Northeast Minnesota White Cedar Plant Community Restoration: Phases I&II

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Introduction

Northern white-cedar (NWC) (*Thuja occidentalis*) grows in a variety of habitats including mesic forests, limestone cliffs, sand dunes, riparian systems, abandoned farm fields, and swamps (Johnston 1977, Kost et al. 2007). Most NWC swamps are typically found in areas with calcium rich groundwater (Johnston, 1977). Northern white cedar swamps are valuable ecosystems in the Great Lakes region for several reasons: 1) NWC swamps are peatlands, which are an important component of the global carbon cycle because they both sequester carbon and emit the greenhouse gas methane (Gorham 1991, Roulet 2000). NWC swamps might be one of the major stores of carbon in the Great Lakes region (Ott 2013), 2) Cedar swamps are valuable wildlife habitat, particularly as thermal cover and browse during winters for deer, 3) Ojibwe tribes use cedar for medicine and ceremony (Rooney et al. 2002, Boulfroy et al. 2012), 4) NWC swamps are one of the most biodiverse ecosystems and are home to many rare species of plants and animals, and 5) NWC occupies more than 2 million hectares of commercial forest land in the northern Lake states (Johnston, 1977) and is an important forestry tree because the rot- and termite-resistant wood is used for products in contact with water and soil (e.g., houses, fence posts, decks, saunas, furniture and shingles). However, despite the importance of cedar swamps, they are an endangered ecosystem because there has been a problem regenerating cedar for over 70 years (Heitzman et al. 1997).

Over-browsing by white-tailed deer is possibly the most well-known factor contributing to regeneration failure in cedar (Curtis 1946, Rooney et al. 2002, Haworth 2011, Boulfroy et al. 2012). Deer find NWC to be particularly tasty, and they rely on cedar as a food source in the winter, when many other nutritious food sources are absent or scarce (Johnston 1977). The dense canopies that are typical of a healthy cedar stand also provide a thermal cover for deer and other wildlife (Johnston 1977, Johnston 1990, Pregitzer 1990, Doepker and Ozoga 1991, Heitzman et al. 1999, Rooney et al. 2002, Boulfroy et al. 2012). Heavily browsed cedar stands are likely to experience inadequate recruitment of young cedar into the overstory, which creates a negative feedback loop that jeopardizes the health and survival of the deer population. Managers believe that deer browse on cedar may be reduced by deep snow packs, small stands, distance from traditional yarding areas, cutting during years of low deer abundance, distance from forest harvesting, protection by tops left by harvesting, or distance from roads (Heitzman et al 1999;

Forester et al 2008); however, most of these concepts are derived from observations with little scientific testing conducted.

Explanations for the lack of cedar regeneration have been concerned mainly with either silvicultural practices (i.e. cutting intensity, seedbed preparation, slash piles, incident light) or with overbrowsing by wildlife (Nelson 1951, Smith and Borczon 1981, Verme and Johnson 1986, Pregitzer 1990, Haworth 2011, Larouche et al. 2011). Both of these factors are important for cedar regeneration, but it is also imperative to understand the problem from an ecosystem level. Managing a species requires understanding not only of the species, but also the ecosystem in which the species inhabits. In this case, northern white cedar is a wetland tree that grows in forested peatlands. However, there have only been a few studies that have tried to understand cedar swamps from an ecosystem or hydrological viewpoint (Satterlund 1960, Chimner and Hart 1996), and there has never been an in-depth study treating cedar as a wetland tree. Forested wetlands are controlled by different processes than other forest types, and require different measurements and methods to quantify what controls tree distribution, production and regeneration. We also need to understand cedar as part of a wetland ecosystem to be able to predict changes to cedar due to changes in climate or other human disturbances (e.g., road building, development, forestry practices and climate change).

Water-plant relations appear to play an important role in cedar success. Microtopography has been found to be a key feature contributing to successful cedar regeneration across different habitat types (Nelson 1951, Caulkins 1967, Holcombe 1976, Scott and Murphy 1987, Chimner and Hart 1996, Cornett et al. 2000, Cornett et al. 2001, Forester et al. 2008). In both dune forests and lowland areas, decaying logs create favorable microsites for cedar germination and growth by retaining an intermediate level of moisture (Holcombe 1976, Scott and Murphy 1987, Forester et al. 2008). In wetland sites, cedars also do well on hummocks which protrude from the water, probably because their roots have been relieved from the stressful anaerobic conditions of water-logged soils (Chimner and Hart 1996). Understanding the importance of these different microsite types in cedar growth may become especially important to implementing successful cedar restoration as climates change.

Roads and other hydrological disturbances can also influence NWC regeneration. Forester et al. (2008) found that cedar density had a negative relationship with proximity to roads. Abiotic and/or biotic factors may explain this relationship. The road-side edge of cedar swamps may serve as both a corridor and refugia for deer, which could potentially cause these to be areas of high browse (Forester et al. 2008). Alternately, or possibly additionally, roads are known to alter the hydrology and water quality in adjacent wetland areas (Forester et al. 2008), and roadside sodium and chloride levels are specifically known to be injurious to northern white cedar (Hofstra and Hall 1971). Understanding the role of edge effects on cedar swamps should be important in deciding restoration priorities.

The importance of forested wetlands and lack of restoration knowledge is currently at the forefront in the Great Lakes region. To exemplify this point, a conference was held in Traverse City MI, by The Association of State Wetland Managers, Inc., Michigan Department of Environmental Quality, Grand Traverse Band of Ottawa and Chippewa Indians, and U.S. Environmental Protection Agency, highlighting the complexities of restoration of northern forested wetlands. The special symposium was titled: ***"Restoration of Northern Forested Wetlands.*** *The science of restoring forested wetlands in the north has lagged behind bottomland hardwoods and other forested wetland types. A series of presentations will be devoted to identifying gaps and improving the science.*" It is clear from the lack of published papers and from symposiums such as this, that NWC swamp restoration is not common, and is mostly guided by poorly tested silvicultural guidelines (Johnston 1990, Boulfroy et al 2012). Because northern white-cedar swamps are in a state of decline and restoration techniques for them are lacking, **the overall objectives of this research were: 1) to assess and prioritize the condition and restoration potential of cedar swamps in N. Minnesota, 2) quantify the feasibility of restoring NW cedar plants by using enrichment plantings, and 3) Design and implement experimental hydrologic restoration of two NW cedar wetlands where they have been hydrologically modified by roads, and 4) Develop recommendations for NW cedar swamps restoration for Minnesota.**

Methods for Cedar Enrichment

Site Descriptions and Treatments

We established seven unique experimental enrichment restoration sites in NWC swamps in Beltrami, Koochiching, St. Louis, and Lake Counties. These sites have primarily organic soil and are less than 80 acres in size. Five of these sites currently have experimental treatments and the other two sites are currently only being monitored as reference sites. Treatments vary across sites and are detailed by site in the sections below.

Northern white cedar seedlings (3-0), as well as northern white cedar transplants (2-2) were purchased from Badoura State Forest nursery (Akeley, MN). Trees were lifted from their growing medium on May 21, 2013, and shipped May 30, 2013. Upon reception, boxes were covered in cold tarp and placed in cold storage. Tree health was vigorous, and the substantial roots (typically about 24" long) required nominal pruning (to 16"-18" long) prior to installation. After pruning, roots were dipped in Terra-Sorb solution (Plant Health Care, Inc., Pittsburgh, PA). Trees were then placed in a tub with a moss-lined bottom and tops were rinsed to remove dirt. During transport to sites, trees were covered by a thermal cold-tarp to prevent wind damage. Upon arrival at the restoration sites, trees were brought to a central location within the planting site that was protected from shade and sun. Here, the planters placed trees in bags for ease of transport within the site. Planting was done by the Conservation Corps of Minnesota and Iowa, trained by and working under direct supervision of BWSR staff.

Installation of trees involved opening a deep hole (about 40 cm) with a sharpshooter-planting spade. Roots were gently pushed to the bottom of this hole, and then the plant was pulled up to the appropriate depth. The spade was then inserted into the ground adjacent to the hole, and was used to close the hole by pushing soil toward first the bottom and then the top of the hole, with a final packing from the surface of the soil to remove any air bubbles. All trees were planted by June 5, 2013.

Cedar protection from herbivory was accomplished through the use of rigid tree protectors (for 3-0 cedar seedlings) and wire mesh enclosures (for 2-2 cedar transplants) (Figure 1). The rigid tree protectors are 5" in diameter and 4' tall and are secured with three zip ties to a bamboo rod (16-20 mm in diameter by 6' tall), driven 2' into the ground. The wire mesh enclosures were 32" diameter and 4' tall and made of 16-gauge wire mesh (2"x4"). They were secured using eight 6" sod staples, although loose top soil conditions at the sites mandated the additional use of four 4'bamboo stakes.

Figure 1. Photo showing the wire cages and plastic rigid tree protectors.

Northern white cedar seeds were gathered at the Badoura State Forest nursery with 70% germination rate. Seeding was performed by hand broadcast and spot application. Seeds were broadcast preferentially over areas that would favor germination, such as mossy patches or decaying logs; however, locations of seed dispersal were not precisely recorded. All seeding was completed by June 16, 2013.

DNR Stand #649

This Beltrami County site (13 acres) was a mixed tamarack (site index = 37) stand that was cutover in 2011, removing dead tamarack and leaving behind northern white cedar (Figure 2). There is currently a low volume residual cedar overstory with scattered paper birch. Low-density regeneration is dominated by balsam fir with paper birch and alder, with little cedar regeneration. It is likely that hydrology is being influenced by the nearby road. The Web Soil Survey lists this site as having Bullwinkle (60%) and Tawas (40%) mucks (Soil Survey Staff).

Along the perimeter of the site, 250 cedar transplants were planted every 20 feet. Fifty wire mesh enclosures were installed on every fourth tree on the west boundary, and every fifth tree on the highway side. From a total of 250 cedar seedlings, approximately 80 were planted every 20 feet in each of three north-south transects, with a rigid tree protector installed on every fourth tree (50 total protectors). Every planted, unprotected cedar tree was marked with a blue ribbon. Between transects, 500 tamarack seedlings (2-0) were installed at 20 foot by 20 foot spacing. Forty ounces of northern white cedar seed was broadcast along the perimeter and down the center transect.

Figure 2. Aerial photo of site #649 (yellow outline) in Beltrami County.

DNR Stand #664

This Beltrami County site is a 21.6-acre, former cedar swamp that was cutover about 26 to 30 years ago and converted to a tamarack (site index = 47) plantation (Figure 3). The Native Plant community is Northern Very Wet Ash Swamp (WFn64) in the south and Northern Wet Cedar Forest (WFn53) in the north (Minnesota Department of Natural Resources 2003). Just prior to implementation of treatments, it was a young, understocked tamarack stand with very little cedar regeneration restricted to nurse logs in the northwest corner and nominal understory that is not representative of a cedar swamp. There is possible hydrological alteration. The Web Soil Survey lists this site as having Northwood-Berner complex (49%), Grygla loamy fine sand (49%), and Bullwinkle muck (2%) soil types (Soil Survey Staff).

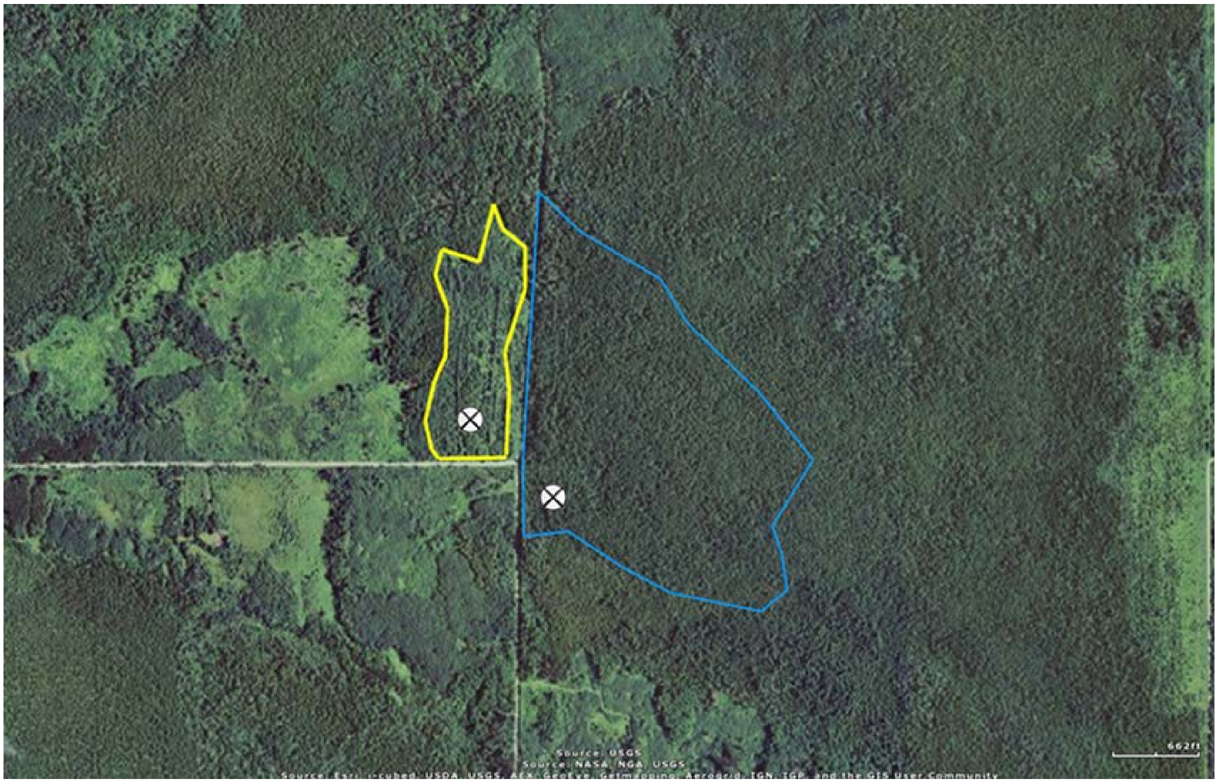

Figure 3. Aerial photo of site #664 in Beltrami County. Yellow outline indicates location of planting and seeding and blue line indicates secondary reference site. White circles indicate location of groundwater wells.

Protection from herbivory at this site was organized into five north-south transects with alternating propagule and protection type. Each transect contained trees installed at 20' spacing with every tree marked by blue ribbon within 3 feet of the tree. Every fourth transplant was protected by wire mesh enclosures, and rigid tree protectors protected every fourth seedling. This created two transects with 240 cedar transplants (60 protected by wire mesh enclosures and 180 left unprotected), and three transects with 240 cedar seedlings (60 protected by rigid tree protectors and 180 unprotected). The west perimeter was planted with 92 cedar transplants, with 23 of those protected by wire mesh enclosures. None of the unprotected, planted cedars on the west perimeter were marked with flagging. The remaining 268 transplants were planted adjacent to wire mesh enclosure transects, and the remaining 360 seedlings were planted adjacent to the rigid tree protector transects. Twelve hundred black spruce seedlings (3-0) were installed at 20 foot by 20-foot spacing in the area located between the two eastern-most transects.

