Department of Environmental Studies

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Developing and implementing long-term monitoring protocols for restoration efforts along riparian corridors in Northern New England

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ABSTRACT

The conservation community is implementing riparian restoration projects throughout the State of Vermont, USA. In an effort to improve the effectiveness of restoration plantings, this study was designed to assess how tree health and survival was related to plant species, plant protection (tree tubes and brush mats), nursery provider, tree planter, planting technique, and plant origin. Researchers visited riparian restoration projects in six watersheds in Vermont, and collected data at 41 sites. Fourteen sites were surveyed the year they were planted and the following growing season (May thru September 2008 and 2009), while an additional 30 sites were surveyed in 2009 that were planted as far back as 1997. Trees were surveyed along transects set up at each restoration site. Transects were marked with stakes at their endpoints and each tree was marked with a numbered tag. Each transect sampled a minimum of 10 trees. Contingency tables were used to compare the frequency of survivorship for seedlings with different forms of tree protection (tree tube, mat, both), species, project, condition, and girdling activity. A nonparametric three-way analysis of variance (Wilcoxin signed rank ANOVA) was used to analyze the effects of survival, tree protection and girdling on variation in mean seedling height. Of the trees planted in 2008, 88% survived the first growing season, and 80% survived the second growing season. Identifiable tree death causes include competition by reed canary grass (*Phalaris arundinacea*) and other grasses, flooding, bank erosion, trampling, accidental mowing, girdling by beavers and meadow voles, and browsing by deer. Species most likely to survive the first full growing season included ash (*Fraxinus spp.),* maple *(Acer negundo),* willow *(Salix spp.),* and dogwood (*Cornus spp.)*. Surviving trees increased in height after the first full growing season, but trees planted with tree protection (mats and tree tubes) increased the least. Although mats and tubes do not promote height growth, they do increase survival. Girdling was one variable that decreased survival, but tree tubes do not prevent trees from being girdled. Additionally, tubes on trees planted eight years ago showed no signs of disintegration and were actually found to be girdling otherwise healthy mature trees.

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INTRODUCTION

The U.S. Department of Agriculture and the U.S. Fish and Wildlife Service (FWS) have restored the trees, shrubs, and plants that grow along waterways, known as riparian corridors in order to improve fish and wildlife habitat, reduce bank erosion and reduce sediment and nutrient loads in waterways in Vermont. A standard restoration project involves fencing livestock out of streams and planting trees and shrubs in the riparian buffer. While planners agree on the need for monitoring tree survival, no standardized monitoring has taken place in Vermont and therefore there is no ability to assess restoration outcomes. Restoration, as used in this study, refers to both "passive" management, such as allowing natural regeneration to occur through the termination of mowing or grazing, and "active" management, which includes planting seedlings, protecting plants from herbivory, and repairing hydrologic alterations (Lapin et al. 2004).

Since 1995, over 1 million linear feet, including 1,000 acres of riparian corridor, have been restored in Vermont and every year more landowners choose to participate in the riparian restoration effort. To ensure maximum ecological benefits from this effort, it is critical to plant trees that survive. Agencies need monitoring information to recognize which techniques are most effective, and which techniques need modification. My comparison study of tree survivorship in restored riparian areas will help planners throughout the region implement more effective restoration projects in the future.

LITERATURE REVIEW

Historically, 45% of the land area of the United States was covered by forest and over four-fifths of that forest existed east of the Great Plains (Soto-Grajales, 2002). The land east of the Mississippi to the Atlantic Ocean was almost an unbroken expanse of forest (Williams, 1989). Human population expansion associated with agriculture and development is responsible for the rapid and increased environmental change along riparian corridors (Jungwirth et al., 2002; Bonnie et al., 2000; Matlack, 1997; Frederickson & Reid, 1986). The history of riparian deforestation has had devastating impact on our landscape with regard to water quality and biotic habitat. The presence or absence of trees adjacent to stream channels is one of the single most important factors altered by humans that affect the structure and function of stream ecosystems, which ultimately supply water to our Oceans, lakes, and estuaries (Sweeney, 1992).

Land cover history demonstrates that the riparian ecosystems that exist in the northeast today developed in association with and are dependent upon forested communities (Soto-Grajales, 2002). Maintaining these corridors is a vital part of maintaining populations of many species (Engelhardt & Ritchie 2002). Trees improve water quality by filtering runoff; trapping sediment, fertilizers and pesticides; reducing erosion; and providing food and habitat for fish and wildlife (Keeton, 2008; Endreny, 2002; Brinson and Verhoeven 1999; Naimen et al, 1998; Peterjohn and Correll, 1984; Soto-Grajales; 2002). Riparian forests play an important role in linking aquatic and upland terrestrial systems via energy and materials exchange (Gregory et al., 1991; Hughes & Cass, 1997). Planting trees along riparian buffers through reforestation seeks to reestablish these natural benefits.

Unfortunately, most of the world's 79 large river-floodplain ecosystems have been altered by human activities (Sparks 1995, Jungwirth et al. 2002). These ecosystems include not only the channel system, but also the floodplain lakes, backwaters, wetlands, and riparian forests. Fortunately, riparian systems are now recognized as biotic sinks and critical habitat corridors, and as such, riparian reforestation has become an integral part of river and stream restoration throughout the US. These projects receive approximately $1 billion in annual funding (Marks, 1983; Noss, 1983; Hughes & Cass, 1997; Keeton, 2008; Bernhardt et al., 2005). This form of restoration is integral to agricultural and developed watersheds where streamside forest cover has been lost (Keeton, 2008; Sweeney & Czapka, 2004). State and federal wildlife agencies, conservation groups, and landowners are responsible for re-creating and restoring the ecological integrity of riparian buffers. Planting trees near streams creates forested buffers that protect the watershed from the impact of adjacent land uses.

The multitude of factors that is responsible for creating the natural communities that exist along these corridors makes replication of them difficult (Engelhardt & Ritchie 2002). The conservation practice of riparian buffer restoration is minimized if tree seedling mortality is high (Keeton, 2008). Therefore, developing and implementing a protocol to monitor seedling survivorship is necessary to assess the effectiveness of planting methods and allow replanting where needed. Once the factors that contribute to seedling mortality are identified, more effective planting plans can be employed. Currently only ten percent of stream and restoration projects include follow-up monitoring (Keeton, 2008; Bernhardt et al., 2002). Monitoring the success of present and past planting projects will help managers plan projects with maximum tree survivability. Monitoring will give managers critical information regarding how specific variables such as tree species, protection, and browse affect tree survival. This information can be used to improve future restoration projects. Restoration monitoring will lead to planting projects more likely to provide the ecosystem functions the conservation community is striving for.

