,000 individuals. It is designated as element occurrence 041 in Natural Heritage Program (NHP) records. Road construction may directly impact all or a portion of the population while secondary impacts from the proximity of the highway will impact the entire population. Secondary impacts include changing hydrology and decreased frequency of prescribed burning. The combined effects of primary and secondary impacts threaten the continued viability of this population.

The flatwood at Site A has an open canopy of longleaf pine. The shrub layer is primarily comprised of *Gaylussacia frondosa* (L.) T. & G., *Pteridium aquilinum* (L.) Kuhn, and *Ilex glabra* (L.) Gray.

The powerline ROW is dominated by *Aristida stricta* Michaux, and has many of the same species found in the flatwood. A variety of grasses and herbaceous plants are also present in both areas, and both have some *Arundinaria gigantea* (Walter) Muhl. present. Trees in the ROW are *Liquidambar styraciflua* L, *Pinus palustris* Miller, and *Pinus taeda* L. saplings.

Water percolates through the soil at Site A rapidly enough to prevent ponding and the area does not regularly flood. The seasonal high water table is around 4 to 5 inches and the soil is in the Lenoir series (The Catena Group, Inc. 2004).

Site B

The second impact site is located approximately one mile south of Site A, immediately north of Sunset Drive and east of Forest Route 613 (see Figure 1). The new roadway and overpass that will be constructed here is likely to directly impact all of this *S. verna* population.

This population is primarily in open-canopied pine flatwood, though plants may also be found in the adjacent powerline ROW. *Pinus palustris* is the dominant tree species, with some *Pinus taeda* interspersed. This area has many of the same species that were abundant at Site A, including *Liquidambar styraciflua* saplings, *Gaylussacia frondosa*, *Pteridium aquilinum*, and *Ilex glabra*, and a few clumps of *Aristida stricta*. Many herbaceous plant species are also present.

Site B, with several small depressions throughout the landscape, has more variable topography than Site A. Soil here is the Goldsboro series with a seasonal high water table at 13 inches (The Catena Group, Inc. 2004).

Like Site A, this area is part of CNF, and is managed for mixed use, including timber production and public recreation. Both sites were burned between the years of 2001and 2003 and are scheduled to be burned every 3 years (U.S. Forest Service 2001).

Justification for Site Selection

The receptor site where the new population is to be established must be chosen carefully for mitigation to be successful. A site close to the impacted populations is more likely to have similar habitat than a more distant location, and close proximity will simplify the logistics of transplanting. The site should also be easily accessible, protected, and managed. Management for the site must include periodic burning, as S. verna requires fire or mowing in order to sexually reproduce (Stucky and Wright 1999). Frequent burning prevents dense shrub growth and the accumulation of deep leaf litter (US Geological Survey 2000), conditions which correlate to increasing *S. verna* mortality (Fleming, Stucky, and Brownie, in review) and should be avoided. Management and protection of the new population will be more likely if the site is owned by a government agency.

Habitat considerations include soil wetness, vegetation, and topography. Topography should be generally flat or gently sloping. In the field study designed to guide this mitigation project (Fleming, Stucky, and Brownie, in review), survival of *S. verna* transplants was extremely low in areas where there was ponding and flooding, where cane was the dominant species, and where there was a mucky soil surface horizon 2 inches thick or greater, so these conditions must be avoided. Transplant survival was excellent on a Leaf variant with evidence of saturated conditions at 9 inches, when neighboring vegetation was cleared and litter removed, but survival was greatly diminished when existing vegetation was left intact. Survival was good on Lenoir with evidence of saturation at 14 inches, both with and without neighboring vegetation. Soil similar to either of these would be suitable, but one like this phase of Lenoir is preferred because a short lapse in management is not likely to devastate the population. Vegetation should include a very open longleaf pine canopy with areas of bright sunlight reaching the ground, and a low herbaceous layer with a species composition similar to Sites A and B. Wiregrass appears to alleviate abiotic stress when soil wetness limits *S. verna* survival, and may be essential for the threatened population at site A to thrive

(Fleming, Stucky, and Brownie, in review). For this reason, and because wiregrass is beneficial for maintaining the appropriate fire regime in this ecosystem, receptor sites with *Aristida stricta* are preferred. The presence of *A. stricta* is essential if the seasonal high water table at the receptor site is within 6 inches of the soil surface, or where the soil surface is observed to be saturated for long durations.

Existing Condition of Receptor Site

An area of longleaf pine flatwood along the west side of Wolf Pit Branch Rd. midway between the two impact sites has many characteristics that make it a suitable receptor site for the new population of S. verna (see Figure 1 of Appendix A). The land is CNF property and has several trees with active nest cavities of red cockaded woodpeckers (RCW). Management and protection strategies for RCW's will be beneficial for S. verna as well. An added benefit is the buffer created by the CNF lands surrounding this site. This provides a buffer against future impacts, such as encroaching residential development, which would make prescribed burning very difficult. The site is burned at least every 3 years (U.S. Forest Service 2001) and has a low, open shrub layer consisting of small woody plants similar to those found at the threatened sites. Wiregrass, varied other grasses, and a multitude of other herbaceous plant species are present. The open canopy is entirely longleaf pine.