DNR Stand #276

This Beltrami County site contains 55 acres of a mature (137 years old), Northern Wet Cedar Forest stand (WFn53; cedar site index = 26; Minnesota Department of Natural Resources 2003) with cedar, balsam fir, and tamarack in the subcanopy (Figure 4). The Web Soil Survey lists this site as having Bullwinkle (71%) and Tawas (28%) mucks (Soil Survey Staff).

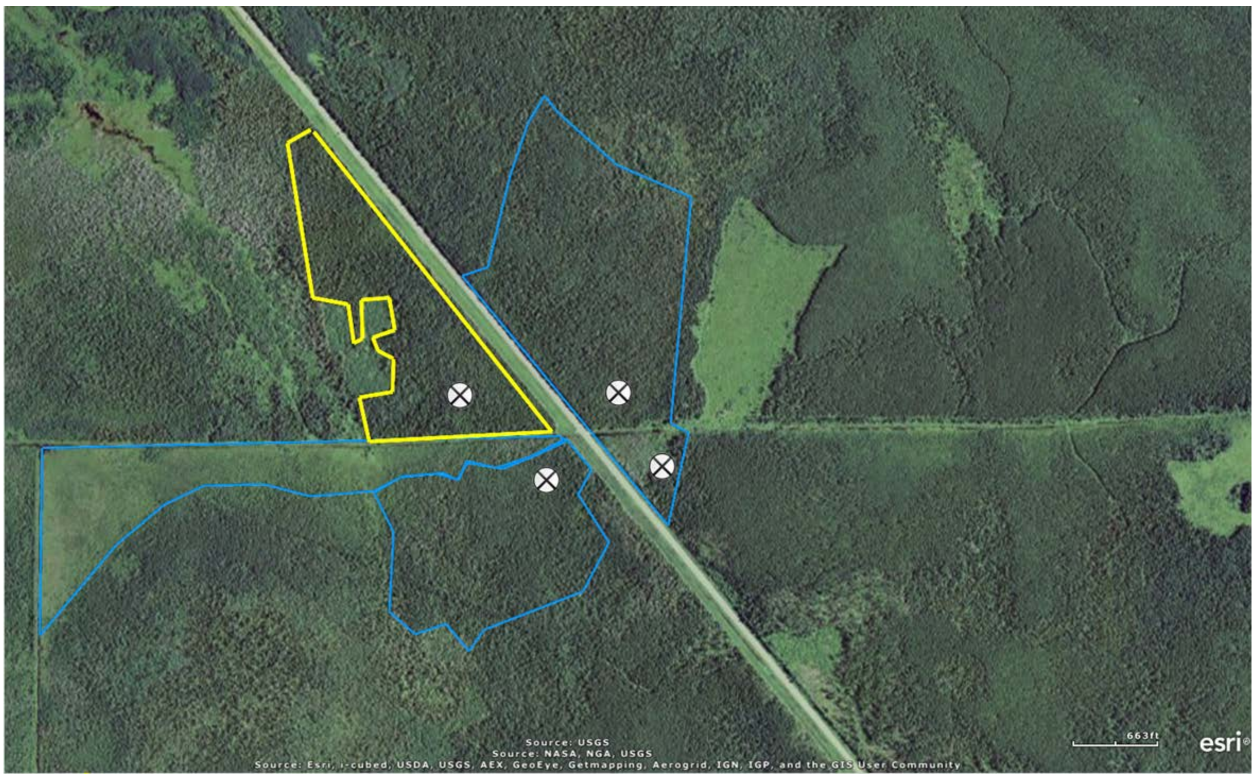

Figure 4. Aerial photo of site #276 (yellow outline) and adjacent sites (blue outline) in Beltrami County. White circles indicate location of groundwater wells.

This site is located in the northwest corner of the intersection of Minnesota State Highway 72 and a ditch that runs from east to west. The construction of these structures occurred about 95 years ago and divided a cedar swamp into four sections and altered the hydrology in the area.

The road and ditch have caused groundwater flowing through this area from the southeast to build up in the southeast corner, while severely restricting flow to the northwest corner.

Excessively wet conditions in the southeast corner have caused massive loss of woody vegetation, including northern white cedar. Excessively dry conditions in the northwest corner have caused subsidence of peat and die-off of wetland shrubs and groundcover. Regeneration of northern white cedar has also reduced in this area. Just upstream of the ditch, and adjacent to this site, there is ample advance regeneration of northern white cedar occurring in the northeast corner of the intersection.

This site provides ideal conditions to observe the effects of roads and ditches, and associated altered hydrology, on cedar swamps. BWSR staff initially installed wells in each corner of the road-ditch intersection to monitor hydrology. Three pressure transducers were placed in the wells with the exception of the northeast corner that was monitored by hand.

No treatments have been implemented at this site; it will continue to be monitored as a reference site.

DNR Stand #117

This St. Louis County site is a 25-acre, mature (128-year-old) Northern Cedar Swamp (FPn63; cedar site index = 23; Minnesota Department of Natural Resources 2003) in which four small patch cuts (0.25 acres each) were made over 20 years ago in a failed attempt to stimulate cedar regeneration (Figure 5). Just prior to application of treatments, the patch cuts were dominated by dense willow and alder with nominal tree regeneration present, and the understories were not representative of a Northern Cedar Swamp. The Web Soil Survey lists this site as being entirely Mooselake mucky peat (Soil Survey Staff).

During the 2012-2013 winter, the shrub component was removed manually from each block, with stumps cut to within two inches of the ground. Cut materials were piled compactly in windrows at the outer edges of the treatment area. Black spruce, tamarack, and other saplings and pole timber were left undisturbed, resulting in variable densities – ranging from 1-5% to 51-75% coverage – of residuals across blocks.

Installation of 300 cedar transplants (75 trees/block) occurred at 12 foot by 12-foot spacing in the west half of all four 0.25 ac blocks (0.5 ac total planting area). Three hundred cedar seedlings (75 trees/block) were interplanted with 6 foot by 6-foot spacing. Mesh enclosures were constructed and installed on 25 evenly distributed cedar transplants in each block (100 total). Tree protectors were installed on 50 evenly distributed cedar seedlings in each block (200 total).

Northern white cedar seed was broadcast over the east half of each block (0.125 acres each, 0.5 acres total) at a rate of 1 ounce per acre by May 28th, 2013.

Figure 5. Aerial photo of site #117 in St. Louis County. Yellow outline indicates location of patch cuts where cutting, planting, and seeding occurred. The blue line indicates the site boundary.

<u>DNR Stand #28</u>

This St. Louis County site is a 57-acre, mature (153-year-old) Northern Wet Cedar Forest (WFn53; cedar site index = 24; Minnesota Department of Natural Resources 2003) with low to moderate density sapling understory and little to no cedar regeneration (Figure 6). Open areas that were created by past timber harvest contain patchy alder. The site is hydrologically isolated by two ditches and a road, Highway 133, which surround it. Areas adjacent to the ditches have experienced peat subsidence and have no cedar regeneration. The Web Soil Survey lists this site as being entirely Mooselake mucky peat (Soil Survey Staff).

Evenly mixed plantings of 500 cedar transplants and 500 cedar seedlings were installed at 20 foot by 20-foot spacing across the planting area (9 acres). Mesh enclosures were constructed and installed on 100 evenly distributed cedar transplants. Tree protectors were installed on 360 evenly distributed cedar seedlings. Northern white cedar seed was broadcast along the border and the center line at a rate of four ounces per acre.

Figure 6. Aerial photo of site #28 (blue outline) in St. Louis County. Yellow outline indicates location of planting and seeding. White circles indicate location of groundwater wells.

County Land Department Stand #09-29TA "Boomer Road"

This Lake County site is a 40-acre Northern Wet Cedar Forest (WFn53; Minnesota Department of Natural Resources 2003; Figure 7). Carbon dating in the soils has indicated the presence of cedar for past 7000 years (Ott 2013). Additionally, old stumps, indicating two previous stand rotations, suggest that this stand regenerated to alder, fir, and ash following harvest.

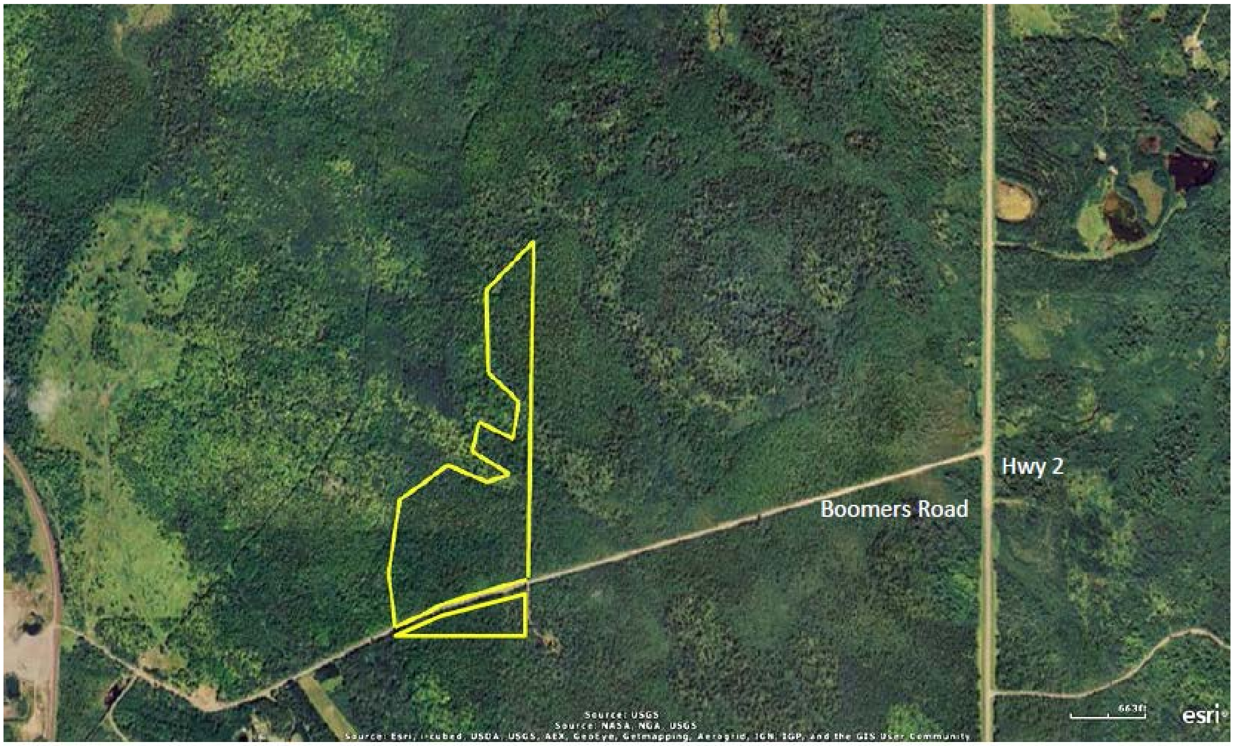

Figure 7. Aerial photo of site #09-29TA (yellow outline) in Lake County.

The soils are patchy mineral soils with woody peat. The Web Soil Survey lists this site as having Mooselake muck (51%), Normanna-Hermantown complex (23%), Dora mucky peat (15%), Normanna-Canosia-Hermantown complex (6%), Ahmeek-Normanna-Canosia complex (3%), Augustana-Hegberg complex (3%), and Giese muck (0.4%) soil types (Soil Survey Staff).

During the 2012-2013 winter, all woody vegetation less than two inches in diameter was removed mechanically (Figure 8) in 20 strips, approximately 30 feet wide and separated by untreated 30 to 60-foot wide strips. A 30-foot buffer was left along the road. Some slash was mulched with a masticator machine, and chips were distributed evenly across the site. Much slash was left as debris across the cut areas. This is the only site for which measurements of initial peat depths exist.

Installation of 1750 cedar transplants (2-2) occurred at 20 foot by 20-foot spacing across the entire planting area (about 16 acres). Evenly mixed planting of 1250 cedar seedlings and 50 yellow birch whips were interplanted with 10 foot by 10-foot spacing. Mesh enclosures were constructed and installed on 325 evenly distributed cedar transplants. Tree protectors were installed on 600 evenly distributed cedar seedlings and on the yellow birch whips.

Figure 8. Photo of equipment used to create strips in dense vegetation at site #9.

Soil and Hydrology

Soil series contained in each site were obtained from the Natural Resources Conservation Service's Web Soil Survey (Soil Survey Staff 2014). At least one groundwater monitoring well with a pressure transducer (for monitoring water table levels; Solinst Canada, Ltd., Georgetown, ON) were installed at each site prior to implementation of treatments. Water table data from the pressure transducers were downloaded once per season. Groundwater pH and conductivity were recorded at each well.

Initial Vegetation Survey

Prior to implementation of treatments, a full vegetation survey was conducted of trees, vascular plants, and mosses. In a 400m^2 (0.1 acre) circular plot, overstory trees and saplings taller than breast height were identified to species as either alive or dead and measured for diameter at breast height (DBH). Trees below breast height (i.e. regeneration) and shrubs were tallied as alive or dead and by three height classes: 0-40cm, 40-80cm, and 80-137cm. For herbaceous vegetation, a 50 m transect was established, with 25m to the east and 25m to the west of the plot center. Herbaceous vegetation was identified in a 50m by 10m belt transect, centered over the 50m transect line. Four 1m^2 (0.5m by 2m) subplots were established at 14m intervals along the belt transect. Herbaceous cover was measured in each subplot.

Seedling Survival Survey

<u>*Tree monitoring*</u>

Survival of planted northern white cedar seedlings and transplants at the five sites was monitored from late April to mid-June of 2014. Monitoring techniques for tree survival varied across sites because unprotected cedar seedlings and transplants were difficult to find. Only two sites – DNR stands #664 and #649 – had unprotected trees that were marked with blue ribbon. DNR stand #117 had high density planting that was done in small (4 x 0.125 ac) areas, making trees far easier to find. At these three sites, site-level monitoring was performed to assess tree survivorship.

At the other two sites – DNR stand #28 and CLD stand #09-29TA – subplots were created within the site in order to devote time spent searching for unprotected trees to a smaller spatial area. Protected and unprotected seedlings were sampled in six haphazardly placed 400m^2 (20m x 20m) subplots across the planting area of DNR stand #28, with three on either side of the old logging road that bisects the site. In CLD stand 09-29TA, 400m^2 (6m x 67m) subplots were placed in every other transect, at a rotating distance of 0, 25, and 50 m from the beginning of the transect.