History of Restoration

In Vermont, approximately two centuries of land-use activities including livestock grazing, agricultural crop production, timber harvesting, and stream channelization are responsible for the degradation of the ecosystem functions of the riparian corridors that exist today. Since early settlement, the Champlain Valley in particular has been a prime agricultural region for New England due to its milder climate, moderated by its proximity to Lake Champlain. Prior to agricultural settlement, this region was approximately 98% forested (Lapin 2003). Numerous farms, predominantly dairy have characterized much of the landscape that is Vermont since the early twentieth century (Otsuka 2004).

A common practice with dairy farming is to use undeveloped land for both hay production and corn production. Many times this land is also used as late season livestock pasture, while some farmers choose to utilize other land strictly for grazing. A goal of most farmers is to utilize the maximum amount of arable land for crop production, historically this included remedial quality riparian land bordering streams. Cattle are allowed to graze along riparian corridors and are allowed direct access to a stream reach for drinking water. Ultimately, these processes can lead to water quality degradation both instream, downstream, and ultimately in Lake Champlain. Water quality problems elicits riparian restoration action via the federal, state, and non-profit agencies working to control both non-point and point source pollutant contributors as well as restore watershed and riparian ecosystem functions (Pendleton, 2008).

The Conservation Reserve Enhancement Program (CREP) is a federally funded voluntary enrollment program that accomplishes the most riparian restoration within the State. Landowners enrolled in this program are required to create a riparian buffer, by taking a variable portion of their land that borders tributaries out of agricultural production, plant native trees along it and allow the historic forest corridor to reestablish. The average cost of implementing a restoration project in Vermont is approximately $23,000 ($2,500/ac), though this can vary dramatically with the size of the project, the degree of restoration required and the landowner's involvement (F. Pendleton, personal communication, February 4, 2008). Landowners who choose to enroll in government-sponsored programs have a choice regarding their participation and the amount, if any; they might contribute to project costs. The restoration contract is maintained for a specified number of years, typically ranging from 10-20 years to allow a vegetative buffer to begin to establish. The width of the vegetative buffer is also regulated and ranges from 35-180ft depending on site characteristics and the landowner's preference. Each contract is tailored to fit the individual landowner's needs in conjunction with restoring the landscape. Some contracts may require fencing to be installed to protect the buffer from disturbance of adjacent livestock, as well as installation of an alternative livestock water source (stock tank), bank revetments, and tree planting while other buffers may be left undisturbed to regenerate naturally. In addition to restoration project implementation the landowner is also paid a rental payment for the term of the contract. This payment includes both one-time signing incentive payments, which are approximately \$10/ac/yr for pastureland and \$127/ac/yr from cropland, multiplied by the number of years of the contract. An annual rental payment is also included in the contract and is approximately \$7/ac/yr for pastureland and \$122/ac/yr for cropland (Vermont Agriculture).

Agencies responsible for designing and implementing restoration efforts are committed to working with individual landowners to create restoration plans that reflect the local landscape characteristics and soil conditions of the specific area (Pendleton, 2008), while at the same time seeking to restore the ecological functions and values of the site. Although restoration projects have become very popular in Vermont with approximately 30 new CREP projects a year (Pendleton, 2008), no long-term monitoring has been implemented to assess restoration outcomes.

Although the ecological benefits of riparian restoration are recognized, the long-term outcomes of these desired benefits are still undetermined. Riparian buffers are known to filter natural and chemical fertilizers and sediment traveling in surface water out of agricultural fields, and developed areas into streams. Trees planted within buffers assist in the filtering process, by trapping pollutants such as nitrogen, phosphorous and sediment in their roots, and thereby keeping the pollutants from entering the waterways. Phosphorus has the ability to attach to soil particles (i.e. sediment), which, without bank stabilization are easily carried into the water (Soto-Grajales, 2002). Although nitrates and phosphates are naturally occurring nutrients, excessive buildup of these nutrients induces algal blooms in waterways and the decomposition of these blooms uses up large amounts of valuable oxygen in the water system (USDA, 2009). Sedimentation is also detrimental to waterways and the biotic life they support. In addition to transporting pollutants, sediment particles cloud the water, increase stream temperature, and degrade wildlife habitat (USDA, 2009).

The roots of planted trees provide stability to the streambank by resisting the erosive power to flooding streams, and allowing room for natural channel structure of the stream to change. The canopy of trees provides shade and nutrients that regulate temperature in the river and provide food and habitat to the macroinvertebrates and insects that feed fish (Soto-Grajales, 2002). The presence of these trees and shrubs also provides food and cover for many wildlife species including microhabitats for migratory songbirds. Despite recognizing the ecological benefits riparian tree planting provides, planners and scientists are still unable to provide substantial documented evidence for riparian tree planting survival over the long-term (Stange & Shea, 1998).

Unfortunately, the extensive history of human and livestock disturbance within some riparian buffers delays them from naturally regenerating on their own. Native local seed sources need to be viable, and available. Planting seedlings on previously forested areas or abandoned farmland can speed up natural successional processes (Stange & Shea, 1998).

It is known that tree mortality has severely impeded restoration success, particularly in the years immediately following planting, yet we are unsure what the causes associated with specific species mortality are (Keeton, 2008). Questions remain regarding the impact of tree protection (tree tubes and brush mats), planting technique, plant origin, plant density, rodent girdling, deer browsing, and water availability on planted tree survivorship. Some assurance is needed to ensure that reforestation of riparian sites provides maximum seedling survival and growth to restore the ecosystem functions that provide water quality, and wildlife habitat within the buffer (Sweeney & Czapka, 2004).

In order to collect data on tree survival we must understand successful restoration. The Society for Ecological Restoration (SER) defines ecological restoration as “the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed” (SER, 2004).

SER highlights various attributes that identify ecological restoration success: “The restored ecosystem contains a characteristic assemblage of indigenous species from all functional groups that occur in the reference ecosystem and that provide appropriate community structure. The physical environment of the restored ecosystem must be capable of sustaining reproducing populations of the species necessary for its continued stability or development and is suitably integrated into a larger ecological matrix, with which it interacts through abiotic and biotic flows and exchanges. All potential threats to the health and integrity of the restored ecosystem from the surrounding landscape have been eliminated or reduced as much as possible in that the ecosystem is resilient to normal periodic stress events (SER, 2004)”. Ultimately, planted tree species need to survive and grow in order for riparian tree planting to be successful.