This area is not subject to flooding or ponding. While the entire area is on the Leaf soil, the depth to the seasonal high water table varies, ranging from 12 inches in the southern part of the site to 3 inches in the northern part (The Catena Group, Inc. 2004). The drier soil in the southern area is suitable, but transplants should not be placed in the northern area.

Seven mature *S. verna* rosettes were found growing at this site, and one was encircled by 20-30 seedlings, which is strong evidence that the species can survive and reproduce in this habitat. Several plants were also found on the ditch bank at the edge of the flatwood, and across the gravel road in the powerline ROW.

Timber has probably been harvested from this site several times since European settlement, and will probably be cut again in the future. Disturbance of nearby vegetation during selective cutting, or thinning clears ground for *S. verna* seedlings and can benefit the population (Stucky and Wright 1999). Clearcutting and bulldozing, on the other hand, would likely be very detrimental to *S. verna*.

Proposed Action

Receptor Site Preparation

The receptor site should be burned within one of the two years prior to transplanting. If they are dense, shrubs should be thinned and any hardwood understory should be removed. If canopy is closed, some openings should be made.

Vegetation Salvage

Populations at Site A and Site B will be the source of plant material for establishing the new population. The number of plants taken from the two impact sites will be proportional to the size of those populations. A combined total of at least 2500 individuals will be transplanted. Plants will be removed using a 4-foot spade. Excess soil will be shaken from the roots, but not thoroughly cleaned away. Plants will then be misted with water and transported to the receptor site in covered plastic containers. The plants should be protected from heat and intense sunlight, and should be kept moist.

Any sized individuals above 0.61g may be transplanted, as initial mass of transplants was not found to affect their survival (Fleming, Stucky, and Brownie, in review.), however larger plants are easier to handle and transplant. There are no upper size or weight limits.

Seeds should be collected from plants at Sites A and B during the summers prior to transplanting. Each plants' seeds will be stored separately in paper bags in a cool, dry place until they are given to the N.C. Botanical Garden at Chapel Hill for germplasm storage. The location where each container of seeds was collected from should be recorded.

Burning of the impacted sites should continue every one to three years prior to transplanting. Scheduling the final burn for one year prior to salvage will facilitate locating individuals to transplant.

Replanting

Salvaged material will be replanted at the receptor site within 7 days. The following method of planting was successful during the field study and will be used for mitigation transplanting. It is relatively quick and simple. Using a 4-foot spade, a cut is made in the soil 5 to 6 inches deep and the spade moved forward and back to widen the cut. A plant is then placed in the hole so that the root crown is level with the ground surface, and the soil is firmed lightly by hand or with the foot. Plants are spaced roughly 1 foot apart at Sites A and B, and will be similarly spaced during replanting. Irrigation will be necessary if dry weather threatens the survival of transplants.

Responsible parties

NCDOT will be responsible for mitigation transplanting.

Schedule

Transplanting will be completed between December 1 and February 28. At this time of year *S. verna* is not actively growing, making it less vulnerable to the stress of transplanting. It does, however, retain its green leaves and is easy to locate in the field.

The transplant may be divided into two phases, depending on weather conditions and availability of workers. This approach will be beneficial, should the first phase transplants suffer some unforeseen disaster.

Concurrent Research

To increase scientific knowledge about *S. verna*, an experiment will be set up as part of the mitigation project. Plants from the two impacted populations at Sites A and B will not be intermingled at the RCW site, but will be established as two distinct groups. Comparing the performance of these two groups during the monitoring stage will help determine if *S. verna* populations in the CNF are genetically dissimilar to one another.

Monitoring Plan

The new population will be monitored for five years to determine if mitigation has been successful. Attributes to be monitored include survival, flowering, individual plant vigor, seedling establishment, number in population, and geographic extent of the population. If, within five years, the level of these performance standards indicates that the population is stable, the mitigation will be considered successful. A stable or viable population is one in which the number of new individuals being produced meets or exceeds the number of individuals dying. Specific success criteria that must be met at five years after transplanting are as follows:

- Number of plants exceeds initial number planted by at least 2%
- At least 25% of plants flower in response to winter burn
- 75% of individuals are healthy
- Seedlings are present in the population

NCDOT will be responsible for funding the monitoring program.

Long-term Management and Protection

Prescribed burning will be necessary, but the first burn should occur no earlier than the end of the first growing season following the mitigation transplant. After the initial growing season, fire frequency should be at least every 3 years, as this was the historic frequency throughout the geographic range of *S. verna* (Frost 1996) and will prevent the detrimental effects of dense shrub growth and litter accumulation. U.S. Forest Service will be responsible for this activity. Their current management and protection of the receptor site for RCW's should be sufficient for maintaining habitat for *S. verna*. Mixed use of the site, for wildlife habitat, timber harvesting, and hunting, is not likely to negatively impact the new population once transplants become well established.