Regardless of sampling technique, each tree sampled was noted as unprotected, protected by wire mesh enclosures, or protected by rigid tree protectors, and was assessed on four variables: condition of the tree, soil moisture, microtopography, and presence and/or level of browse. Condition of the tree was marked as one of the following:

Alive (“A”)	Indicates that tree is alive, even if it is in poor health
Nearly Dead (“ND”)	Indicates that tree looks like it will soon die
Dead (“D”)	Indicates absence of any green foliage

Soil moisture was ranked on a scale of 1-4:

1. There is standing water at the base of the tree
2. The soil at the base of the tree releases water when pressure is applied
3. The soil at the base of the tree is moist to the touch, but does not release water under pressure
4. The soil at the base of the tree is without any moisture

Microtopography was noted visually as one of the following:

	The level of the ground at the base of the tree is:
Lawn (“L”)	similar to most of the site
Pool (“P”)	lower than most of the site
Hummock (“H”)	higher than most of the site

If a tree was browsed, it was noted as such by one of the following:

Heavily Browsed (“+B”)	Browsing which appears to significantly impact the tree's health
Lightly Browsed (“-B”)	Browsing which does not appear to have a significant impact on the tree's health

Results and Discussion for Cedar Enrichment

Hydrological and Environmental Conditions

The pH of the water ranged from about 5 to 7 units across all the sites (Table 1). The lowest pH values were found in Site #28 and the greatest occurred at #9 and #664 (Table 1). Specific conductivity ranged between 75 and 350 µS cm^{-2}. Most of the pH and conductivity values are within the normal range for NWC swamps (5.5 – 7.2: Johnston 1990). However, two of the restoration sites, #28 and #117 are at the very low end or just below the recommended pH gradient (Table 1).

Continuously recorded water table levels indicate that these cedar swamps have a very wide amplitude (Figure 9). Natural undisturbed water table levels from two sites in the Upper Peninsula show a much smaller annual fluctuation, with water table levels typically fluctuating between 20 cm above and below the ground surface as measured from a pool (Figure 10: Chimner unpublished data). This pattern of water table levels was also seen in another study of cedar in the Upper Peninsula of Michigan (Chimner and Hart 1996).

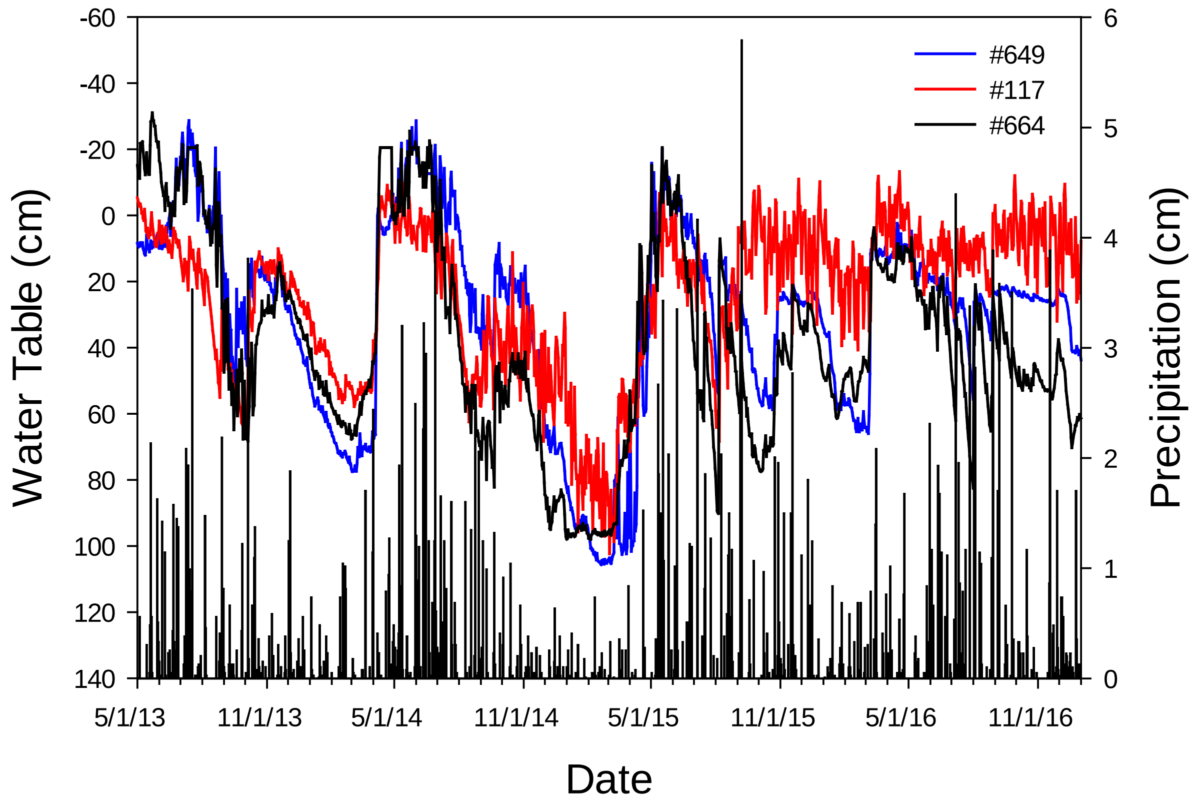

Figure 9. Time series of water table elevations at two of the restoration sites. Precipitation data is from USFS Marcel Experimental Forest (S2). Negative water table values indicate water table levels are above the ground surface.

Contrastingly, all the restoration sites had water table levels that dropped below 20 cm below the surface during 2013 (Figure 9). In the early half of the summer, all the sites were wet from snow melt and spring rains, with the exception of #664, which was 20-40 cm below the soil surface. In the northern Beltrami County sites (#664 and reference site), the water levels spiked after a large precipitation event(s). By later summer, most of the restoration sites had rapidly dropping water table levels that reached a low of 40 to 110 cm below the soil surface, then rose again in the spring of 2014.

In addition to monitoring the restoration sites, we also monitored a few reference sites (Figure 11). The impeded drainage site (#649SE) was the wettest site with a water table that rarely dropped below the soil surface. The other sites showed a similar pattern to the restoration sites, they were wet in the spring and very dry in the late summer/fall.

In summary, most of the restoration sites had acceptable hydrology and water chemistry values to support cedar restoration. However, site #664 has low water tables that could be problematic, and site #117 and #28 have low pH values that could also be problematic.

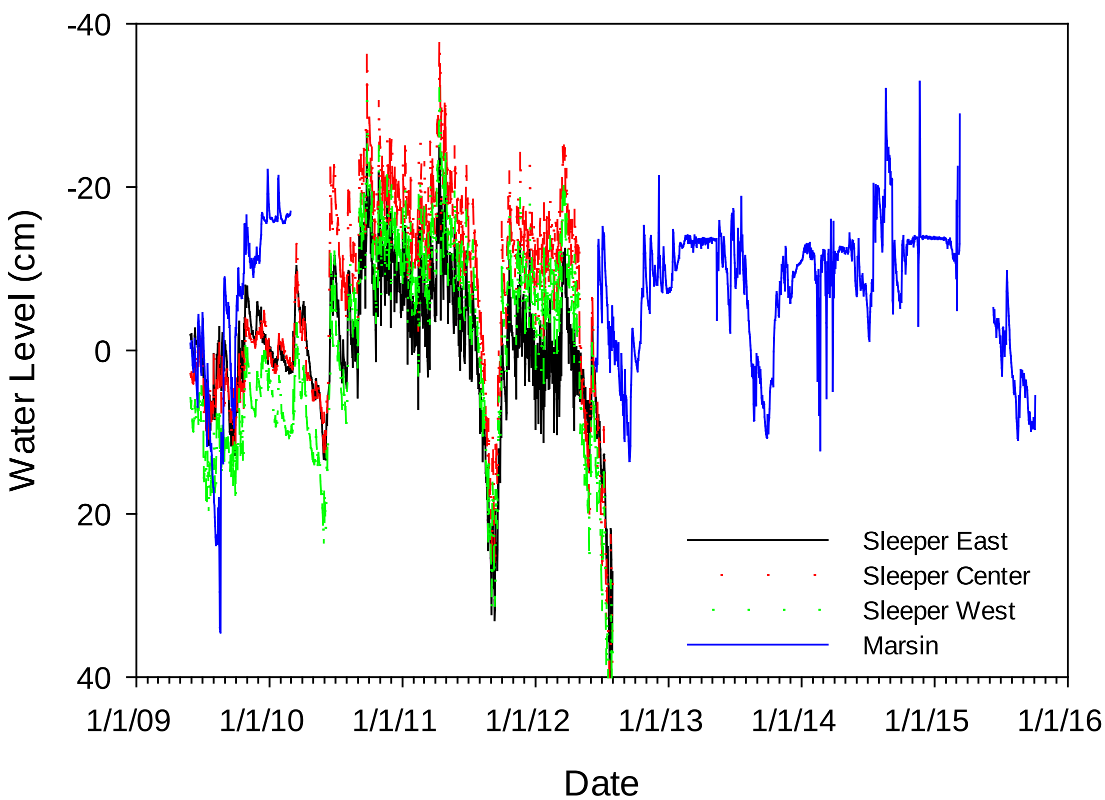

Figure 10. Reference water table levels from two undisturbed cedar swamps (Sleeper and Marsin) in the Upper Peninsula of Michigan (Chimner unpublished data).

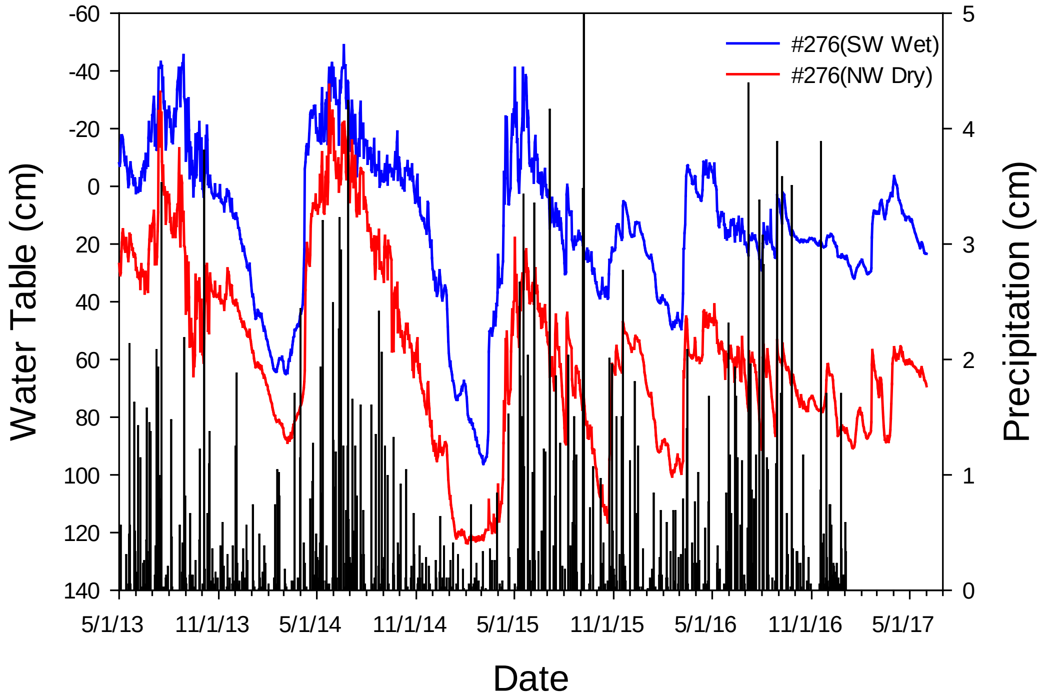

Figure 11. Water table levels of non-restoration sites in Minnesota.

Table 1. Descriptions of water chemistry and summary water table data.

Site	pH	Specific Conductivity (µS cm)	Average Water Table (cm)	Minimum Water Table (cm)
#649	6.38	99	30	80
#664	6.82	354	43	112
#664-ref	6.69	257	18	85
#276 (SE)	6.74	132	-17	3.5
#276 (NE)	5.80	228	22	66
#117	5.05	75	21	64
#28	4.95	107	9	42
#9	6.90	166	15	60

Initial Vegetation Surveys

Our sampling found 75 species of vascular plants and bryophytes in the understory (Appendix 2). The most common species found were various species of sedges, grasses, *Sphagnum* mosses, bunchberry (*Cornus canadensis)*, bog Labrador tea (*Ledum groenlandicum*), *Thuidium delicatulum*, and raspberry (*Rubus ideaus* & *R. pubescens).* Cluster analysis found that understory plants at our sites separated into two main types of communities, with a few outliers that did not fit into these two groups (Figure 12). These two groups were also evident in the NMS analysis (green and red polygons in Figures 13 & 14).

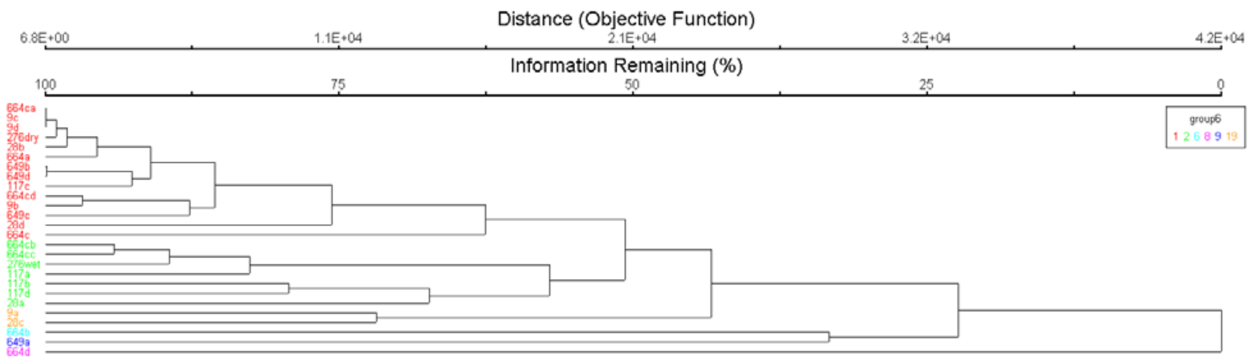

Figure 12. Cluster analysis of understory species at restoration sites.

The NMS analysis found that these two groups were correlated with hydrology and, to a lesser extent, water chemistry. NMS and indicator analysis found that community 2 (green lines in Figures 13 & 14) was a transitional black spruce swamp with slightly lower pH levels and indicator species that include: *Cornus canadensis*, *Ledum groenlandicum*, *Sphagnum* mosses, and *Thuidium delicatulum*. This community was found mostly at the site #117 and some locations in #664-ref, both of which had black spruce in the overstory (Table 2).

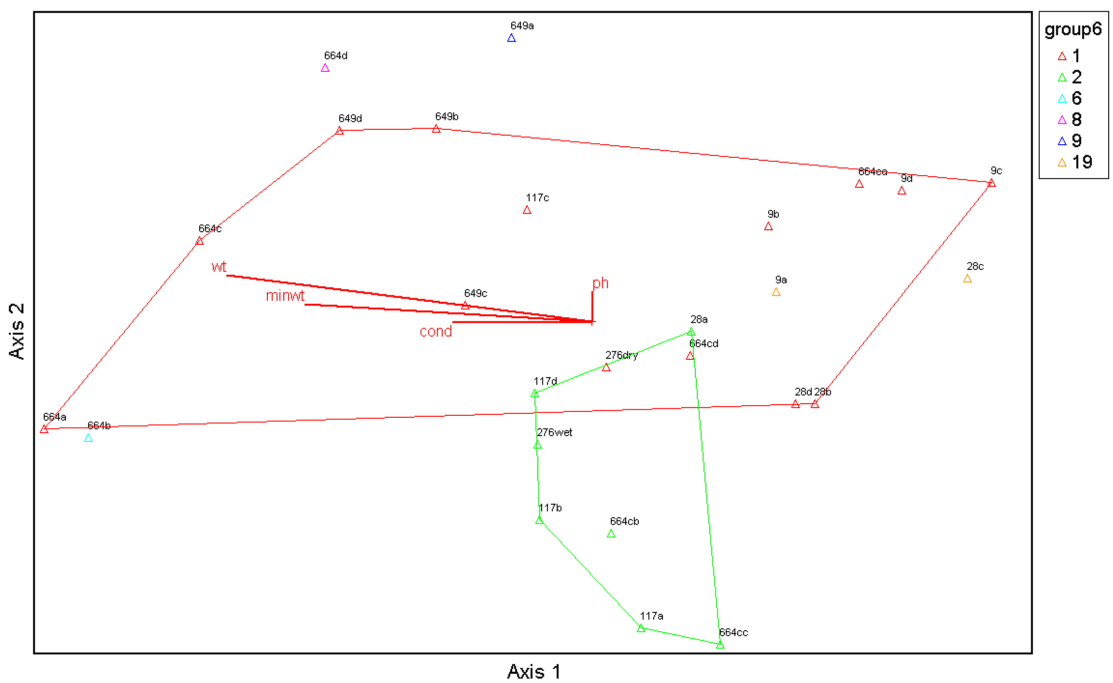

Figure 13. NMS showing sites.