Researchers have studied the effects of some factors affecting seedling mortality in restoration efforts (Keeton, 2008; Bernhardt et al., 2005; Canham et al., 1994; Opperman & Merenlender, 2000; Lai & Wong, 2005; Stange & Shea, 1998; Sweeney & Czapka, 2004; Ward et al., 2000). Yet, these monitoring projects isolated specific variables and lack an overarching standardized monitoring protocol. Variables such as herbivory, plant competition, tree guards, and weed mats were looked at in isolation. There are no long-term monitoring studies that evaluate the effectiveness of various tree planting restoration practices over different project sites. In addition, there are no comprehensive studies that compare vegetation survivorship among planted restoration buffers with buffers that are left to naturally regenerate. Long-term monitoring is needed to evaluate whether restoration goals are achieved and ecosystem processes are working (Jungwirth et al, 2002). The ability of riparian forest restoration to provide ecosystem functions (i.e. streambank stabilization; filtering runoff, trapping sediment, fertilizers, and pesticides, reducing erosion, and providing habitat and food for wildlife) needs to be comprehensively addressed (Keeton, 2008; Jungwirth et al., 2002; Sweeney et al. 2002).

After recognizing these areas of riparian tree planting insufficiency, we developed a standardized protocol to monitor trees in Vermont (Appendix 1).

Restoration Ecology and Project Purpose

To understand restoration ecology one must understand what restoration ecology is used for and why it is carried out. Hobbs (1996) offers these uses: to restore highly degraded but localized sites including improving the physical and chemical characteristics of the substrate and ensure a return of vegetative cover; to improve productive capability in degraded lands: to enhance conservation values in protected landscapes and extensively disrupted landscapes. Ultimately, the goal of restoration is to return the degraded system to some form of landscape cover that is protective, productive, aesthetically pleasing, or valuable in a conservation sense (Hobbs 1996).

To integrate restoration successfully into land management it is necessary to identify the key elements of restoration. Hobbs (1996) recommends these steps: identify the processes that lead to the degradation or decline of the landscape; develop methods to ameliorate the degradation; determine realistic goals for reestablishing functioning ecosystems; develop practical techniques for implementing restoration goals, develop easily observable measures of success; share these techniques with land managers to create cohesive widely used strategies; monitor restoration variables to assess progress relative to goals, and adjust procedures if needed.

Monitoring is necessary to document the results of restoration projects so that the lessons learned from one project can be applied to others, and shared by other landowners, agencies, and ecologists (Opperman & Merenlender, 2000). Although some standardized parameters have been established for riparian reforestation (NRCS VT, 2008), we need to continue to consider the application and integration of the fundamental elements Hobbs (1996) outlines. To date, we have a piecemeal at best form of reforestation monitoring to assess the outcomes of our tree planting parameters.

This research addresses this gap in knowledge by developing and testing a standardized monitoring protocol that will help ensure that riparian restoration effectively replaces the loss of natural plant communities. Critical information is needed to make certain that restoration projects are planned effectively with a maximum likelihood of producing the desired ecosystem functions. By comparing planted tree survivorship among restored areas, we can use this information as a tool to accurately assess restoration techniques and model future restoration planning. For example, riparian buffer monitoring will tell us which species grow successfully when planted using specific protection techniques, nursery providers, and soil characteristics, while another species may be more successful when allowed to naturally regenerate from a nearby seed source. These questions cannot currently be answered due to the lack of long-term data on restoration planting.

Through the collaboration and participation of the agencies involved in restoration planting in the region including, but not limited to: U.S. Fish and Wildlife Service, U.S. Department of Agriculture, and the Vermont Agency of Agriculture as well as non-profit agencies including Intervale Conservation Nursery, and local watershed groups including the Winooski Conservation District and the Missisquoi River Basin Association, we were able to collect long term data to improve restoration planting. The participation of these agencies was necessary to insure that the best standardized monitoring protocol was created to provide more effective riparian restoration projects for the future.

Monitoring is necessary to evaluate restoration outcomes. Therefore, an assessment of restoration efforts is essential to ensure reforestation benefits are provided. These benefits were characterized by the following variables: landscape structure (prior land use), composition (tree species planted, tree protection, nursery origin, tree planting experience, prior land use, and invasive competition); and function (planted tree growth and survival rates and natural regeneration). The purpose of this study was twofold: first, to assess which techniques and species are most affective at restoring riparian communities. Second, to provide a standardized protocol for conservation organizations to use to assess the effectiveness of restoration planting practices into the future.

Tree Survival, Protection, Growth and Herbivory

Riparian restoration sites provide challenging conditions for seedling establishment. The typically degraded condition of these sites with regard to moisture, soil condition, and invasive species presence make tree survival the greatest challenge (Keeton, 2008, Stange and Shea 1998, Harmer 2001, Opperman and Merenlender 2000), and growth and survival in the first year is critical.

Tree protection tubes or shelters are known to improve survival of planted trees by providing two functions: they physically protect the trees from animals (deer and small mammals) and human damage and they are known to increase the seedlings' juvenile height growth allowing them to compete with other vegetation (Lantagne et al 1990, Walters 1993, Clatterbuck 1999). Planting trees with tubes provides an 'easy to see' focal point that alerts humans to a planted tree's presence and decreases the risk of trampling from walking or operating machinery in the vicinity (Clatterbuck 1999). Tree tubes can help more particular "site-adapted species" to establish in less ideal conditions and/or in sites that may be nutrient deficient or have compacted soil (Windell 1992, West et al. 1999). Tree tubes offer these benefits by providing a sheltered environment that prolongs the growing season, giving the seedling more time to grow at warmer temperatures (Ponder 1994, West et al. 1999). The tree tube environment is also known to promote the opportunity for increased chlorophyll retention (Minter et al. 1992). Graham Tulley (1985) established that tree shelters improved early growth rates and protected oak (*Quercus spp.*) seedlings from deer (*Odocoileus spp.*) browse by demonstrating that tree tubes create a "greenhouse environment" around young seedlings (Potter 1988). Clatterbuck (1999) found that height growth advantage of sheltered trees although initially greater is not maintained once the seedlings emerge from the shelters. It is still undetermined that given the high cost of tree tubes and the short duration of the height growth advantage, whether the use of tubes is justified (Clatterbuck 1999).