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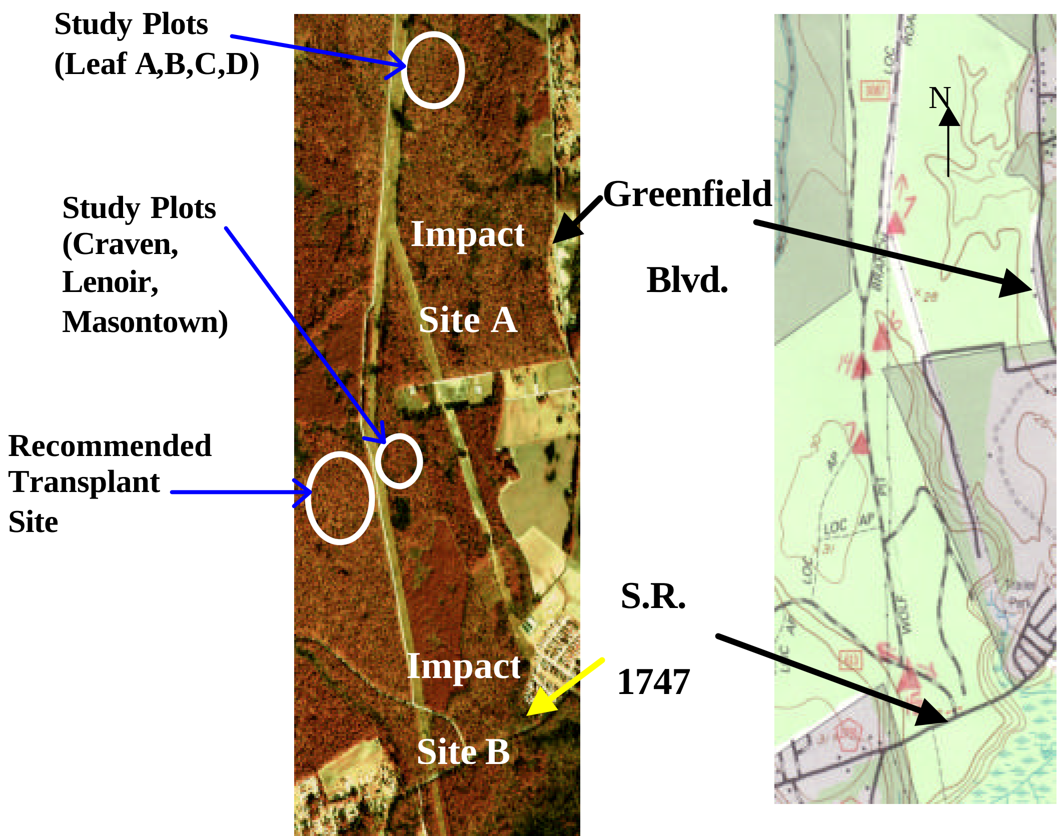
Figure 1. Aerial photo and map of mitigation area.



USGS 7.5 min. topographic Havelock quadrangle map.

Appendix B

EFFECTS AND IMPORTANCE OF SOIL WETNESS AND NEIGHBORING VEGETATION ON *SOLIDAGO VERNA*

by

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Abstract

Solidago verna (spring-flowering goldenrod) is a rare endemic primarily of frequently burned longleaf pine flatwoods in the Carolinas. It is listed as threatened in North Carolina and as a federal species of concern. Continued threats to the species are fire suppression and habitat destruction, including planned highway construction through the largest known population. Plants in this threatened population were transplanted into study plots on seven Coastal Plain soils varying in wetness. Full vegetation and reduced vegetation treatments were applied to test the effects of plant interactions. Soil was the most important factor affecting transplant survival. Survival was low in areas where ponding or flooding occured. Plant interaction effects on survival differed significantly among soils. Both increasing soil wetness and the presence of neighboring vegetation negatively affected transplant growth; however, most of the decrease in transplant mass was attributed to other environmental factors, possibly shading from the tree canopy or transplanting stress. We recommend establishing mitigation transplant sites on the Lenoir soil series and burning those sites every 1-3 years.

Introduction

Spring-flowering goldenrod (goldenrod), *Solidago verna* M. A. Curtis, is a rare endemic primarily of longleaf pine (*Pinus palustris* Miller) flatwoods in the southern Coastal Plain of North Carolina and the Sandhills of North and South Carolina (N.C. Natural Heritage Program 2004; S.C. Natural Heritage Trust 1993). Goldenrod is listed as threatened in N.C. and as a federal species of concern (N.C. Natural Heritage Program 2004). The primary threats to goldenrod are habitat degradation by fire suppression and habitat loss (Leach and Givnish 1996). For example, highway construction currently threatens the largest known population, which is located in the Craven County, N.C. portion of the Croatan National Forest. A mitigation plan is being developed that involves moving goldenrod individuals from this threatened population to a secure site yet to be selected. This plan would benefit from information concerning the performance of *S. verna* on various soil types at the candidate mitigation transplant sites. The study reported here describes the survival and growth of *S. verna* transplants on these soils.