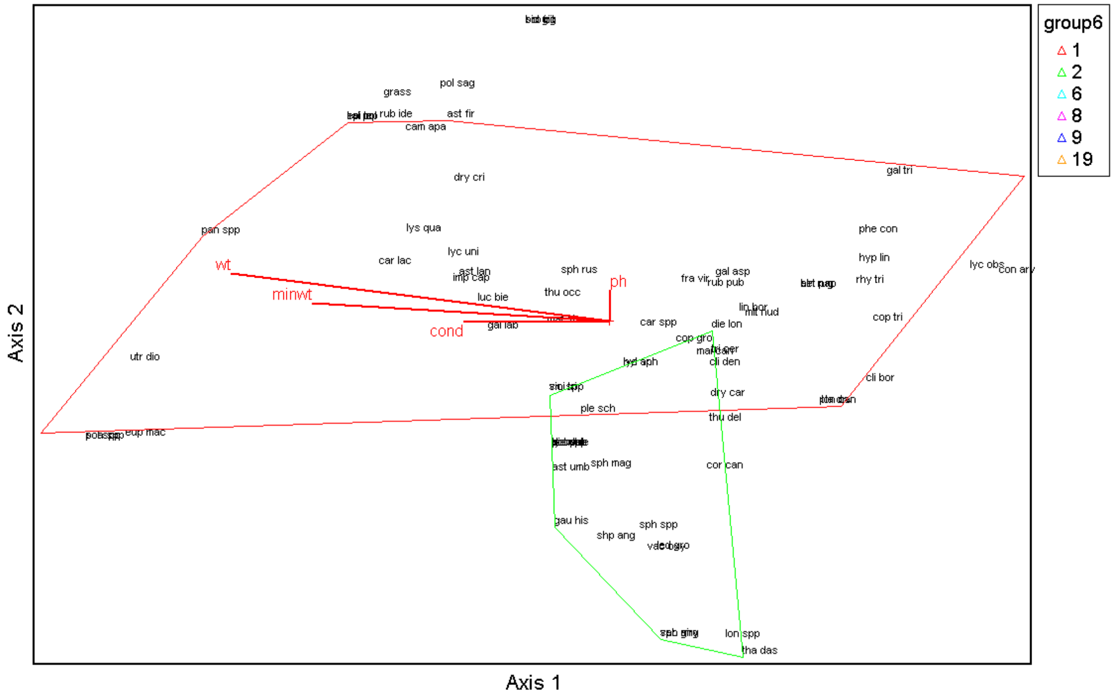

Figure 14. NMS showing species.

Table 2. Basal area (m2/ha) of overstory trees at sites before restoration treatments.

Species	**#9**	**#28**	**#117**	**#649**	**#664**	**#664-Ref**
Abies balsamea	7.55		1.30	0.47		6.88
Acer saccharum	0.08					
Acer spicatum	0.19					
Alnus incana	2.04		0.37			0.10
Amelanchier sp.	0.07					
Betula papyrifera	6.03			0.32		0.87
Cornus spp.			1.28			
Fraxinus nigra	6.80					
Larix laricina			1.98		12.62	0.28
Picea mariana			3.67			1.01
Populus balsamea						0.69
Salix sp.			0.20		2.94	3.41
Thuja occidentalis	1.02	70.53	0.28			17.15
Grand Total	**23.78**	**70.54**	**9.09**	**0.79**	**15.56**	**30.39**

Table 3. Tree density (trees/ha) of overstory trees at sites before restoration treatments.

Species	**#9**	**#28**	**#117**	**#649**	**#664**	**#664-Ref**
Abies balsamea	3800		150	150		1825
Acer saccharum	100					
Acer spicatum	275					
Alnus incana	1550		450			100
Amelanchier sp.	75					
Betula papyrifera	125			100		125
Cornus spp			125			
Fraxinus nigra	1000					
Larix laricina			350		400	75
Picea mariana			450			75
Populus balsamea						125
Salix sp.			250		1225	675
Thuja occidentalis	50	2225	25			3750
Grand Total	**6975**	**2225**	**1825**	**250**	**1625**	**6750**

Basal area and density of trees at restoration site varied greatly. Basal area of overstory trees at the restoration sites ranged from 0.9 m2/ha at #117 to 70.54 m2/ha at #28 (Table 2). Basal area of cedar also varied from zero at #649 and #664, to 70.53 m2/ha at #28. Tree density was very high at sites #9 and #28, and very low to absent at the rest of the sites (Table 3). There was almost no cedar regeneration at any of the sites, with most regeneration consisting of balsam fir, tag alder, willow and dogwood (Table 4).

Table 4. Regeneration density (trees/ha) of understory trees and shrubs at sites before restoration treatments.

Species/ Size class (cm)	#9 stems/ha	#28 stems/ha	#117 stems/ha	#649 stems/ha	#664 stems/ha	#664-Ref stems/ha
Abies balsamea						
0-40	1900				100	800
41-80	800				200	300
81-137	1100				200	100
Acer spicatum						
0-40	400					
41-80	300					
81-137						
Alnus incana						
0-40	400		200			
41-80	400		200			
81-137	200					
Amelanchier sp.						
0-40	300					
41-80	400					
81-137						
Aronia melanocarpa						
0-40						
41-80			100			
81-137			100			
Betula pumila						
0-40						
41-80			300			
81-137					200	
Cornus spp						
0-40				15900	1600	
41-80				5200	2900	
81-137				2300	400	
Corylus cornuta						
0-40						
41-80			100			
81-137						
Fraxinus nigra						
0-40	200					
41-80						
81-137						
Salix sp.						
0-40			700			
41-80			900			
81-137			1800			
Thuja occidentalis						
0-40	100					1400
41-80						1500
81-137						600
TOTAL	**6500**	**0**	**4400**	**23400**	**5600**	**4700**

Seeding Success

We found no seeds germinated at any site during the initial visits in the spring of 2014 (Figure 15). However, some seeds were seen germinating by the next sampling trip in the late spring. It appears that the seeds over summered and wintered before germinating.

Figure 15. Photo showing ungerminated cedar seed.

Survival of Planted Stock

General survival of planted cedar

We found no significant differences in any parameter between seedlings and transplants, so all further analysis is done with pooled seedlings and transplants. Average cedar survival across sites was 69% after the first year (2014) (Figure 16), and dropped to 45% after 2 years.

Roughly 20% of cedar found were dead, 10% were missing, and 20% were classified as nearly dead. Most of the missing cedar was assumed to be dead by herbivory, but some were likely alive and not able to be located. The cedar classified as nearly dead were very sickly looking and were thought to be dying (Figure 16). Most of the cedar found dead appeared to die from obvious causes (e.g., to wet or high herbivory), however, many had no clear cause of death. Many of those had fungus on them.

Overall survival of found cedar varied by site, with Site #649 having the lowest survival of found cedar, averaging ~70%. Site #664 had survival rates near 80%, while site #28 had just over 40% survival (Figure 17).

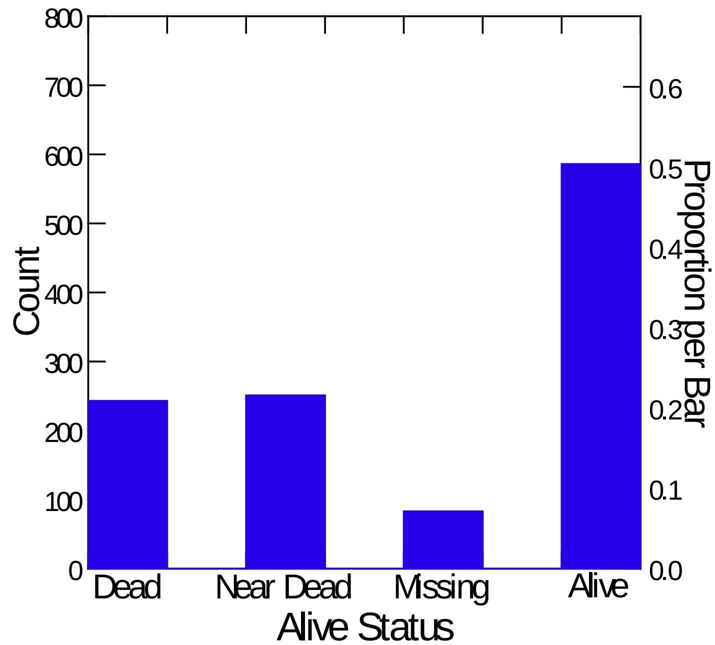

Figure 16. Histogram showing status of planted cedar after the first year across all sites.

Hydrology effects on planted cedar

Wetness of the microsite was the most important variable explaining short-term cedar survival (Figure 18). Both the soil moisture index and microtopography feature were highly significant factors ($p<0.0001$) explaining survival of planted cedar (Figures 19 & 20). Cedar survival was lowest (~20%) after two years when they were planted in a depression or pool (Figure 19). Survival of cedar was greater when planted on flat lawns

(~45%) or mounded hummocks (60%). The microtopographic position was strongly correlated with the soil moisture index that we used ($p<0.0001$; Figure 21). Therefore, a similar pattern emerged when looking at cedar survival compared to soil moisture index. The cedar survival was lowest in the wettest index (standing water) compared to the other categories (Figure 19). This indicates that cedar survived poorly in very wet pools, and survived better in slightly drier lawns and hummocks.

Height growth also varied by where the cedar was planted. Cedar grew slowest when planted in pools (Figure 22). In 2015, cedar appeared to grow faster in the pools, but the data is skewed by the fact that only a couple of cedar survived in the pools after the first year. In summary, cedar had much lower survival and grew slower when planted in pools compared to lawns or hummocks.

Certain hummocks, however, can be too dry to encourage cedar survival. For instance, at site #649, the many of the hummocks planted were actually perched root mats with lots of air space under them. The effect of this was that cedar roots were dried out, and the trees often died when planted on these hollow root mats (Figure 23).

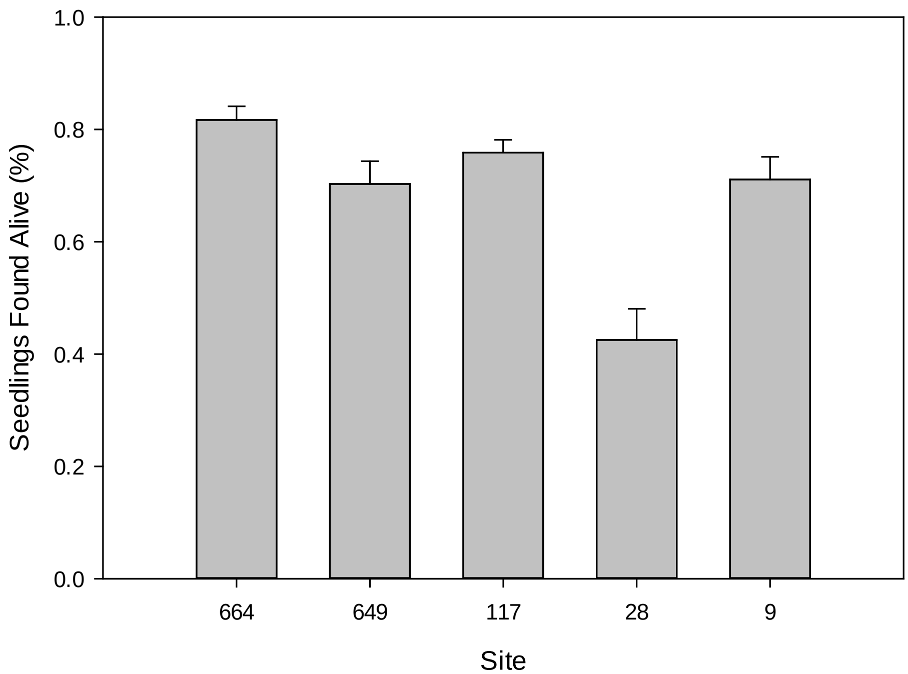

Figure 17. NW cedar survival varied by site after the first year ($p<0.001$).

Figure 18. Photo showing a dead cedar planted in wet conditions.

Our results are in line with other studies that have found that microtopography is important for cedar survival (Chimner and Hart 1996, Kangas 2012). Microtopography is small-scale variation in topography creates microhabitats with different water levels, ranging from drier, raised hummocks to flooded pools. In a study of a northern white-cedar stand 30 years following clearcutting (Chimner and Hart 1996), the land area composed of hummock microtopography was correlated with white-cedar density. Areas with greater than 70% hummock microtopography had the greatest densities of white-cedar. As hummock microtopography decreased in extent, white-cedar density decreased proportionally, with less topographically diverse areas becoming dominated by shrubs and hardwoods (Chimner and Hart 1996).

White-cedar cannot withstand prolonged inundation (Johnston 1990), thus, hummock microtopography benefits cedar by elevating seedlings above high water levels. Our results suggest that the effectiveness of hummocks vary depending on site hydrology. Hummocks were associated with improved seedling survival in sites with long periods of standing water, but as the number of days of inundation decreases, hummock microtopography may become less necessary.

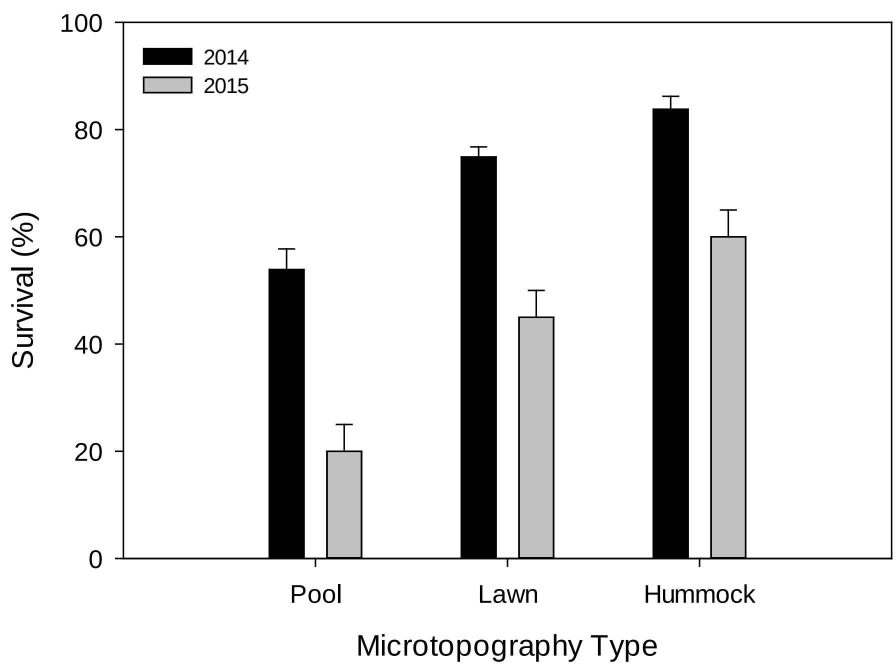

Figure 19. Cedar survival by microtopographic feature ($p<0.0001$). All differences between years and microtopography are significant at $p<0.05$.