Tree tubes also require maintenance, which can increase planting costs, and if not properly maintained can lead to tree death. Improperly installed and sized tubes can fall over, and sometimes smother seedlings or if not removed within a proper timeframe are likely to girdle a growing tree. Marquis (1977) observed cambium damage from rubbing of tree tubes against seedlings from wind. This was found to occur once the seedling had grown out of the tube and may mean that tubes need to be removed or should be designed to disintegrate at the appropriate time.

Stange and Shea (1998) reported that tree tubes were effective in preventing browsing by deer, because they provide a barrier between the growing seedling and the deer (Dubois et al. 2000).

Another form of tree protection is brush mats. These perforated plastic or fabric sheets are placed on the ground to surround the base of newly planted trees. Brush mats are commonly used in riparian tree planting to control competition from herbaceous plants (Keeton, 2008). To date, there is minimal data supporting there success in improving seedling survival (Lai and Wong

2005; Sweeney et al. 2002). Keeton’s study (2008) showed that herbaceous plants grow through the perforated center of the mat after the first growing season, and ultimately displaced mats by the end of the first, second, and third growing seasons.

METHODS

Study Location and Plant History

Planted tree survival and condition data were collected at forty-one riparian restoration sites within six watersheds throughout Vermont, USA. Monitoring took place within the first year of tree planting for 14 sites (May-September 2008), which were monitored again the following growing season (May-September 2009). Additionally, data were collected at 27 additional sites including six sites planted in 1997/1998, 8 sites planted in 2002/2003, 1 in 2006, 11 in 2007, and 4 in 2009.

Planting stock was provided from a combination of local, regional, and national plant nurseries, with trees arriving from as far away as Montana, and Michigan, as well as trees provided by local in-State nurseries or collected at adjacent locations within the same watershed.

Tree planting was completed by a range of experience levels from paid tree planting professionals, to youth and community volunteers. Prior to tree planting, land use (past ten years) at the restoration sites included: livestock pasture (to be defined from this point forward as LIPA), agricultural cropland (AGCR), fallow land, and recreational parkland (REPA). Following tree planting all agricultural and livestock pasture activities were required to cease within the delineated buffer for the extent of the contract, while fallow and recreational land could continue with its current use.

Study Design

First year survival data were collected from May-September 2009 at 14 sites planted in either the spring of 2008 or the fall of 2007. Long-term tree planting survival was collected at 27 additional in 2009: including six sites planted in 1997/1998, 8 sites planted in 2002/2003, 1 in 2006, 11 in 2007, and 4 in 2009 (Table 1). The purpose of collecting data at older sites allowed us to identify common characteristics of planted tree species over longer time spans. The 1997/1998 sites were the oldest known sites we were able to visit with adequate tree planting records to identify species survival. Using 1997/1998 as a starting point for older years, I collected data in a 5-year interval sequence forward. Additionally, the one site I monitored that was planted in 2006 (Bridport1) was unique in that only seeds were planted at this site, and the Berkshire1 property that was established in 1997/1998 was also unique in that no trees were planted at this site and only natural regeneration was encouraged to take place. In addition to collecting data on planted tree survival, natural regeneration of native trees was also documented at each monitored site.

Table 1. List of all riparian restoration project sites monitored in 2008 and 2009, Vermont, USA.

Year Planted	Town	Watershed[1]	Size (ac)[2]	Prior Use[3]
1997/1998	Berkshire1	Missisquoi	13.57	LIPA
1997/1998	Berkshire2	Missisquoi	198.61	LIPA
1997/1998	Ferrisburgh1	Otter Creek	3.88	fallow
1997/1998	Morrisville	Lamoille	4.69	fallow
1997/1998	Williston1	Winooski	2.26	AGCR
1997/1998	Wolcott	Lamoille	3.35	AGCR
2002/2003	Addison	Otter Creek	17.71	LIPA
2002/2003	Chelsea	White River	3.01	REPA
2002/2003	Ferrisburgh2	Lake Champlain	10.87	LIPA
2002/2003	Ferrisburgh3	Lake Champlain	19.79	LIPA
2002/2003	Georgia1	Lake Champlain	36.93	LIPA
2002/2003	Randolph1	White River	6.55	REPA
2002/2003	Tunbridge	White River	8.63	AGCR
2002/2003	Waltham	Otter Creek	16.17	LIPA
2006	Bridport1	Otter Creek	54.99	LIPA
2007	Bridport2	Otter Creek	21.94	AGCR
2007	Brookfield1	White River	7.81	LIPA
2007	Brookfield2	White River	21.22	LIPA
2007	Cornwall1	Otter Creek	14.54	AGCR/LIPA
2007	Cornwall2	Otter Creek	9.6	LIPA
2007	Ferrisburgh4	Lake Champlain	37.78	LIPA
2007	Hinesburg	Lake Champlain	12.41	LIPA
2007	Middlebury	Otter Creek	6.3	AGCR
2007	Richmond	Winooski	8.77	AGCR
2007	St. Albans	Lake Champlain	13.32	LIPA
2007	Westford	Lamoille	0.86	LIPA
2008	Cornwall3	Otter Creek	6.52	AGCR
2008	Georgia2	Lake Champlain	3.99	LIPA
2008	Marshfield1	Winooski	29.58	fallow
2008	Marshfield2	Winooski	6.76	fallow
2008	Newport1	Missisquoi	79.82	AGCR/LIPA
2008	Newport2	Missisquoi	79.82	AGCR/LIPA
2008	Newport3	Missisquoi	79.82	AGCR/LIPA
2008	North Troy1	Missisquoi	34.75	AGCR
2008	North Troy2	Missisquoi	34.75	AGCR
2008	Randolph2	White River	19.7	AGCR
2008	Shorham	Otter Creek	40.21	LIPA
2009	Clarendon	Otter Creek	10.52	AGCR

2009	Huntington	Winooski	0.64	fallow
2009	Randolph3	White River	14.39	LIPA
2009	Williston2	Winooski	10.34	fallow

Watershed[1]: USGS hydrologic unit code (HUC 8).

Size (ac)[2]: Some projects had multiple sites planted at different years and/or in different geographical areas; size (ac) includes land that was restored, but not monitored for all planting sites combined.

Prior Use[3]:AGCR=agricultural crop; LIPA=livestock pasture; fallow=land that has not been used recently; REPA=recreation park.

Although 40 out of 41 projects were planted with native woody species along a restored riparian buffer, each project varied with regard to planting density, buffer width, total acreage, tree protection measures, species composition (planted and naturally occurring), soil types, and adjacent watercourse characteristics.