Competition is one factor that may influence goldenrod transplant success (Howard and Goldberg 2001). Welden and Slauson (1986) defined competition as “the induction of strain in one organism as a result of the use, defense, or sequestering of resource items by another organism.” It is commonly thought that species are rare because they are poor competitors, however, this is not so for all rare species (Lloyd et al. 2002). Stucky and Wright (1999) found that *S. verna* seedlings established in plots where herbs and shrubs were cleared mechanically or with fire, but not in uncleared control plots. They also found that goldenrod flowered and produced seeds primarily during the growing season following winter burning. They and others (Brewer and Platt 1994) have attributed these and similar results to competition.

Goldenrod is part of an ecosystem that historically experienced low intensity, ground-level fire every 1-3 years (Frost 1996). Such fires remove plant litter and inhibit the growth of woody species (US Geological Survey 2000). In this way, fire reduces the amount of competition for light, space and other resources, but it may also affect plant mutualisms and facilitation (Callaway 1995, Bertness and Callaway 1994), the spread of pathogens, the depth of plant litter on the ground, water infiltration, and soil surface moisture and temperature.From a management standpoint, then, it is more useful and reasonable to study the effects of competition together with effects of other interactions, rather than attempt to separate these effects. Here the combination of competition and other interactions is referred to as neighbor effects. Neighbor effects can be manipulated by cutting aboveground portions of neighboring plants and removing plant litter to simulate some of the effects of fire. Fire has additional effects which are not simulated by this method, such as making nutrients available for plant growth and stimulating seed germination, so the total effect of fire is not examined here. Brewer (1998) determined that killing neighboring plants and removing dead biomass were both necessary to increase densities of pink sundew (*Drosera capillaris* Poiret) seedlings. Neighbor effects, though, are not solely responsible for determining the distribution and abundance of species.

Soil factors can influence the abundance and distribution of plant species (Molles 1999, Rice and Rice 1997). Although Brewster (1995) found no significant relationships between goldenrod densities and soil chemical characteristics and proposed that goldenrod can survive in a wide variety of environmental conditions, she suggested that soil moisture may be an important factor affecting *S. verna* distribution. Soil moisture influences the structure of fire-dependent plant communities in the longleaf pine ecosystem of the southeastern Coastal Plain (Kirkman et al. 2001), amount and schedule of litterfall (West et al. 2003), and the effects of litter (Xiong et.al. 2003). Variation in soil moisture is typically accompanied by differences in soil texture, drainage capacity (USDA Soil Conservation Service 1989, West et al. 2003), redoximorphic features (Buolet et al. 2003), microtopography (USDA Soil Conservation Service 1989), distance to drains

(Daniels and Gamble 1967), and changes in vegetation (Frost 1996, USDA Soil Conservation Service 1989, USFWS 1988).

In survivorship and growth studies of the type reported here, it is sensible to measure the soil moisture x neighbor effect because interactions are likely to be more important than single factor effects (Xiong et al 2003). The objectives of this study are to (1) quantitatively describe the importance of neighbor effects, soil moisture, and the neighbor effect x soil moisture interaction on *S. verna* transplant survivorship and growth and (2) recommend a soil type to which *S. verna* should be transplanted as mitigation for impacts to the threatened population.

Field-Site Description

The study was conducted in the Craven Co. portion of the Croatan National Forest (CNF), on the outer Coastal Plain of North Carolina, USA. The 64,749 ha CNF is a diverse landscape with areas of longleaf pine, loblolly pine (*Pinus taeda* L.), upland and bottomland hardwoods, and pocosins. Longleaf pine vegetation in the Croatan region historically burned every 1-3 years (Frost 1996). Our study site was burned within the two years prior to the start of this study (U.S. Forest Service 2001). The longleaf pine flatwood study site, N34°53’30”-54’14”, W76°56’34-45”, was included on the USGS 7.5 min. topographic Havelock quadrangle map. Soil series within the study site included Craven, an Aquic Hapludult; Lenoir, an Aeric Paleaquult; Masontown, a Cumulic Humaquept; and four phases of Leaf, a Typic Albaquult. The population of goldenrod that is threatened by road construction was located near the center of the study site on Lenoir soil. Field indicators of soil wetness (USDA Natural Resources Conservation Service 2006) for these soils included accumulated mucky organic matter, depth to low chroma and depth to redoximorphic features (Table 1), and upon wetland indicator status of dominant species present (Table 2). The composition of groundcover vegetation and the height and aerial cover of the shrub canopy in the study site varied by soil (Table 2).

Table 1. Morphological field indicators of wetness for the soils at study site.

Soil	Wetness Indicators
Craven	Redoximorphic concentrations at 22"
Lenoir	Redox. concentrations at 14"
Leaf A	Redox. concentrations at 8"
Leaf D	Redox. concentrations at 9"
Leaf C	Chroma 2 at 6", high % fine organic matter at surface
Leaf B	Chroma 1 at surface, mucky organic surface 2" thick
	Firm clay at 6" causing observed ponding
Masontown	Chroma 1 at surface, mucky surface 9" thick. flooding observed

Table 2. Dominant plant species on each soil type and their region 2 wetland indicators (USFWS 1988). Nomenclature follows Radford et al. (1968). Data collected June 2004.