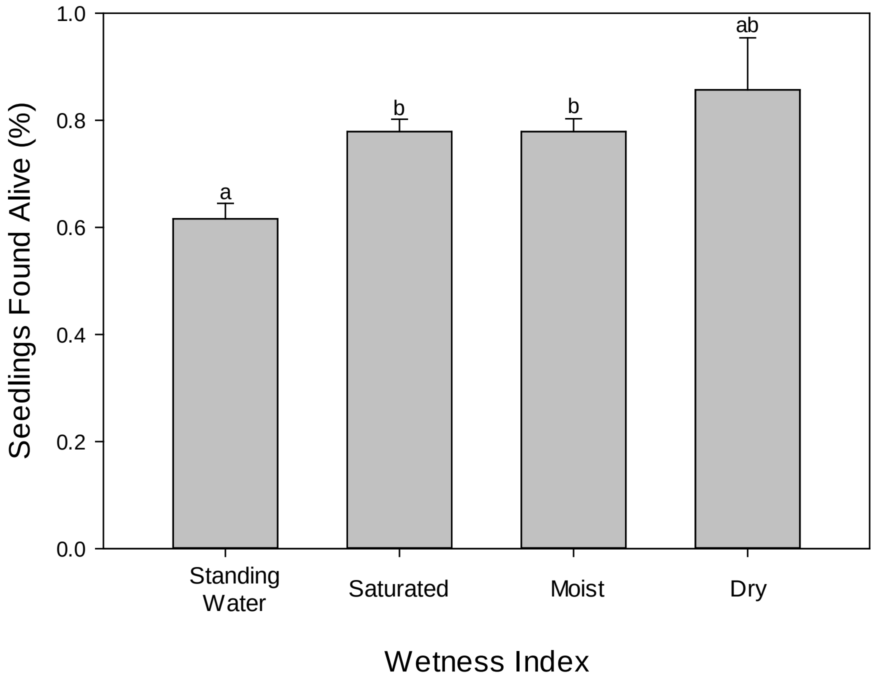

Figure 20. Cedar survival by moisture status (P<0.0001). Letters denote significant differences at p<0.05.

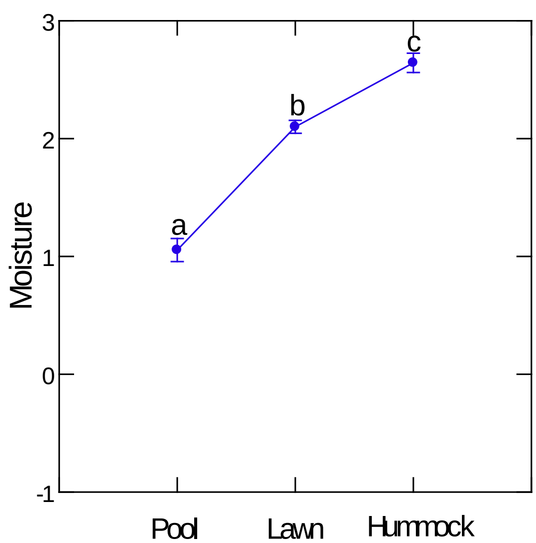

Figure 21. Correlation between microtopography and moisture status (1=standing water, 2=saturated, 3=moist, 4=dry). Letters denote significant differences at p<0.05.

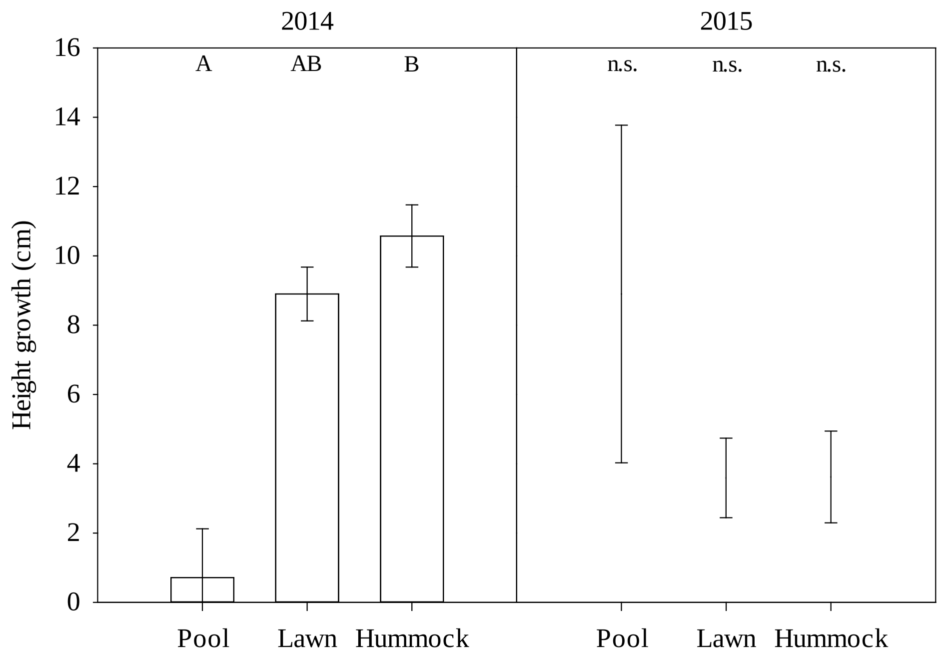

Figure 22. 2014 and 2015 mean height growth by microtopography on which the tree was planted. Error bars are ±1 standard error. Mean and standard error of height growth were calculated across all sites.

Figure 23. Planted cedar dead on top of hummock root mat. Notice the large air space between water table and peat in left photo.

Herbivory effects on planted cedar

There was no effect after two years of single tree protectors on planted cedar survival (Figure 24). Single tree protection devices did, however, reduce the amount and severity of browsing on planted cedar ($p<0.001$) (Figure 25 & 26). Roughly 80% of protected cedar had no evidence of browsing with the other 20% being split equally among light and heavy browse (Figure 27). Roughly 50% of all unprotected cedar showed no signs of browse on them, with 20% having light browse and 30% having heavy browse (Figure 28). There was little difference between rigid and wire protectors ($p> 0.05$), but rigid protectors appeared to be slightly more effective at preventing browse (Figure 26). Heavy browsing occurred most often in unprotected cedar, but also occurred in protected seedlings (Figure 29). Browsing was observed to have occurred from deer, rodents, porcupine, and grouse. The larger herbivores ate the unprotected cedar, while the smaller herbivores routinely browsed trees in both types of single tree protectors.

There was no significant difference in cedar survival between cages and plastic ($p=0.29$) (Figure 30). However, there was a significant difference ($p<0.001$) between seedling and transplant survival when unprotected. Cedar seedlings had greater survival (89% (0.03 SE)) than transplants (70% (0.04 SE)). There were however, no significant differences in browsing between seedlings and transplants when left unprotected. This indicates that seedlings planted into the swamps had generally better survival than transplants, however, both had sufficient survival to justify their use.

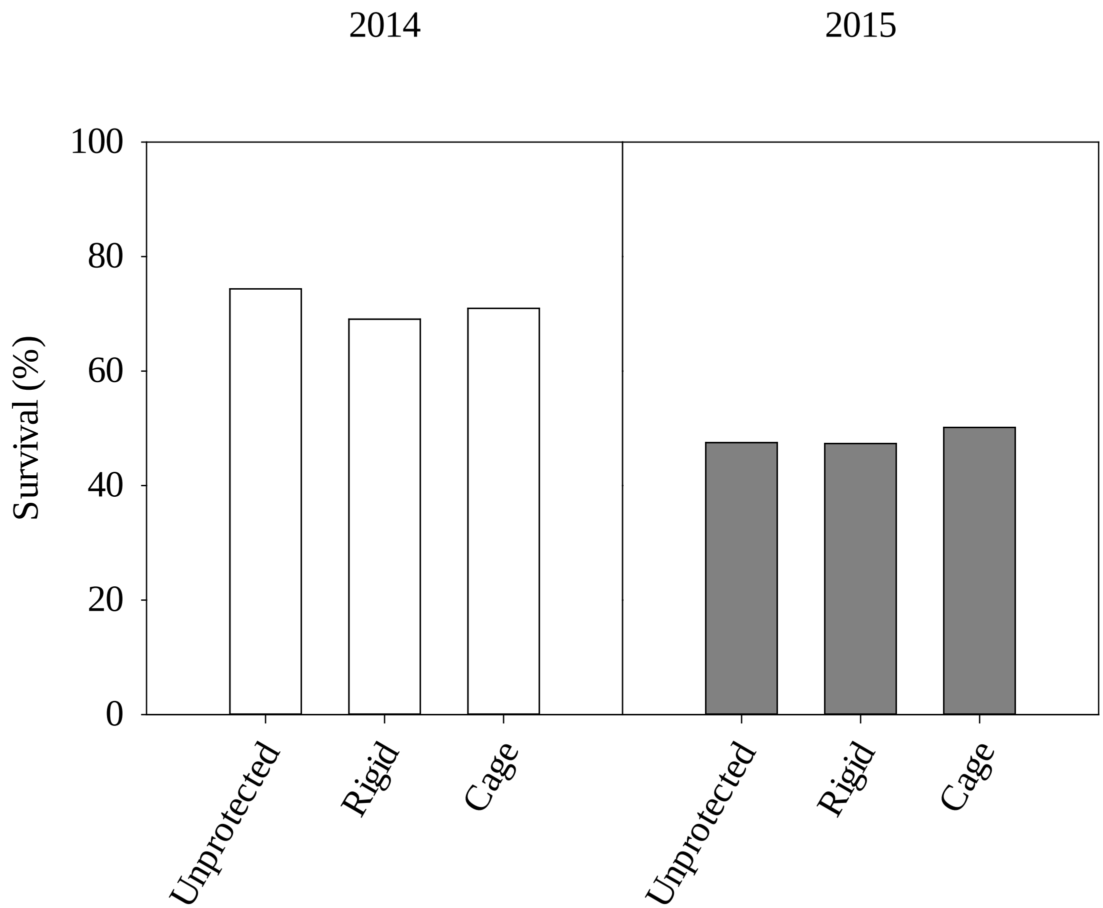

Figure 24. Survival of unprotected trees, trees with rigid plastic protectors, and trees with wire cage protectors one year after planting (2014) and two years after planting (2015). Percent survival for each year was calculated by taking the number of alive trees in each protection form divided by the total number of trees in that protection form.

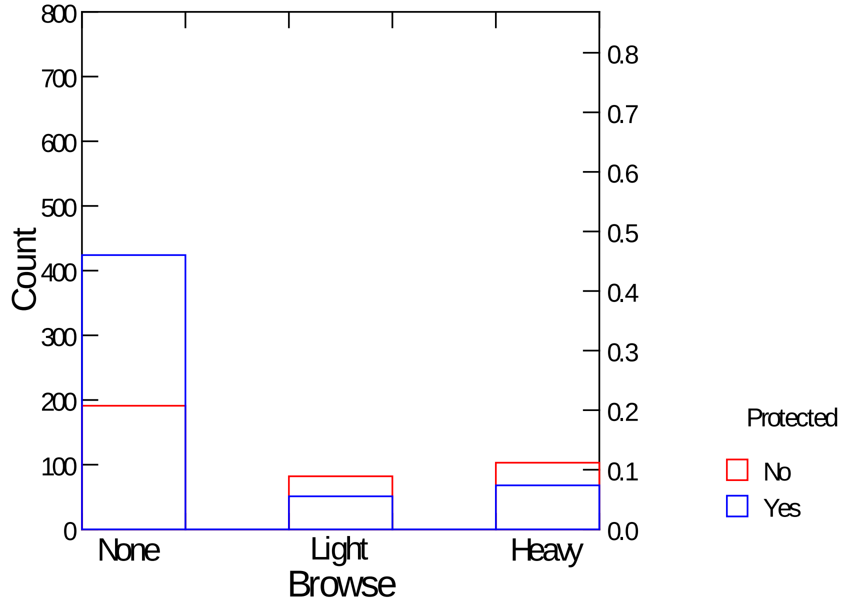

Figure 25. Pattern of browsing observed by protected (blue) and unprotected (red) cedar.

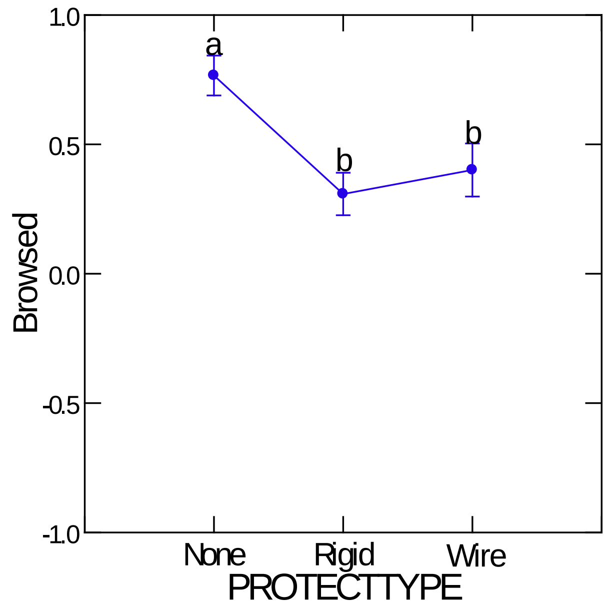

Figure 26. Browsing was significantly lower in protection units (0=no browsing, 1=some browsing, 2=heavy browsing). P>0.001.

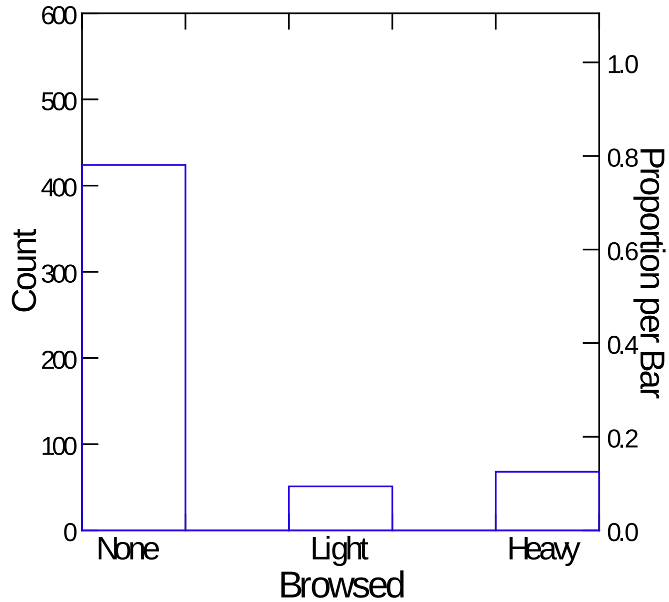

Figure 27. Pattern of herbivory on protected planted cedar.