Three transects were completed at each site spaced approximately 300 ft apart or equally distributed throughout a representative portion of the property to sample >200 individual species, additional transects were added to the protocol if necessary to increase sample size. All transects were perpendicular to the watercourse across the extent of the planted buffer. Variations in transect length were due to varying buffer widths at each site. The first transect would begin at approximately 50 feet off the project boundary and was perpendicular to the watercourse (Figure 1, Appendix 1).

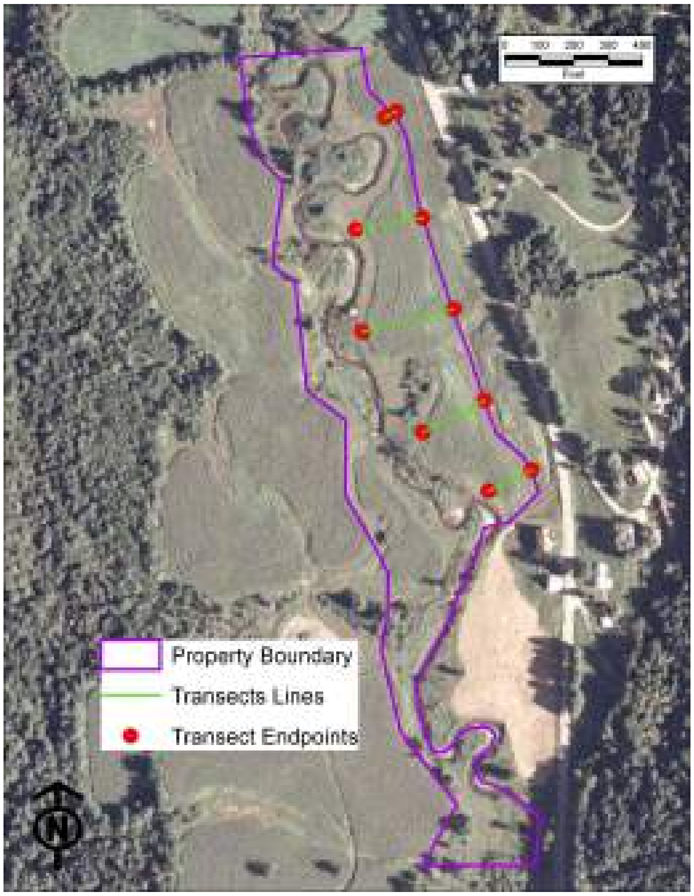

Figure 1. Transect spacing for restoration monitoring protocol, Randolph 2 property, Vermont, September 30, 2008.

Transects were labeled in consecutive order 1, 2, 3, etc on a stake that was put in the ground at each end of the transect, and marked on the Trimble GeoXT datalogger or Garmin GPS. A digital photograph with supporting documentation was taken at each end of the transect to capture the transect location and characteristic vegetation and is useful as a historic reference point. A tape measure was then run along the length of the transect between the stakes and was left on the ground to mark the transect centerline. All trees within 10 feet of the tape (both sides) were counted for the entire length of the transect. If tree density was sparse, it was necessary to go beyond 10 feet of the tape and count a minimum of 10 trees. Tree data collection began by counting the trees on the left side of the tape first (Figure 2).

Figure 2. Transect with tape measure and planted trees, Cornwall 3 property, Vermont, June 23, 2008.

In order to return to the same tree over time and record its relative condition, trees were individually numbered with a corresponding tree tag staked to the base of the trunk. Additionally, a corresponding GPS reference position, and a digital photograph was taken, while tree data variables were measured and documented. The photograph was also helpful to identify specific condition/species characteristics that were not always readily identifiable in the field. The process of tree tagging, GPS recording, photographing, and data recording began for all trees on the left side of the tape in consecutive order beginning with the tree farthest away from the water. The same process was then completed on the right side of the tape/transect centerline. Natural regeneration of trees and shrubs found within 10 feet of the tape was also recorded.

Data Collection

Thirteen variables were examined in this study. Independent variables included plant species, plant origin, planting technique (bareroot, livestake, tubling, seed, or container grown), prior land use, tree planter, year monitored, year planted, tree protection (mat, no mat, tube, or no tube, mat and tube, no protection), percent browse, and percent girdling. Dependent variables included plant survival (dead/alive), condition (vigorous, healthy, moderate, unhealthy, very unhealthy, dead), and stem height (inches).

Mat type consisted of green brush mats, black plastic and burlap. Tube or shelter types consisted of Blue-X shelters (a 24” tall plastic film with a clear blue-tinted poly sleeve/liner), Tubex tree shelters, and white spiral tree guards (Figure 3).

Blue-X shelter Tubex shelter Spiral tree guard

Figure 3. Three common types of tree protection tubes and green brush mat found during 2008 and 2009 monitoring, Vermont, USA.

These variables were recognized as most important based on my findings from a preliminary restoration monitoring season conducted in 2008 and collaboration and research from other agencies involved in riparian restoration.

Tubelings are defined as woody plant seedling grown in plastic "plug" containers with a small amount of soil. Although tublings are technically a type of ‘container grown’ plant material their smaller size makes them unique enough to be treated separately. Live stakes are defined as living woody plant cuttings capable of quickly rooting in moist soils; generally ½ - 2 inches in diameter and 1-3 feet long and large enough to be tamped-in as stakes. Seeds are defined as embryonic plants enclosed in a seed coat covering (http://www.merriam-webster.com/dictionary). Bareroot stock are defined as woody plant seedlings lifted from the nursery soil and delivered 'bare-root' (without soil). Container grown or balled-burlapped plants are woody plant seedlings and saplings grown and delivered in soil within a plastic container or wrapped in burlap (Table 2).

Table 2. Definition of tree and shrub types and associated planting materials for riparian restoration efforts.

Tree/Shrub Type	**Definition**	**Planting Material**
Tubelings	Woody plant seedling	Container grown with soil
Live stakes	Living woody plant cuttings	Staked down
Seeds	Embryonic plants	Seed coat covering
Bareroot stock	Woody plant seedling	Roots without soil
Container grown	Woody seedlings and saplings	Container or burlap with soil

In addition, to planting technique, the study also attempted to identify who planted the trees at each site, and where the trees came from (i.e. nursery origin). Tree planters were grouped into two skill level categories: volunteer (little to no experience) and professional (past tree planting experience expected).