Soil	Dominant Species	Region 2 Indicator	Aerial Cover %	Total Aerial Cover % (all species)	Mean Shrub Canopy Height (cm)
Craven	*Gaylussacia frondosa* (L.) T. & G.	FAC	40	113	65.5
	Ilex glabra (L.) Gray	FACW	40		
	Pteridium aquilinum (L.) Kuhn	FACU	30		
Lenoir	*Gaylussacia frondosa*	FAC	63	128	70.5
	Pteridium aquilinum	FACU	46		
	Liquidambar styraciflua L.	FAC+	10		
Leaf A	*Ilex glabra*	FACW	35	149	80
	Arundinaria gigantea (Walt.) Muhl.	FACW	35		
	Gaylussacia frondosa	FAC	30		
	Pteridium aquilinum	FACU	28		
Leaf D	*Gaylussacia frondosa*	FAC	53	155	98
	Arundinaria gigantea	FACW	33		
	Osmunda cinnamomea L.	FAC+	30		
	Ilex glabra	FACW	23		
Leaf C	*Arundinaria gigantea*	FACW	70	84	45
	Ilex glabra	FACW	5		
	Aristida stricta Michaux	FAC-	5		
Leaf B	*Arundinaria gigantea*	FACW	85	99	58
	Liquidambar styracifluafa	FAC+	7		
	Ilex glabra	FACW	3		
Masontown	*Arundinaria gigantea*	FACW	60	63	62
	Liquidambar styraciflua	FAC+	3		

In April 2003, 60 goldenrod plants of various sizes were collected from the threatened population and used to determine a method for non-destructively estimating individual plant dry weight. For each plant, several structural characteristics were measured and then the plant was dried to a constant weight. SAS PROC GLM (SAS Institute 2001) was used to perform a linear regression of dry weight (dependent variable) on each characteristic (independent variable) to determine which plant characteristic most reliably predicted dry weight.

One group of experimental plots each was established on the Masontown, Lenoir, Craven , and on the four phases of the Leaf series (USDA Soil Conservation Service 1989). Each plot group consisted of five pairs of adjacent, 2m x 2m plots randomly placed within a 15m radius on the soil unit. *Solidago verna* was found in the general study area, but not within any study plots. One plot of each pair was designated full neighbor and the other reduced neighbor. Vegetation was cut at ground level in each reduced neighbor plot in mid-May 2003, and litter and the cuttings were removed. Full neighbor plots were unmanipulated. On May 23 and 24, 615 goldenrod plants were collected from the threatened population. After removing unusually small and large plants, the remaining plants were washed, weighed and allocated to eight weight classes, each including 70 plants. One plant from each weight class was randomly selected and transplanted into each study plot. Transplants were planted approximately 50 cm apart and 50 cm from the perimeter of the plot and each transplant was assigned an individual identification number. Periodically during 2003, survivorship of individual transplants was determined.

On May 19, 2004, we again cut the vegetation in the reduced neighbor plots to ground level and raked the litter away, being careful not to disturb goldenrod plants. On this same day, a PAR (Photosynthetically Active Radiation) light meter (Apogee Instruments Model QMSS) was used to measure light intensity in each experimental plot. Three measurements were taken at chest height and three at ground level. Ground level PAR (expressed as percent of PAR at chest height) was determined for each plot by dividing the mean PAR at ground level by mean PAR at chest height and multiplying by 100. In reduced neighbor plots, measurements were taken immediately before and after clipping. PAR was measured again at breast height and ground level on July 29, 2004 and Nov. 19, 2004.

In June 2004, aerial cover for each plant species and height of the shrub layer was determined in 2m x 2m plots randomly located in each soil unit, close to, but not overlapping, transplant study plots. Shrub height was measured at 3 locations in each plot and averaged. Vegetation appeared homogenous across the Leaf B and Leaf C soil units, so a single plot was evaluated. For all other soils, two plots were sampled and means were reported.

In late Nov. and early Dec. 2004, at the end of the second growing season, each surviving transplant was collected, washed, and air dried. The fresh weight of each survivor was then determined.

SAS PROC GLM (SAS Inc. 2001) was used to perform a type of split plot analysis of variance to determine if soil and/or neighbors significantly affected survival, per plot, of the transplants and to determine if neighbor effects varied by soil series. Soil type was treated as a whole plot factor and neighbors as a sub plot factor. Because growth data were unbalanced, SAS PROC MIXED (SAS Inc. 2001) was used to perform the mixed model analysis of variance to estimate the effects of soil, neighbors, and their interaction on transplant growth. The DDFM = Kenward option was used to compute denominator degrees of freedom. The effect of initial mass on survival was tested by a mixed model analysis of covariance on the outcome for individual plants. SAS PROC MIXED (SAS Inc. 2001) was also used to perform a random effects analysis of variance to estimate the components of variance and, thereby, determine the relative importance of soil, neighbors, their interaction, and all other unspecified factors in the survival and growth of *S. verna*.

Results

Preliminary dry weight investigation

The range of fresh weight for the 60 plants was 0.25 to 23.66 g. Among the independent variables measured, only fresh weight was strongly correlated to dry weight ($F_{1,58}$ = 2037.05, P < 0.0001, R^2 = 0.97). Dry weight was predicted by the equation Dry Wt. = 0.0304 + 0.3451 (Fresh Wt.). Fresh weight was used for all growth analyses.