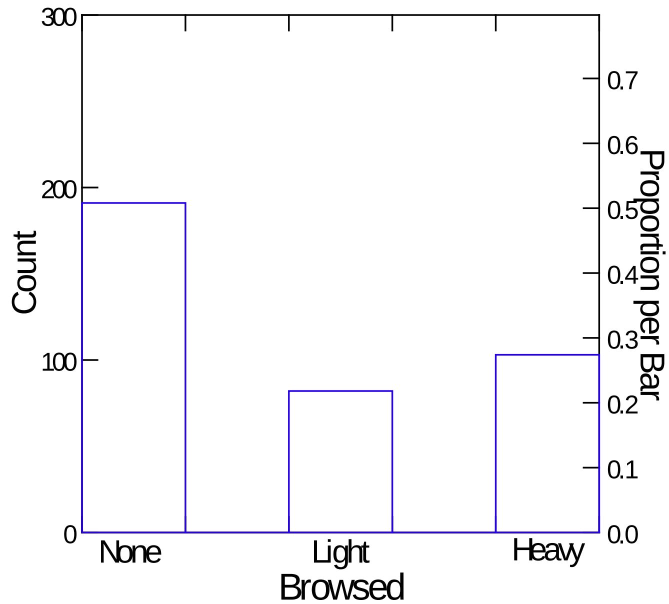

Figure 28. Pattern of herbivory on unprotected planted cedar.

Figure 29. Photo showing a heavily browsed cedar.

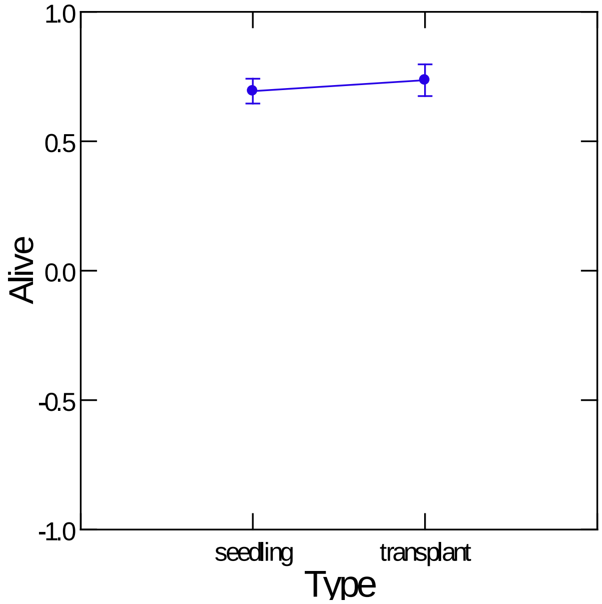

Figure 30. Survival of protected cedar seedlings and transplants (p=0.29).

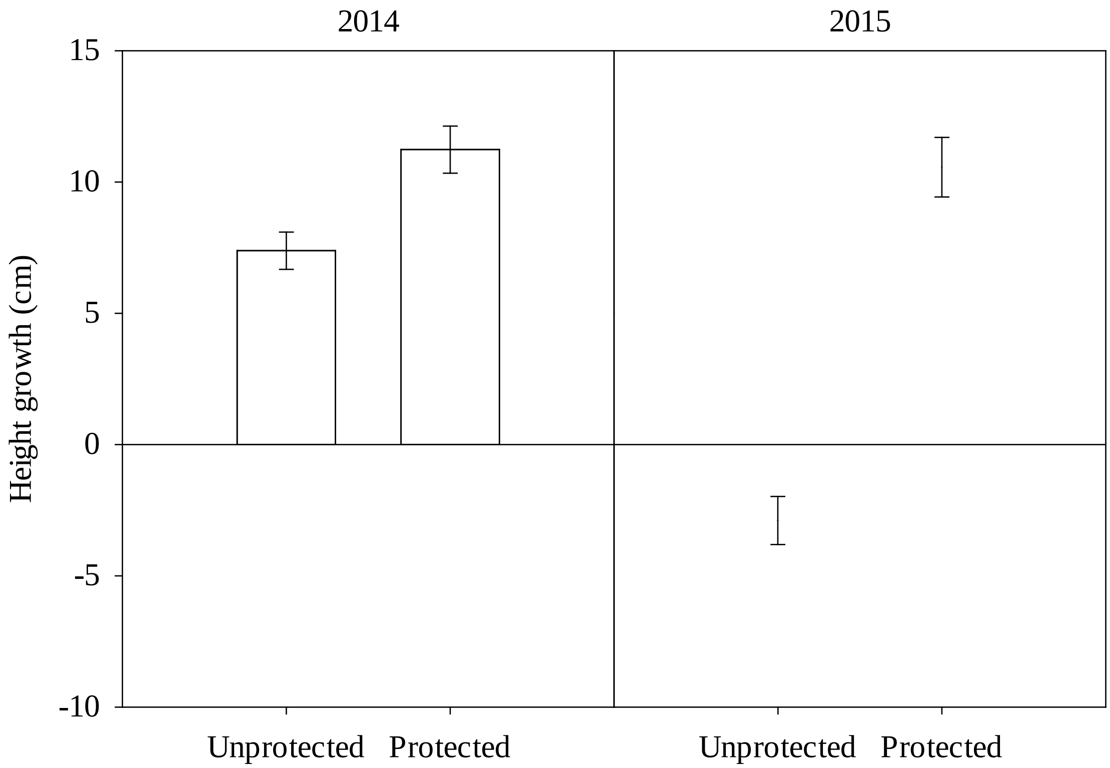

Figure 31. Mean height growth of unprotected trees and trees protected by wire cages by season of measurement. Error bars are ±1 standard error. Mean and standard error of height growth were calculated across all sites. A t-test found a significant difference ($p<0.05$) in height growth between unprotected and protected trees in both 2014 ($p = 0.0009$) and 2015 ($p < 0.0001$).

Figure 32. Photos of cedar in wire and plastic protectors.

Although short-term survival was not altered by protection, the decreased herbivory allowed for significantly faster tree growth compared to unprotected cedar trees. Trees that were protected had significantly greater growth than those that were unprotected in 2014 ($p = 0.0009$) and 2015 ($p < 0.0001$) across all sites (Figure 31). Although there was no significant difference in survival between cages and plastic, we did notice that wire cages seemed to be working better. Most of the trees in the wire cages were much taller and had more biomass than in the smaller plastic cages (Figure 32). Also, the plastic protectors tended to be knocked over frequently, have trees stick out of them, or have foliage browsed when sticking out of the plastic (Figure 33). The plastic also did not fare well in areas in heavy snow.

Figure 33. Some examples of issues with plastic protectors.

Light effects on planted cedar

Cedar height growth over the entire 2-year measurement period was influenced by the amount of light reaching the trees (Figure 34). Trees with less than 20% PPFD grow very slowly, and increased in growth linearly increasing growth. The light affect was also influenced by browsing levels. When the trees were browsed, light had little to no influence on growth, mainly because growth was removed by grazing.

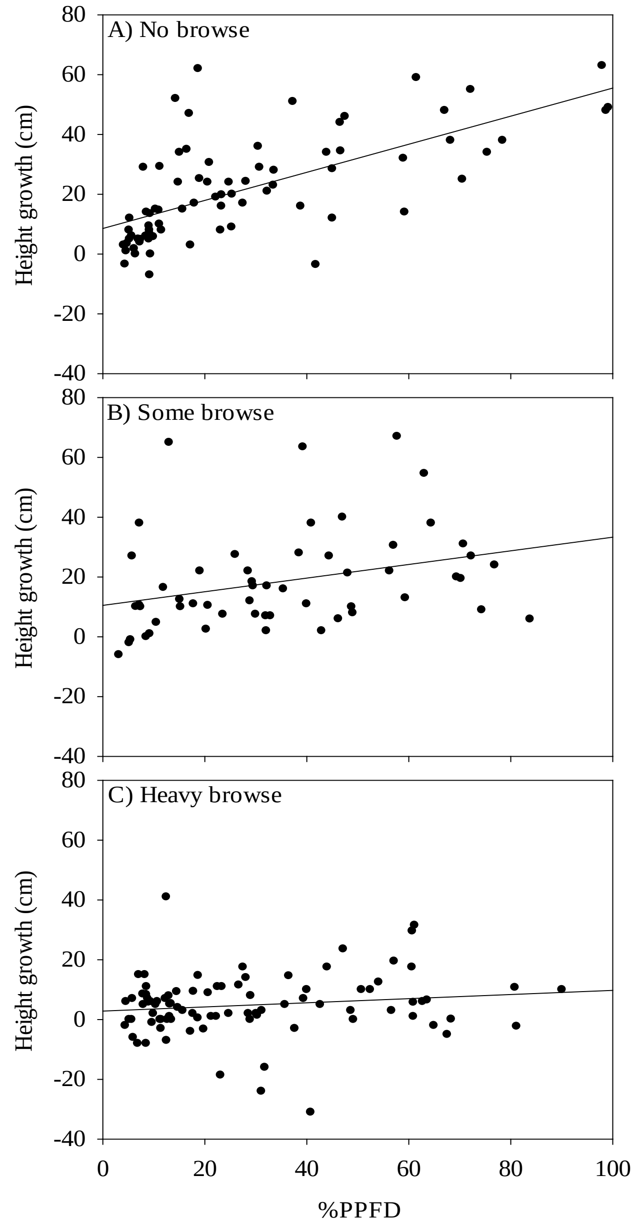

Figure 34. Height growth of each sample tree over the two-year measurement period (spring 2014 to fall 2015) by average %PPFD (canopy transmittance of photosynthetically active light) measured over that tree in July 2014, October 2014, and July 2015, for trees with A) no browse, B) some browse, and C) heavy browse. Each tree is separated into one of these three graphs, based on the highest level of browsed observed for that tree over the measurement period.

Methods for Cedar Assessments

To gauge the condition of NWC swamps in the study region, a rapid field assessment form (Appendix 1) was created for dissemination. The form was designed to rapidly evaluate the condition of cedar swamps and what if anything was impacting the swamps. The form was modified from a long-term peatland assessment formed used in Colorado (Chimner et al. 2010).

Disturbances were identified using aerial imagery, topographic maps and during site visits. The level of severity of each disturbance was assessed by the proportion of swamp it impacted. Hydrologic disturbances – including ditches, diversions and road cuts to swamps – were assessed by estimating the proportion of area that was altered, based largely on the vegetational characteristics of the swamp. Vegetation disturbance was assessed by determining the adequacy of regeneration and cedar density, and by identifying the degree of browsing. Each site's restoration priority was assessed as very high, high, low or very low based on the likely ease or difficulty of restoration and the condition of the swamp. Sites considered high or very high restoration priorities could easily be restored or were poor-condition swamps. Sites rated as low or moderate restoration priority were slightly impacted or so severely impacted that restoration would be cost prohibitive.

Results and Discussion of Cedar Assessments

A total of 93 sites were field assessed by managers in Aitken, Itasca, and Koochiching counties. An additional 51 cedar swamps were assessed using MNDNR inventory and are not presented, but listed in Appendix III. Half of all the sites assessed were county lands, and the other half were split between state and private lands (Table 5). Most of the assessed cedar sites were less than 20 acres, but some sites were greater than 50 ac (Table 6).

Table 5. Ownership categories of cedar assessment sites.

Ownership	# of Stands	Total Area (ac)	% of Total Area
Federal	0	0	0
State	35	515	34
Private	13	291	19
Industry	1*	4	2.5
Tribal	0	0	0
County	46	696	46
Other	1	7	0.5

Table 6. Count of cedar swamp area of assessed sites.

Area (ac)	Count	%
0-10 ac	12	14
10-20 ac	35	41
20-30 ac	14	16
30-40 ac	7	8
40-50 ac	15	17.5
50-100 ac	3	3.5

Thirty-nine percent of all assessed cedar sites were ranked as being in fair or poor condition (Table 7). Only 8.5% of assessed sites were listed as being in excellent condition. Greater than half of the sites were ranked as being in good condition. Roughly 50% of all sites were listed as needing restoration, with 25% of those ranked as having high or very high restoration priority (Table 7).

Table 7. Overall condition category.

Overall Condition	Count	%	Restoration Priority	Count	%
Excellent	8	8.5	Very High	13	14
Good	51	53	High	10	11
Fair	25	26	Moderate	25	27
Poor	12	12.5	Low	45	48

Two major disturbances, roads and animals (deer), were identified as the most common disturbances found to be impacting the cedar swamps (Table 8). Combined, they accounted for almost half of the identified disturbances. Other common disturbances noted were from forestry, drainage ditches, recreation vehicles, and utilities.

Overall, around 38% of all sites assessed were listed as being hydrologically altered. Roughly half of all the assessments indicated that there was a road, ditch or other barrier to groundwater flow near their sites. The proportion of the cedar swamps impacted was evenly distributed across the categories, with impact area varying from less than 10% to greater than 50% of the swamps being hydrologically modified (Table 9). Two-thirds of the sites identified as being hydrologically modified were identified as being drier than normal, with the other third listed as being too wet with dead trees killed by flooding.

Table 8. Types and percentages of disturbances encountered during assessments.

category	**count**	**%**
Roads	32	23.0
Forestry	13	9.4
Drainage ditch	5	3.6
Grazing	1	0.7
Animal	28	20.1
4x4	7	5.0
Recreation	9	6.5
Utilities	7	5.0
Other	4	2.9
None/Unknown	33	23.7

Overall, 55% of the sites were identified as not having acceptable cedar density compared to what it should have been. However, only 10% of sites were listed as being harvested in the last 50 years. In addition, 85% of sites were listed as not having enough cedar regeneration. At least 25% of sites had browse lines, with many additional sites listed as not having trees within browse height.

Table 9. Count of cedar swamps hydrologically or vegetatively altered.

	Hydrologically Modified	Vegetation Modified
0%	44	29
1-10%	7	9
11-20%	7	7
21-50%	7	15
≥51%	6	5

Figure 35. Very shady conditions hampered cedar seedling growth, but moderate light was fine.

Methods for Road Restoration

Two roads were identified in N. Minnesota that were impeding water flow, which had caused inundation and cedar mortality on the upgradient side and drying on the downgradient side (Figure 36). We conducted experimental restoration in two segments of the roads to allow for better hydrologic connection between both sides of the road. One road was in Itasca Country and the other was in Lake County.

Figure 36. Dead cedar killed by inundation from poorly design road in N. Minnesota.

Site Descriptions and Methods

Itasca County Site

The first site is on a minimum maintenance forest road (Ranch Road) near Wirt in northern Itasca County (Figure 37). The road provides access for forest management on county land and seasonal access for one privately owned parcel. The road crosses about 200’ of NW cedar wetland that flows toward the Big Fork River, which is about 300’ South of the road. The road crosses over about 3’ of mucky peat and was originally constructed on a corduroy base, which is now rotted. The main culvert was partially blocked, causing inundation on the upstream side of the road (Figure 38. The private landowner installed a smaller plastic pipe in an attempt to allow some of the surface water to drain past the road. A porous roadbed was designed to restore the normal surface and subsurface water flow through the wetland to the river.