Tree nursery providers were grouped according to vicinity to project area (local, Vermont, New England, Eastern US, Midwest, and Western US). However, most project sites had trees supplied by at least two or three nurseries, with specific tree species coming from one nursery versus another.

Collecting data about the plant including its stem height, planting technique (tubling, live stake, seed, or bare root, or container grown), and the nursery that provided the plant is necessary to identify how these factors contribute to its development. Similarly, recording what, if any, protection measures were used including brush mats and tree tubes allowed us to determine if these measures improve survival or growth.

The type of browsing/girdling was identified by bite characteristics for known species including beaver, deer browse, meadow vole, and insects. For example, insect browse on tree leaves was differentiated from vole or beaver browse along the trunk and stem of trees.

Data Analysis

Survival, condition, and height were dependent variables that were analyzed by independent variables including all trees, species, site, protection, herbivory, origin (nursery provider), labor provider, prior land use, planting technique, natural regeneration, and tree height at planting. This analysis was completed for both first year monitoring data, and for long-term planting data. However, the majority of detailed analysis came from first year monitoring data, while only some variables could be statistically analyzed with long-term planting data, but biological trends and patterns were noted where relevant.

Data were analyzed in SAS program JMP 4.0 and Excel 2003. Contingency tables (chi square statistic) were used to compare the frequency of survivorship for seedlings with different tree protection (tree tube, mat, both), species, condition, project and girdling activity. When appropriate conifer trees were removed from tree protection analysis, since conifer trees are not typically planted with protection. Mean survival were calculated across sites for each monitoring year with first year survival data, and for each planting year for long-term planting data. Variables that did not provide a big enough sample size ($n \geq 5$) when analyzed by monitoring year or planting year were not represented. For a specific species to be analyzed a minimum of five species ($n \geq 5$) needed to be found at one project, and minimum of three ($n \geq 3$) projects needed to have an occurrence of the species. These numbers were deemed necessary to gain a mean survival by species across project areas. Annual tree survival data was labeled dead or alive according to survival status, and subjected to a contingency table for year monitored and planting year. Condition data was also labeled by categories of percent damage, 0-5% for vigorous trees, 6-25% for healthy trees, 26-50% for moderate trees, 51-75% for unhealthy trees, 76-99% for very unhealthy trees, and 100% for dead trees and subjected to a contingency table for the following independent variables (site, species, and height).

Different species of similar genera were grouped together to eliminate potential monitoring error in there identification as young seedlings and to improve strength of sample size in analysis. In the maple genus (*Acer*) this included red maple (*Acer rubrum*), silver maple (*Acer saccharinum*), and sugar maple (*Acer saccharum*). Boxelder (*Acer negundo*) was analyzed separately from the maple grouping because its physical characteristics were easier to discern in seedling stages from other Acer species and it had a very large sample size of its own. In the ash genus (*Fraxinus*) species groupings included white ash (*Fraxinus americana*), black ash (*Fraxinus nigra*), and green ash (*Fraxinus pennsylvanica var. subintegerrima*). In the oak genus (*Quercus*) this included: bur oak (*Quercus macrocarpa*), swamp white (*Quercus bicolor*) and red oak (*Quercus rubra*). In the dogwood genus (*Cornus*) this included red-osier dogwood (*Cornus stolonifera*), red panicled dogwood (*Cornus racemosa*), and silky dogwood (*Cornus amomum*). In the willow genus (*Salix*) this included all shrub willows (*Salix spp.*). Black willow was analyzed separately from the willow groupings because its physical characteristics were easier to discern in seedling stages from other willow species and it had a very large sample size of its own. Statistical analysis and figures for most data were only provided for species with a sample size ($n \geq 30$) and all trees with unknown species were removed from species analysis. Three species (ash, boxelder, and maple) with a sample size ($n \geq 6$) were analyzed with and without protection for a full year. Tree species and shrub species were not differentiated for data analysis and species were not separated by planting technique.

A nonparametric three-way analysis of variance (Wilcoxin signed rank ANOVA) was used to analyze the effects of survival, tree protection, species, and girdling on variation in mean seedling height (SAS Institute 2007). Although, browse and girdling data was originally collected in 10% increments, the girdling data was grouped into three categories (0-20%, 20-60%, 60-100%). A Pearson correlation analysis (SAS Institute 1985) was used to examine the relationship between first and second year height growth and tree protection. Dead trees were removed from tree height analysis. Additionally, all missing trees were presumed dead. Older and taller "witness" trees that were planted along some projects buffer boundaries to delineate the restoration area boundary were removed from some height data analysis.

RESULTS AND DISCUSSION

Baseline and First Year Condition

Survival, Species and Growth

Trees monitored in 2008 had 88% survival at the end of the planting season. In 2009 after a full year in the field, overall survival of individuals planted in 2008 decreased to 80%. The 8% drop in survival was significant (X^2=11.7, p=0.0006), but the decrease was due to four sites that had ≤57% survival (Newport 1, Newport 2, Brookfield 2, and Newport 3) one year after planting. Survival in 2009 was substantially higher at all other sites with three out of the 14 sites at 100% survival including Westford, St. Albans, and North Troy 2, while all other sites monitored had ≥77% survival (Figure 4).

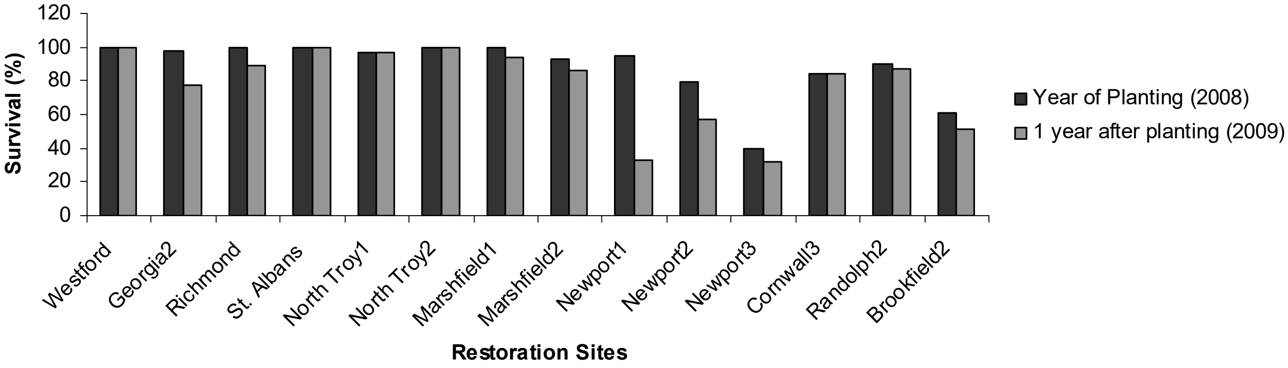

Figure 4. Tree survival by restoration site for trees monitored for one year, Vermont, USA.