Effects of clipping vegetation

Clipping vegetation in reduced neighbor plots increased the amount of PAR available to transplants (Fig.1), and the effect continued throughout the growing season (Fig. 2). The increase was less pronounced on the three wettest soils (Leaf C, Leaf B and Masontown), indicating that shrub layer vegetation on these soils was not initially as dense as on the relatively drier soils (Fig.1). Before clipping, ground level PAR in reduced neighbor plots was higher than in full neighbor plots due to lasting effects from clipping reduced neighbor plots the previous year (compare Fig.1 "before" with Fig.2 "unclipped, May 04"). PAR reaching ground level tended to decrease over the growing season in both clipped and unclipped plots, and then increase slightly during the Fall (Fig.2).

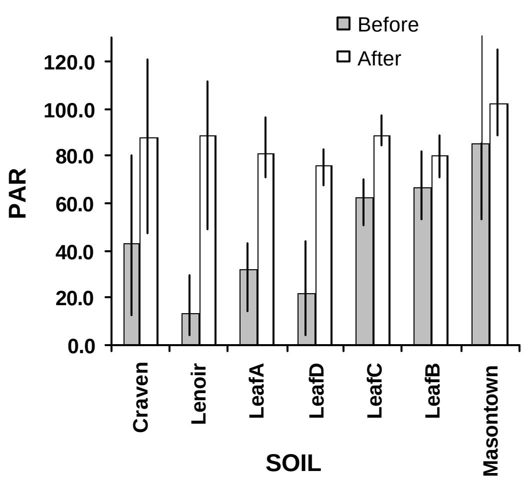

Figure 1. Mean PAR at ground level (expressed as % of PAR at chest level) for reduced neighbor plots (n=5) before and after removing vegetation on May 14, 2004. Error bars are ranges.

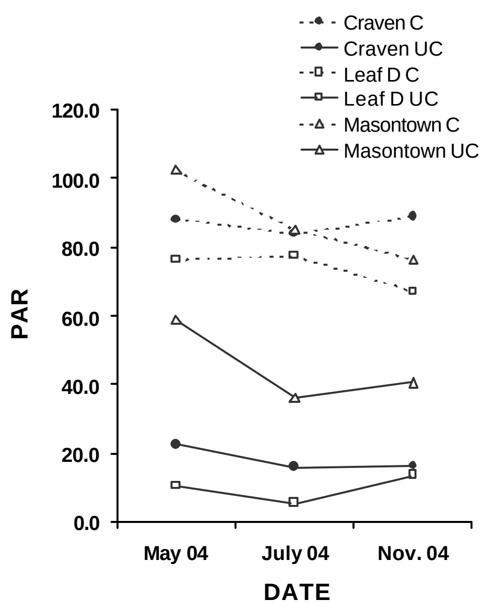

Figure 2. Change in light reaching ground level (expressed as % of PAR at chest level) over time in clipped (C) and unclipped (UC) plots.

Effects on survival

Soil series significantly affected transplant survival, with survival being lowest on the three wettest soil series (Fig.3; soil main effect $F_{6,28} = 33.29$, $P < 0.001$). Survival on Leaf C, Leaf B, and Masontown was very low by the end of the first growing season, but other soil main effects did not become evident until the end of the second growing season. Overall survival of goldenrod was greater when neighboring vegetation was removed (Fig.3; neighbor main effect $F_{1,28} = 10.29$, $P = 0.003$). But, neighbor effects differed significantly between soil series. Among soils in the drier to mid range of the wetness gradient, the intensity of neighbor effects increased as soil wetness increased. (Fig.3; neighbor X soil interaction $F_{6,28} = 4.64$, $P = 0.002$). At the end of the first growing season the neighbor effect was apparent only on the Leaf D soil. Initial mass of transplants did not significantly affect their survival (covariate effect $F_{1,351} = 0.49$, $P = 0.485$).

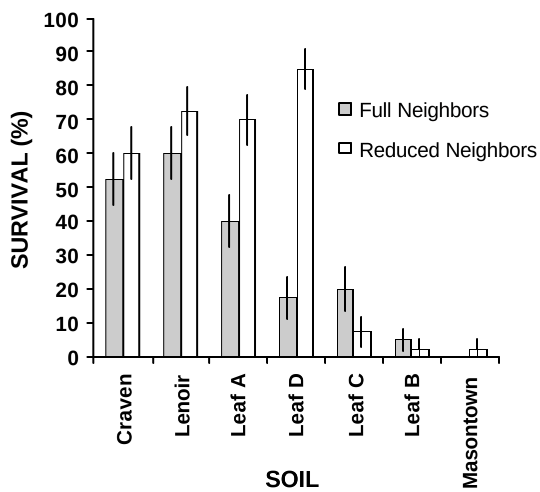

Figure 3. Effects of soil series and neighbor treatments on transplant survival (mean % surviving in each plot). Soils are ordered from driest to wettest. Error bars are $\pm$ 1 SE.