A transect of groundwater monitoring wells were installed perpendicular to the road in October of 2014 (Figure 39). Wells were monitored periodically by hand and three pressure transducers were installed for daily automatic readings.

Construction consisted of removing the existing roadbed down to the corduroy with useable material stored for reuse and the remainder hauled away. Then a rock bed wrapped in non-woven geotextile was installed to permit subsurface flow to move through the road bed (Figure 40A). A new culvert was added to allow water to flow through during periods of high volume surface flow. Geotextile was laid out and 12” of 4 to 6-inch rock was spread out over the fabric, then another layer of geotextile fabric was laid over the top of the rock (Figure 40B). Additional 4 to 6”-rock was placed at the toe of the slope over the geotextile fabric exposed below the gravel roadbed. Erosion blankets were placed to cover the disturbed surfaces alongside the road (Figure 40C). Construction began on August 8, 2016 and was completed on August 12, 2016. The total cost of the project was $55,174.90.

Figure 37. Ranch Road in Wirt, MN before restoration.

Figure 38. Ponded water upgradient that caused NW cedar tree mortality.

Figure 39. Wirt site with well placements.

Figure 40. Sequence of Wirt road restoration: A) Roadbed was removed, then geotextile was laid out and 12” of 4 to 6-inch rock was spread out over the fabric, B) then another layer of geotextile fabric and more dirt was laid over the top of the rock, C) additional rock was placed at the toe of the slope over the geotextile fabric exposed below the gravel roadbed and erosion blankets were placed to cover the disturbed surfaces alongside the road, D) finished road as of June 2017.

Lake County Site

The second experimental location is the Dufrene Road in Lake County, which is an old railroad grade that was converted into a road. Dufrene is a now a county forest road used for management, access for several private properties, by hunters, and the general public. Originally. there was a culvert in place, but was completely blocked, causing ponding on the upgradient side, killing all the trees (Figure 41A). The wetland surrounding the road is a mineral soil forested wetland.

Figure 41. Sequence of Defrense road restoration: A) Upgradient road before restoration showing deep ponding, B) Upgradient road after restoration show large drop in ponding and new vegetation growing, C) Downgradient of road after restoration, and D) Close up of water seeping out under the road on the downgradient side of the road after restoration.

The goal of this road retrofitting was to use a modified H-culvert design to allow the water to flow under the road (Figure 42). The first step was to replace the blocked culvert on June 27-29, 2016, with a new culvert (Figure 43). The second step was to dig trenches about 4-feet deep alongside the toe of the roadbed on both sides of the road to intercept subsurface water flow above the road and redistribute it below the road (Figure 42). Each trench was filled with clean 1.5-inch rock. The original design was to wrap the rock in geo-textiles and put drain tiles in the middle of the trench. However, when work to dig the roadside trenches began, conditions were too wet so that it was not safe to have people get in the trench to lay the geotextile and drain tile. Time and funding constraints forced a decision to install the rock in the roadside trenches without the geotextile wrap or the drain tile. Additional trenches were installed under the road connecting to the two lateral trenches to move water under the road. It was possible to utilize the geotextile wrap and drain tile in the cross road trenches. One additional leadoff trench with drain tile was installed perpendicular to the down flow roadside trench. The trenches were constructed over two days in September 20-23, 2016 at a total cost of $33,057.55.

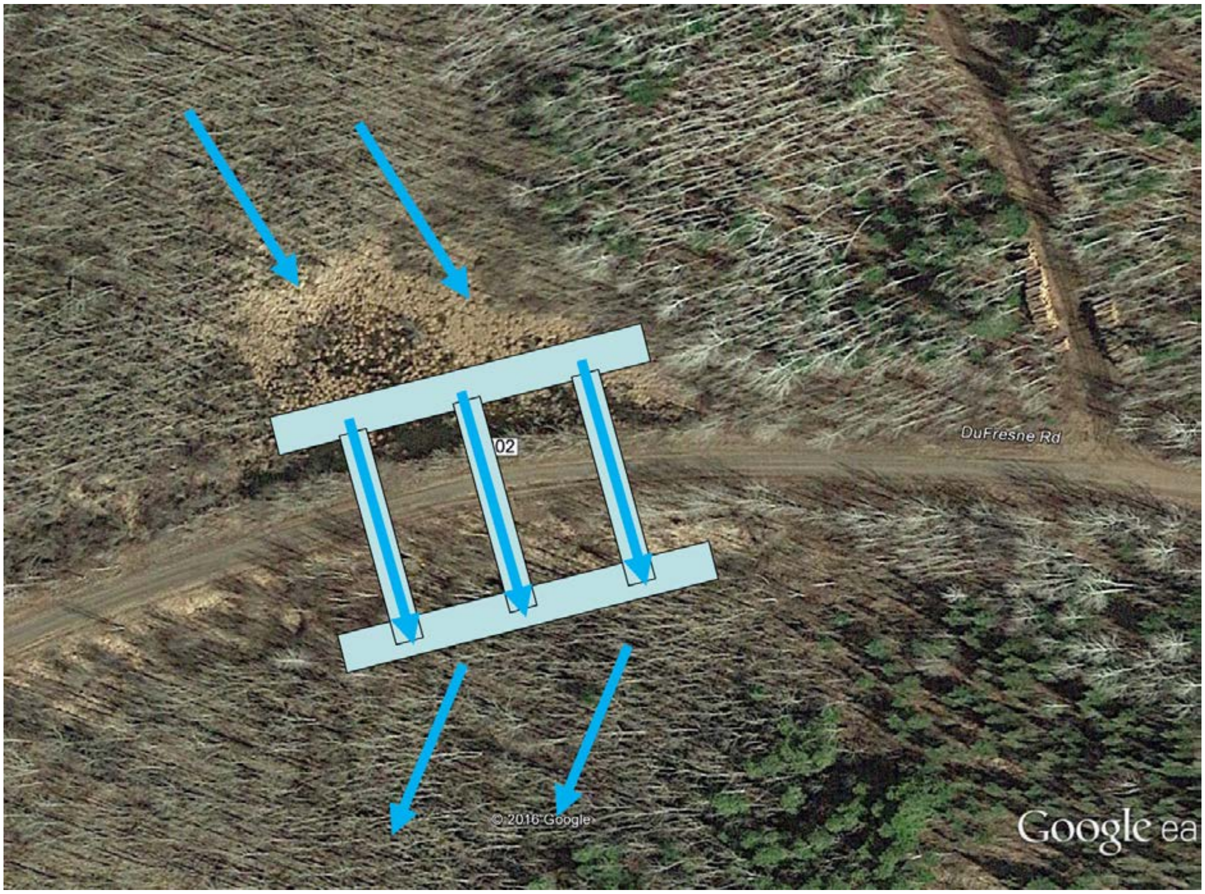

Figure 42. Modified H-culvert design used for Defense site. Blue arrows indicate water flow. Blue boxes represent buried rock trenches.

Two transects of groundwater monitoring wells were installed parallel to the road in 2015 (Figure 44). Wells were monitored periodically by hand and three pressure transducers were installed for daily automatic readings.

Figure 43. Replacing old culvert at Defrense Road.

Figure 44. Defrense site with well placements.

Results and Discussion for Road Restoration

At Defrense Road, manual well reading indicated that major changes in water table levels occurred after road restoration. Water table levels were 18-45 cm (average 28 cm) greater in June 2017, compared to July 2015 in wells downgradient of the road. Whereas, wells upgradient of the road were 20-24 cm (average 21 cm) lower in June 2017, compared to July 2015. This indicates that the water is not backing up as high behind the road, and that water is flowing under the road and rewetting the wetland behind the road (Figure 41). The largest change in water tables levels occurred when the culvert was replaced, which lowered the water table upgradient by ~30 cm in a couple of days (Figure 45). The large change us water table levels upgradient has already started to change vegetation composition, with horsetails now growing in an area that was previously too deep for emergent vegetation (Figure 41B).

Less obvious changes occurred when the trenches were built. The wetlands away from the culvert is wetter due to water flowing under the road and discharging into the wetland (Figure 41 C&D). Manual water table reading in June of 2017 indicated that water table levels were much wetter below the road than it was before restoration. Monitoring will continue to quantify longer-term changes.

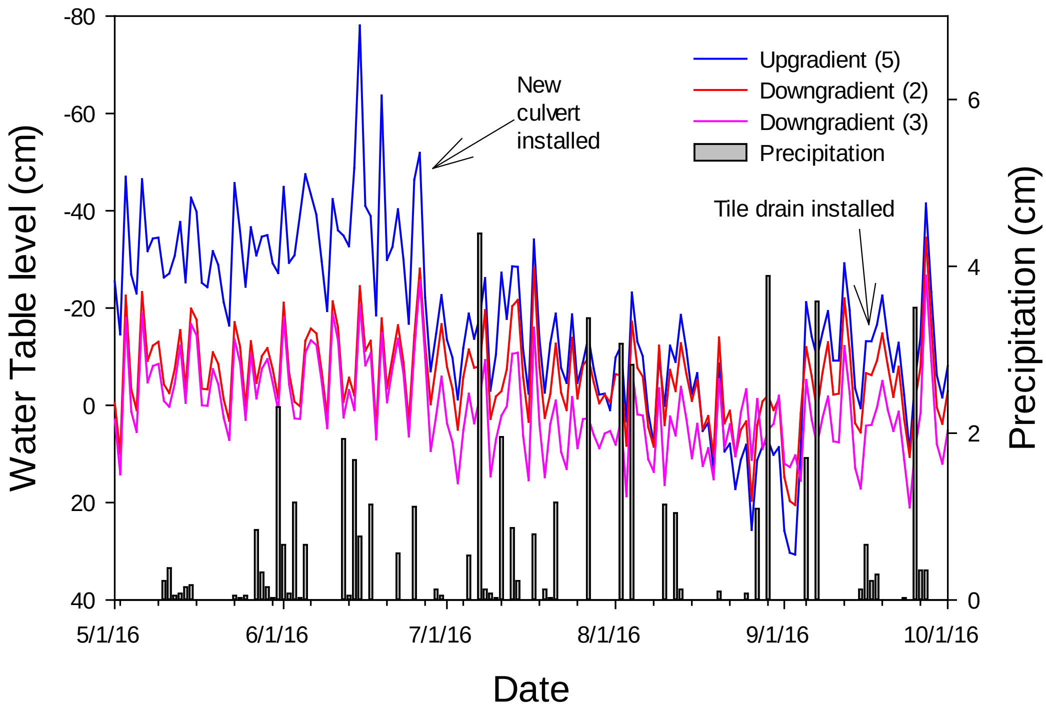

Figure 45. Daily values of water table levels at Defense Road before and after restoration. Daily precipitation values are from Marcel Experimental Forest.

Water table levels in Wirt Road did not show as large of a response of Defrense Road (Figure 46), but restoration did appear to be successful. After the restoration, ponding was decreased upgradient of the road (Figure 47), which made the road bed drier and drivable throughout the spring. Water was also discharging along the entire length of the porous roadbed on the downgradient side (Figure 48). During site visits, now water was seen flowing out of the culvert, which indicates that enough water was flowing under the road to not raise the water table high enough to enter the culvert.

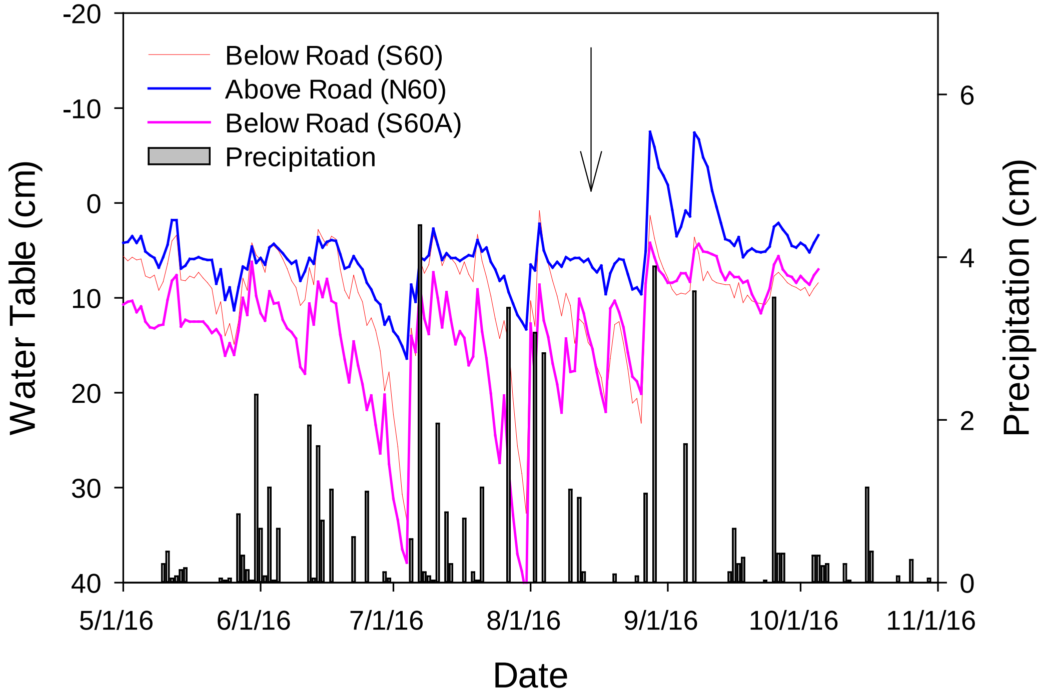

Figure 46. Daily values of water table levels at Wirt Road before and after restoration. Daily precipitation values are from Marcel Experimental Forest.

Figure 47. Upgradient of Wirt road after restoration showing lower ponding of water.

Figure 48. Downgradient of Wirt Road showing water flowing out of the porous roadbed.

Summary and Recommendations

Our assessments confirmed that many NWC swamps are degraded and need restoration. The major disturbances identified were from roads, ditches and high herbivory. Our initial results from NWC tree planting confirm that NWC are sensitive to hydrology and to herbivory. High herbivory has long been known to be detrimental to NWC regeneration. In summary, most harvested cedar sites have not regenerated back to cedar, but instead have been replaced by species such as tag alder (*Alnus rugosa* DuRoi), balsam fir (*Abies balsamea* M.) and red maple (*Acer rubrum* L.) (Nelson 1951, Zasada 1952, Thornton 1957, Chimner and Hart 1996, Heitzman et al. 1997). A study by the Michigan Department of Natural Resources showed that even 50 years after an experimental cutting in a cedar swamp near Marquette, Michigan, cedar was still absent with tag alder and balsam fir dominating in the cut areas (Chimner et al. unpublished data). This indicates that active restoration will be needed in many areas were herbivory levels are high.

The main method used for protecting cedar from herbivory are physical protection. Two main physical methods for protecting NWC are constructing high fences around many cedar (Kangus et al. 2016) or using single tree protectors. Fencing is very expensive, but can be successful for protecting trees from large herbivores. However, fencing still requires constant monitoring because falling trees can damage the fence allowing herbivores to enter the fence.