The decline in survival between planting year and the following season demonstrate how site specific some tree planting stressors can be. Newport 1, 2, 3, and Georgia 2 sites all had high numbers of dead trees likely from invasion by reed canarygrass (*Phalaris arundinacea*), while the Brookfield 2 site had a large amount of trees die from meadow vole girdling damage and flooding. Marshfield 1 and Marshfield 2 sites had a fair number of trees die from beaver damage. Overall, the majority of dead trees found, died of unknown causes.

Like survival, tree condition decreased after one year. Vigorous, healthy, and moderate condition categories decreased or stayed the same in percent occurrence across sites for the first year after planting, while unhealthy, very unhealthy, and dead trees increased. Vigorous trees maintained the same average (11%), healthy trees decreased from 55% to 31%, and moderate trees decreased from 21% to 17%. Unhealthy trees increased from 9% to 15%, while very unhealthy trees increased from 8% to 9%, and dead trees increased from 18% to 28% (Figure 5).

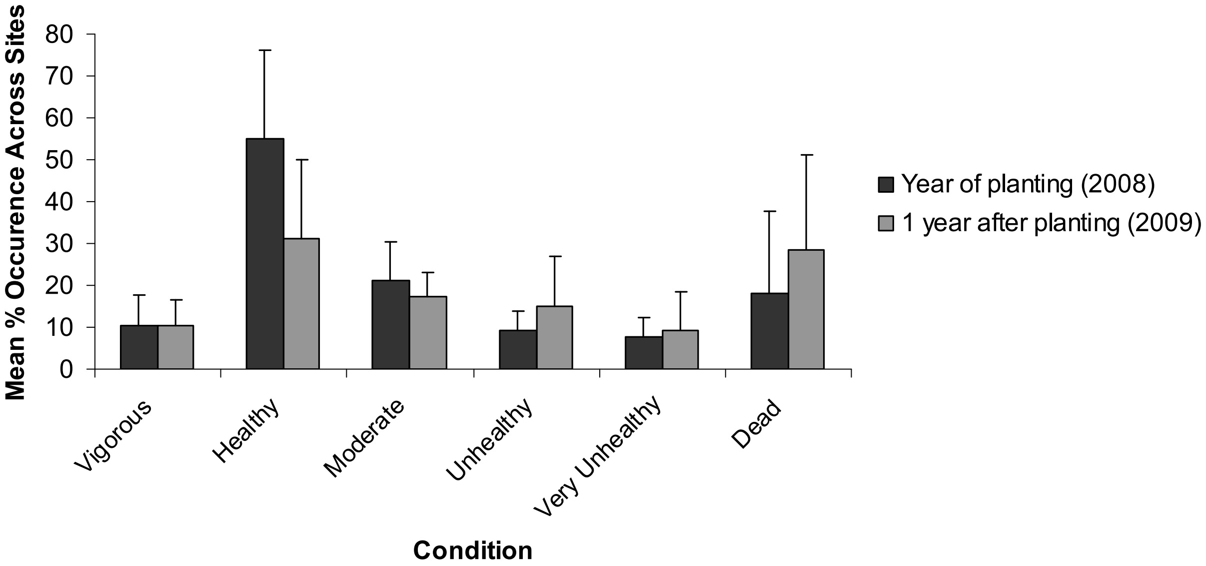

Figure 5. Mean percent occurrence across sites by condition class of trees monitored in 2008 and 2009 in Vermont, USA.

Trees declining in condition one year after planting were struggling from many of the factors that make tree planting along restoration sites challenging such as poor soils, lack of moisture, invasive species competition, and wildlife and/or human disturbance (Keeton, 2008, Stange and Shea 1998, Harmer 2001, Opperman and Merenlender 2000). The first year of establishment is widely recognized as the most challenging for any tree or shrub species regardless of site conditions, and future monitoring will provide necessary long-term data to track condition status of restoration plantings.

Species with the highest overall survivorship for both monitoring seasons was ash, followed by maple, and dogwood. Willow had the lowest survival (Table 3).

Table 3. Survival for planted trees species (n≥30) monitored for one full year, Vermont, USA, 2009.

		Survival (%)	
Species	**n**	**2008**	**2009**
Ash	38	95	100
Dogwood	84	90	87
Maple	173	94	87
Willow, spp.	49	90	73

Although ash trees had the highest survival they also had the lowest representation (n=38). Maple trees had the largest population (n=173), followed by Dogwood (n=84), and shrub willow (n=49). When mean survival for species is grouped across sites, ash was still the highest, followed by dogwood, and maple. Shrub willows had the lowest mean survival (Table 4). Additionally, ash was the only species to increase in survival one year after planting (Table 4). This 4% increase in survival was attributed to one planting site (Cornwall 3) where the trees were mistakenly presumed dead in 2008, due to there poor condition and when revisited in 2009 were found alive.

Table 4. Mean survival ± 1 standard deviation across sites for planted trees species (n≥3) monitored for one full year, Vermont, USA, 2009.

Species	**n**	**2008**	**2009**
Ash	5	96±9	100
Dogwood	3	99±2	94±6
Maple	12	96±12	84±38
Willow, spp.	4	90±11	74±18

Out of the 20 species monitored, ash, maple, dogwood, and willows were the only species with a large enough representative population to be analyzed. Although, these species were the most commonly planted species, the data demonstrates that they maintain high rates of survival over consecutive (two) monitoring seasons and should continue to be included in future plantings where they were historically part of the natural community.

Overall, there was a significant increase in tree height for all species combined after the first full growing season (Wilcoxen signed rank test, z=11676.0, p≤0.0001). Increase in tree height one year after planting was significant for only dogwood (Wilcoxen signed rank test, z=409, p=0.0065) and shrub willows (z=100.5, p=0.019). All species increased in height with the exception of maples that stayed the same. Shrub willows had the greatest increase in height (10in), followed by ash trees (5in). Dogwood species increased the least (<2in) (Figure 6). It is important to note however, that each species varies dramatically in individual tree height at time of planting. Trees and shrubs can range anywhere from 6” to 140” at time of planting.