Soil was the most important factor affecting transplant survival in this study (Table 3; accounting for 47.44% of the variance in survival). Neighbor vegetation was of little importance when examined outside the context of soil (Table 3; neighbor main effect importance was 4.89 %). The importance of the interaction between soil and neighbors was similar to the importance of all other unspecified factors (Table 3; explaining 23.26 % and 24.40 % of the variance in survival respectively).

Table 3. Importance of experimental and other factors in the survival and growth of transplants. Figures are the relative percent of variance attributable to each factor.

Factor	Importance	
	Survival	Growth
Soil	47.44	6.43
Neighbors	4.89	9.13
Soil X Neighbors	23.26	0.00
Other	24.40	84.44

Effects on Growth

The majority of transplants decreased in mass during this study. Because survival was extremely low on the Leaf C, Leaf B, and Masontown soils, data from plots on those soils were excluded from analyses of growth data. Transplants grown with full neighboring vegetation lost significantly more mass than transplants in plots with reduced neighboring vegetation (Fig.4; neighbor main effect $F_{1,175} = 8.76$, $P = 0.0035$). Transplants tended to lose more mass as soil wetness increased (Fig.4; soil main effect $F_{3,18.2} = 3.24$, $P = 0.0463$). The effects of neighboring vegetation did not differ significantly among soils (Fig.4; neighbor X soil interaction $F_{3,174} = 0.24$, $P = 0.8667$).

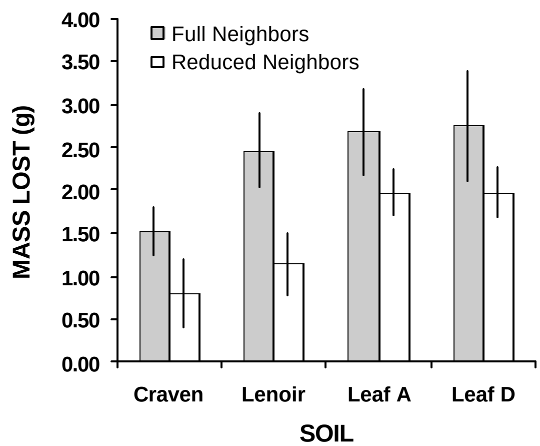

Figure 4. Effects of soil series and neighbors on transplant growth (mean individual mass (g) lost). Error bars are ± 1 SE.

Other factors, possibly environmental factors not specifically examined in this study or genetic differences between transplants, accounted for a larger percentage of the variation in the amount of mass lost by goldenrod transplants than experimental factors (Table 3; other 84.44 %). Among experimental factors, neighbor effects were most important, explaining 9.13 % of variance in transplant mass loss, while soil differences accounted for 6.43 %, differences among plants (replicates) explained 2.96 %, and the interaction between soil and neighbors was of no importance (Table 3).

Discussion

Soil series, neighboring vegetation and their interaction are more important to goldenrod transplant survival than to growth. Goldenrod is an obligate wetland species (Region 2 indicator status, USFWS 1988), but this does not mean that goldenrod occurs in only very wet conditions. In fact, almost no transplants in this study survived on extremely wet soils, including Masontown where there was frequent inundation, and Leaf B where there was ponding. Results from this study reveal that goldenrod is not suited for survival in soils that are saturated for extended durations. *Solidago verna* populations have been found on soils ranging from the poorly drained Rains to the well drained Vaucluse, and the somewhat excessively drained Tarboro. The Craven soil falls within this range of soil wetness, though populations have not been documented on Craven. Populations have been found on Leaf and Lenoir soils (N.C. Natural Heritage Program EO's).

Among soils where overall survival was greater than 50% (Craven, Lenoir, Leaf A and Leaf D), the intensity of neighbor effects increased as soil wetness increased (Fig.3). There was a general trend among these soils of increase in shrub height and total aerial cover as wetness increased (Table 2). However, the amount of PAR blocked by the shrub layer did not show a corresponding increase (Fig.1). Competition for light, then, does not adequately explain the neighbor effect.

Although a single type of plant interaction can not be singled out as the cause for the neighbor effect, the quality and quantity of litterfall, as it varies between soils, may be responsible for much of the decreased survival. Soil surface wetness influences the decomposition of litter. Organic materials accumulate on very wet soils, where less oxygen is available for aerobic microbial decomposers (Buol et al. 2003). A thick layer of woody fibers and shrub leaves formed dense mulch covering the ground on the Leaf A and Leaf D soils, with Leaf D having the deepest litter layer. Transplants were rooted in this material in reduced neighbor plots, where the litter formed a moist but well drained soil surface horizon, but they were buried under it in the full neighbor plots (Fleming, personal observation). Dense litter covering transplants may deprive them of light and oxygen or may prevent air circulation and promote infection by pathogens.

Litter on the drier Craven and Lenoir soils was sparser and consisted mainly of longleaf pine needles and other large but lightweight plant parts that did not form a dense layer on the ground.

On the wettest soils where survival was nearly zero, Leaf B and Masontown, neighboring vegetation appeared to have no effect on survival (Fig.3), however when other factors are limiting, as soil wetness appeared to be in this case, the neighbor effect may have been harder to detect (Welden and Slauson 1986).