The option we tested was using single tree protectors to protect seedlings of NWC. We tested both plastic ridged and larger wire protectors. We found that both protectors worked equally well after two years on survival and reducing browsing. The plastic protectors provided extra protection from smaller herbivores (rodents, etc.) compared to the large wire protectors. However, we did find several instances of small rodents burrowing under the rigid protectors. We also found that some larger herbivores were able to push aside the plastic protectors to eat the trees. We also found that many of the plastic protectors where broken and on the ground, or bent over and inhibiting the trees. In our opinion, we feel that the wire protectors are a much better option compared to the plastic protectors. However, the wire protectors are much more expensive compared to the plastic protectors.

Interestingly, we did not find any differences between NWC survival when protected compared to unprotected plantings. However, the tree protectors greatly decreased the herbivory levels compared to unprotected levels. However, results must be taken with caution as these results are only for the first two years. Previous research indicates that seedlings that have been heavily browsed will eventually die after a few years (Kangas et al. 2016). So we hypothesize that there will be large differences in NWC survival between protected and unprotected after several years. Informal monitoring in 2017 found that it was difficult to find unprotected cedar trees.

After two years, the largest single factor affecting NWC survival was due to hydrological conditions. NWC survival was low if they were planted in wet depressions (pools, hollows) and high if planted in higher and drier flat lawns or higher hummocks. This has direct application to planting cedar in restoration projects. Often the surrounding plant species were a guide to the wetness of the area. If the area was dominated by more obligate wetland species (sedges, dogwoods, etc.) then it is probably too wet for NWC. One factor that came to light in this research is that the seedlings and transplants were planted with roots straight down. This might have accentuated the high mortality in wetter areas. Future research should focus on planting NWC roots more horizontal in wet areas or perhaps grow the seedlings in wetter conditions in the greenhouse.

Some areas were also found to be too dry for NWC. The best example of this is when NWC where planted in root mats with an air pocket below the roots. This resulted in high mortality of planted NWC. Site level hydrological conditions also appear to have been altered by roads and may end up explaining tree growth and mortality across sites. However, it is too early to assess this yet.

Light levels also appear to play a role is successful cedar enrichment plantings. At very low light levels, like seen at site #28 (Figure 35), cedar growth was very low. This indicates that planting cedar under dense canopies are likely to not be successful, planting at moderate light levels are fine as cedar is shade tolerant.

Success of planted cedar also appeared to be correlated with pH. Sites at the low pH end of the gradient had much lower survival compared to the sites with greater pH. This result is in line with the notion that NW cedar is a calciphile and is most abundant when the pH is greater than 6. Our results indicate that NW cedar has a limited ability to be a replacement for tamarack at lower pH sites. NW cedar has a greater ability to be a replacement for Black Ash following emerald ash borer infestations, as Black Ash tend to grow and greater pH levels than tamarack. However, Black Ash tend to grow in more flooded conditions, which become more flooded after Black Ash die back, which is not ideal for NW cedar as our results show that NW cedar mortality is very high in inundated conditions. NW cedar might be able to be established in Black Ash sites if the seedlings are only planted on the highest hummocks.

Another indication that NW cedar are very susceptible to flooding is the high mortality seen along the upgradient side of many roads that have poor cross drainage (Figure 36). Many roads, especially in the Great Lakes region, dissect groundwater wetlands. The groundwater ponds up against the roads, causing flooding, which kills the wetland trees. Wetland drying also normally occurs on the downgradient side of the road. The normal way to deal with this situation is to use culverts to pass the water through the road. Although culverts can help move water and eliminate flooded conditions, the water is channelized through the culverts and stays channelized on the other side of the road as it discharges from the culvert. The groundwater is thus changed to channelized surface water, which can erode wetland and not allow for rewetting the wetlands on the downgradient side. This phenomenon is large scale in the region and requires new technology to solve it. To this end, we tested two porous road designs that moved the water under the road to allow for better hydrologic connection between both sides of the road.

After one season, the two roads appear to be functioning as designed. The water is not ponding as much behind the roads, and water is discharging under the road and rewetting the wetlands. The roads are also more drivable during the wet periods. The water is flowing under the road and discharging on the other side. No problems have been observed after 1 year. However, the main process that needs to be monitored is the permeability of the porous road bed. If the permeability decreased from excess buildup of sediment, or by blocking by beaver, the design would fail and all the water would flow through the culverts. This will have to be monitored through time to assess this concern.

At a cost of 132-275$/foot to redo the roads, these techniques are cost effective means of improving wetland habitat and in some instances, the drivability of the road. Although these costs may seem high for a long road, usually only small sections of the road need to be redone to improve cross drainage.

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Appendix I: Assessment form and notes used for this study.

MN Swamp Assessment Form 2013		
Site Description		
Swamp name or ID		
Date		
GPS Location		
Ownership	(1=federal, 2=state, 3=private, 4=industry, 5=tribal, 6=other)	
Area of swamp being assessed (acres)		
pH (if you have meter)		
Swamp type (cedar (FPs63 or Wfn53), tamarck, or ash)		
Disturbances		
Hydrology (applies to cedar, tamarack and ash sites)		**Yes/No**
Is the surface of the peat dry?		
Are tree roots visible?		
Are mosses common in the understory?		
Are there lots of dead trees and emergents (~cattails)?		
Are there drainage ditches in the wetland?		
Is there a road/ditch/railroad just upgradient from the wetland?		
Do you think the hydrology of the site altered?		
What % of the swamp is hydrologically altered?		
Vegetation (cedar only)		**Yes/No**
Was site harvested?		
Cedar density acceptable?	Or is there a high density of balsam fir, alder?	
Cedar recruitment acceptable?	Are there cedar trees between 3-15' in height?	
Browse lines visable?		
Is cedar continous, in clumps, or scattered?		
What % of the swamp do you think has altered vegetation?		
Overall Site Condition		
		Condition
Overall condition (pick one)		
Excellent=	All catagories rated as excellent	
Good=	All catagories rated as good or better	
Fair=	All catagories rated as fair or better	
Poor=	All catagories rates as poor or better	
Disturbances that are impacting swamps (list all that apply)		
(1=roads,2=forestry, 3=drainage ditch, 4=irrigation canal, 5=agric,6=grazing,7=mining)		
(8=animal, 9=4x4,10=rec,11=utilities,12=fire,13=development,14=other)		
% of swamp assessed that is disturbed		
Does this swamp need restoration?		
Restoration Priority		
1. very high	disturbances are easily fixed or site has a high value	
2. high	disturbances are fairly easily fixed and site is in fair to poor condition	
3. moderate	disturbances are hard to fix or expensive, or site is in good condition	
4. low	site is in good to excellent condition, or site is very difficult to fix	
List photo names:		

Notes for questions on form: Rapid Swamp Assessment

1. Give a name or location for site. Also add location for each site (GPS or google earth)
2. Date of assessment
3. GPS coordinates, list what coordinate system you are using
4. Who owns the property?
5. Size of NW cedar stand being assessed.
6. If you have a pH meter, take reading of groundwater. If not, do not worry about it
7. Are you assessing a cedar, ash or tamarack swamp? Give MN NPC class if known.
8. Is the surface of the soil dry in mid-summer (discount this if it is in the spring or after a heavy rain)
9. Can you see the large cedar roots easily? This is an indication of drying and peat subsidence. See below photo for example.

10. Mosses are a good indicator of drainage. Put yes if there is less than 50% cover of mosses on the ground. This could be a sign that the site has undergone drainage and is drier than should be. The two photos below show sites with no mosses (drained from road), and one with lots on mosses in undisturbed site.

11. Are there lots of dead cedar trees? Usually from blocked drainage. See photo below for “road kill” cedar from blocked drainage.

12. Are there drainage ditches in the swamp?
13. Look at maps or walk site to see if there is impeded groundwater drainage from roads, train tracks, power lines right of ways, large ditches, or anything that alters ground water flow.
14. Given from what you have seen, and answers to above questions, do you think this swamp’s hydrology (movement of water) has been altered?
15. What percentage of the swamp is hydrologically altered? Give a guess, does not have to be precise.
16. Was the site harvested recently (< 50 yrs ago)? Look for stumps or paper trail.
17. Are there as many cedar trees here as would expect given the ecotype? Is the basal area greater than 100 ft2/acre for cedar? If not, put no. Is most of the basal area in balsam fir, tamarack or alder? They typically replace cedar if cedar is removed. See photo below for balsam fir replacing cedar for an example.

18. Are there cedar regenerating in the understory? If there are numerous cedar trees between 3’-15’, than say yes. Below show what this size tree looks like.

19. Are the cedar trees showing a “browse line”. See photo below for an example of a cedar tree browsed, except for the bottom which was under the snow.

20. If you are in a tamarack or ash stand, is the NW cedar found in a few clumps, scattered about, or continuous found in the under or over-story?
21. What is you best guess for how much of the swamp has altered forest canopy?
22. What condition do you think this site is in overall given the above answers?
23. What do you see that has disturbed this swamp. Typical disturbances to swamps are from: forestry activities, excessive deer herbivory, or hydrology (ditches, roads).
24. Of the total area of swamp assessed, what proportion is disturbed (best guess)?
25. Does this site require restoration?
26. And if so, what priority would you give it? Low priority sites are those that would be expensive, overly difficult, or for sites that are in good shape. High priorities are for sites that are easily restored, high value, or modest effort can restored large areas. Basically, does this site have a " big bang for the buck".
27. List all photo names for this site.

Appendix II: Checklist of plant species identified by site.

649	646	276	9	117	28	*Species list*	Common Name
*			*	*		*Abies balsamea*	balsam fir
			*			*Acer saccharum*	sugar maple
			*			*Acer spicatum*	mountain maple
			*	*		*Alnus incana ssp. Rugosa*	tag alder
			*			*Amelanchier sp.*	service berry
			*		*	*Aralia nudicaulis*	wild sarsaparilla
				*		*Aronia melanocarpa*	black chokeberry
*						*Aster firmus*	Purple stem aster
				*		*Aster nemoralis*	bog aster
*						*Aster lanceolatus*	white panicle aster
			*			*Aster sp.*	aster
			*	*		*Aster umbellata*	parasol whitetop
*			*			*Betula papyrifera*	paper birch
*						*Bidens frondosa*	beggartick
*						*Bromus ciliatus*	fringed brome
*						*Campanula aparinoides*	marsh bellflower
			*			*Carex intumescens*	shining bur sedge
*	*	*				*Carex lacustris*	common lakeshore sedge
*		*	*	*	*	*Carex sp.*	sedge
				*		*Chamaedaphne calyculata*	leatherleaf
			*			*Clintonia borealis*	blue-bead lily
					*	*Convolvulus arvensis*	field Bindweed*
			*	*	*	*Coptis trifolia*	Three-leaf goldthread
		*	*	*	*	*Cornus cancanadensis*	bunchberry
			*			*Cystopteris bulbifera*	bulblet bladderfern
					*	*Diervilla lonicera*	northern bush honeysuckle
*						*Epilobium leptophyllum*	bog willowherb
			*			*Equisetum arvense*	field horsetail
	*			*		*Eupatorium maculatum*	spotted joe-pye-weed
*			*			*Fragaria virginiana*	wild strawberry
			*			*Fraxinus nigra*	black ash
	*	*	*		*	*Galium asprellum*	rough bedstraw
*		*				*Galium labradoricum*	northern bog bedstraw
				*		*Galium triflorum*	fragrant bedstraw
				*	*	*Gaultheria hispidula*	creeping snowberry
*			*	*	*	*Grass sp.*	
*		*			*	*Impatiens capensis*	common jewelweed
*						*Kalmia polifolia*	bog laurel
				*		*Iris versicolor*	blueflag
*						*Lactuca biennis*	tall blue lettuce
	*			*		*Larix laricina*	tamarack
*		*		*	*	*Ledum groenlandicum*	bog Labrador tea
		*	*			*Linnaea borealis*	twinflower
			*		*	*Lonicera candensis*	american fly honeysuckle
		*				*Lonicera oblongifolia*	swamp fly honeysuckle
		*			*	*Lycopus americanus*	american water horehound

*				*		*Lycopus uniflorus*	northern bugleweed
*	*	*				*Lysimachia quadrifolia*	whorled yellow loosestrife
			*		*	*Maianthemum canadense*	false lily-of- the-valley
		*				*Menyanthes trifoliata*	buckbean
*		*	*		*	*Mitella nuda*	naked miterwort
	*					*Panicum sp.*	grass
				*		*Picea mariana*	black spruce
	*					*Poa sp.*	Blue grass
*						*Polygonum sagittatum*	arrowleaf tearthumb
		*		*		*Potentilla palustris*	purple marshlocks
*	*			*	*	*Rubus ideaus*	wild red raspberry
*				*	*	*Rubus pubescens*	dwarf red raspberry
			*			*Ribes sp.*	gooseberry
	*			*		*Salix sp.*	willow
		*				*Scuttelaria lateriflora*	blue skullcap
		*		*		*Smilacina trifolia*	three-leaved solomon's-seal
*						*Solidago gigantea*	giant goldenrod
	*					*Solidago sp.*	goldenrod
				*		*Symplocarpus foetidus*	skunk cabbage
						Thalictrum dasycarpum	purple meadow-rue
		*	*	*	*	*Thuja occidentalis*	nw cedar
			*	*		*Trientalis borealis*	starflower
	*					*Trifolium sp.*	clover
						Trillium cernuum	nodding trillium
*	*					*Utrica dioica*	stinging nettle
				*		*Vaccinium angustifolium*	lowbush blueberry
				*		*Vaccinium myrtilloides*	velvetleaf huckleberry
		*		*		*Vaccinium oxycoccus*	dwarf bog cranberry
		*		*		*Viola sp.*	violet
		Ferns					
*			*	*	*	*Dryopteris carthusiana*	spinulose woodfern
*				*		*Dryopteris cristata*	crested woodfern
			*			*Gymnocarpium robertianum*	scented oakfern
		*		*		*Matteuccia struthiopteris*	ostrich fern
			*			*Phegopteris connectilis*	long beechfern
		Mosses and Clubmosses					
		*	*		*	*Climacium dendroides*	tree climacium moss
		*				*Dicranum sp*	
			*			*Hypnum lindbergii*	lindberg's hypnum moss
				*	*	*Huperzia lucidula*	shining clubmoss
				*		*Lycopodium annotinum*	stiff clubmoss
				*	*	*Lycopodium obscurum*	rare clubmoss
			*			*Leucobryum glaucum*	leucobryum moss
			*			*Mnium hornum*	horn calcareous moss
					*	*Plagiomnium drummondii*	drummond's plagiomnium moss
*		*		*	*	*Pleurozium schreberi*	schreber's big red stem moss
				*		*Polytricum sp.*	haircap moss

	*		*	*Rhytidiadelphus triquetrus*	rough goose neck moss
		*		*Sphagnum angustifolium*	
		*		*Sphagnum fuscum*	
		*		*Sphagnum girgensohnii*	
		*	*	*Sphagnum magellanicum*	
	*	*		*Sphagnum russowii*	
*		*	*	*Sphagnum sp.*	
	*			*Sphagnum warnstorfii*	
*				*Thuidium delicatulum*	delicate thuidium moss