Underground plant interactions were not specifically addressed in this study but could have affected transplant survival (Casper and Jackson 1997). Increasing soil wetness was accompanied by increasing dominance of cane (*Arundinaria gigantea* (Walter) Muhl.) (Table 2), a species with very large and extensive rhizomes.

Neighbors actually improved transplant survival in some cases. Overall survival was low (< 15%) on the Leaf C soil, which ranked fifth in wetness, but survival on full neighbor plots was more than twice that on reduced neighbor plots (Fig.3). In this case soil wetness likely was the limiting factor, but neighboring vegetation may have reduced soil wetness by taking up water from the soil through transpiration. Leaf C, the only soil in the study where facilitation was apparent, was also the only soil with wiregrass (*Aristida stricta)* (Table 2). Wiregrass has hydraulic lift ability, that is the ability to bring water from deep within the soil and redistribute it to dry surface soil, facilitating other species under xeric conditions (Espeleta, West, and Donovan 2004). This study indicates that it may also be capable of transferring moisture from surface soil to the atmosphere under saturated conditions. Neighboring plants with very low moisture content, like wiregrass, may also reduce relative humidity around goldenrod leaves by wicking moisture away. Lower humidity accelerates transpiration and decreases the growth of harmful fungi and bacteria (Rice and Rice 1997). When searching for transplants to use in this study, field workers found many individuals covered by clumps of wiregrass. The wiregrass may have facilitated goldenrod by creating relatively dry microsites. The importance of facilitation is highly variable across landscapes and may differ with small changes in elevation (Pennings, Selig, Houser, and Bertness 2003) or other biotic and abiotic conditions (Espeleta, West, and Donovan 2004), so the assumption should not be made that wiregrass is always beneficial to goldenrod. Wiregrass may interfere with goldenrod, rather than facilitate it, when soil wetness does not produce abiotic stress.

Although soil was important in determining transplant survival, it was not as important in the growth of those plants which did survive, and soil did not influence the effects of neighboring vegetation on growth (Table 3). Soil and neighbor effects were responsible for a significant portion of the decrease in transplant mass; however, combined, they explain only 15 % of the data variation. Some other factor or factors were the primary cause. Stress from the transplanting process might explain loss of mass. Another possible explanation is shading from the tree canopy. Transplants were taken from a powerline right-of-way with no tree canopy, while the study site had a canopy of longleaf pine, so all plants were grown in lower light conditions during the study than prior to the study.

Survival of transplants is essential for successful mitigation for the threatened goldenrod population, but transplant growth may be less important. Transplants need not increase in size in order to flower and reproduce. Many survivors (100+) were replanted in a recently burned area following this study and well over half of them flowered during the first spring, despite their small size (Fleming, personal observation). Flowering may have been stimulated by nutrients made available during the previous burning of the area, or by the sudden increase in available light. This species is known to benefit from disturbance events, reproducing more vigorously following fire and mowing, but the exact trigger for flowering is unknown. Additional research on all the effects of fire is essential to better understand and develop management strategies for *S. verna*. The effects of fire on individuals of different sizes should be examined.

In conclusion, soil wetness likely is the most important factor determining the survival of goldenrod. Neighboring vegetation and increasing soil wetness negatively affect growth of goldenrod. Soil and neighboring vegetation interact in ways that may not be easily predicted. Careful site selection for appropriate soil wetness and long-term management of interacting vegetation are necessary for successful establishment and viability of transplant populations. Ongoing management must include burning every 1 – 3 years, and candidate sites should have a consistent burn history to be assured that the site has vegetation that can support that burn frequency. Any lapse in burning that allows woody species to become dense and litter to build up is likely to extirpate the population. High survival rates may be achieved by transplanting to a dry phase of the Leaf soil, similar to Leaf A or Leaf D, and keeping woody vegetation cleared, but management may be difficult. A better choice may be the Lenoir soil, not only because Lenior is the soil on which the threatened population is found, but also because transplant survival was good on this soil both with full and reduced neighboring vegetation. If management problems do arise, populations on Lenoir soil are likely to survive longer than populations on wetter soils. Soil wetness can vary significantly within a series, as was demonstrated in the Leaf series in this study, so transplant site soils should be evaluated based on the field indicators in Table 1, not on series name only. The threatened goldenrod population is on a wetter variant of Lenoir than the Lenoir used in this study, with seasonal high water tables at 5 and 14 inches, respectively (The Catena Group, Inc. 2004). Receptor sites with wiregrass are preferred, as that species may facilitate goldenrod survival on wetter variants of Lenoir and Leaf. Additionally, goldenrod should not be transplanted to sites with cane since it may negatively affect goldenrod. Because the initial mass of transplants did not affect their survival, individuals of all sizes (above 0.61 g) may be transplanted during mitigation. Finally, the focus of this study is limited to a single species and a few soils, and predictions can not, with high confidence, be made regarding other soils or species, butthe study does indicate that complex interactions are important in this ecosystem and deserve further investigation. Additionally, the role of facilitation should be examined more closely for this and other rare species.

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