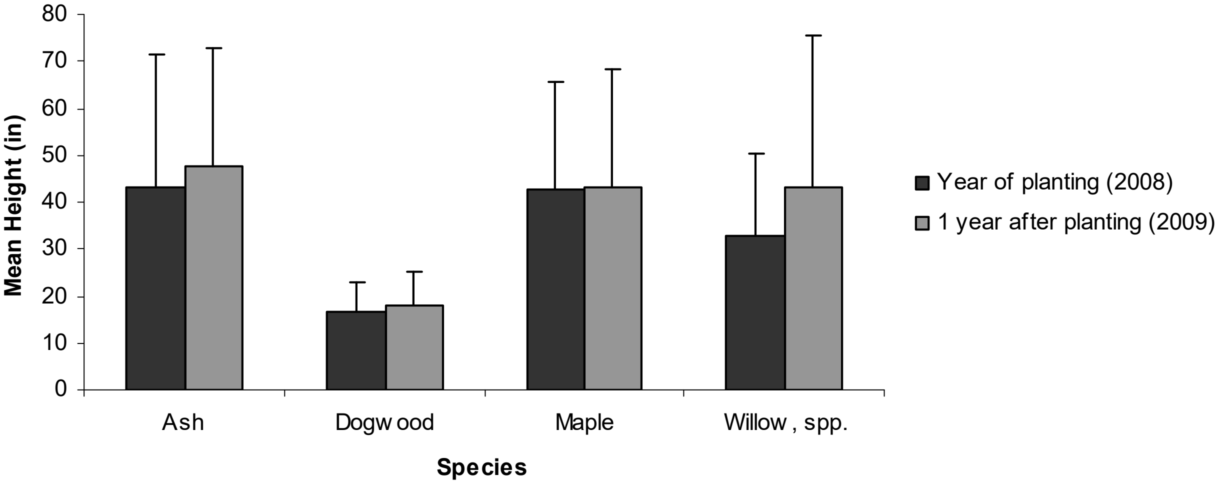

Figure 6. Mean tree height by species (n≥30) for trees monitored for one year, Vermont, USA.

Although tree survival and condition decreased with the first full growing season, surviving trees increased in height by an average of 5in between the year of planting and the first full growing season. The substantial height increases from these species in one year demonstrates that they are important early successional tree planting species. Their foliage may be the most important in the first growing season as habitat, food, and cover for a host of wildlife species. Additionally, if these trees are increasing as much as they are above ground it is presumable that their roots are also spreading underground, providing added security for erosion control, water filtration, and sediment trapping.

Protection

There was a significant difference in survival depending on the type of protection used (X^2=38.7, p=0.0001). Survival was highest for trees with both mats and tubes combined (94% and 93%) for the two monitoring seasons. Survival decreased by 8% for trees with mats and trees with tubes between the two seasons, and survival decreased by 25% for trees with no protection (Figure 7). Large error bars within the graph demonstrate variation in survival across planting sites for trees with no protection and trees with tubes.

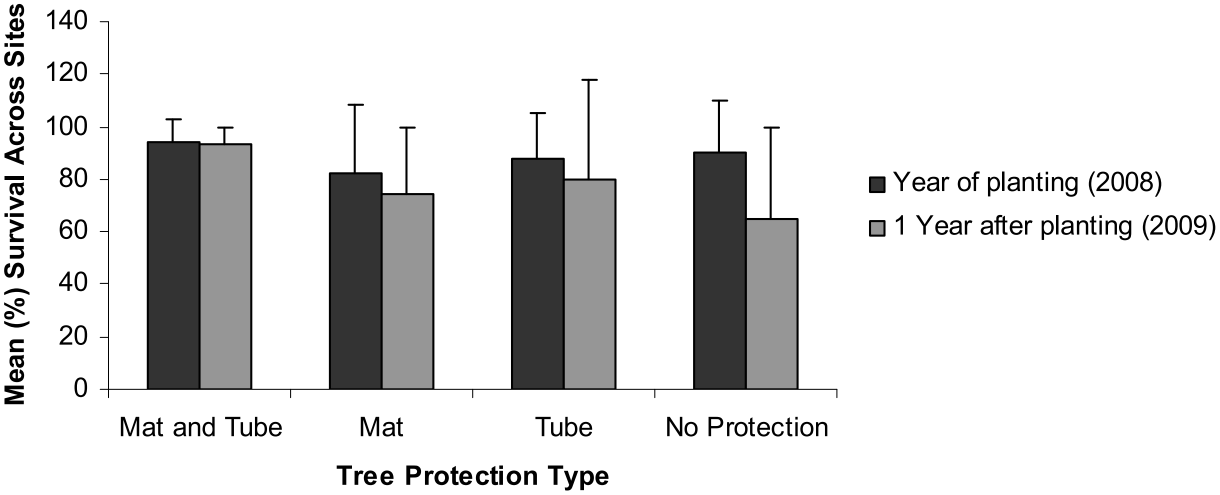

Figure 7. Mean percent tree survival across restoration sites with different protection measures for trees monitored for one year, Vermont, USA.

This data demonstrates that mats and tubes combined provide the best protection for trees in their first year. Additionally, if planners are not able to use both forms of protection combined using just mats or just tubes is better than no protection. Also, it is important to understand that while all tree and shrub species may benefit from brush mats, only deciduous tree species benefit from tree tubes. The increased number of radial branches throughout the trunk on conifer trees and shrub species make protection tubes too constricting to their growth. To identify if conifer trees affected the no survival category they were removed from Table 5 to further analyze tree protection (Table 5).

Table 5. Survival (%) of planted deciduous tree and shrub species with and without protection, Vermont, USA, 2009.

Protection Type	(%) Survival 2008	n	(%) Survival 2009	n
Mat and Tube	93	120	91	107
Mat	90	151	84	148
Tube	92	100	91	85
None	93	74	70	105

The removal of conifer trees from protection analysis did not change survival rates. The combination of mats and tube still had the highest survival for both seasons, and the no protection category has the most substantial drop and lowest survival of all four categories. Table 5 also shows the amount of trees that lose their tubes, and mats over the course of one season. For example, the number of trees with mats and tubes dropped from 120 to 107 individuals, while the number of trees without protection increased from 74 to 105 individuals. Clatterbuck's (1999) research found the opposite to be true over a five-year growing season with no significant difference between survival of sheltered and unsheltered seedlings.

Trees planted with a combination of brush mat and tree tube protection had the least amount of height growth (X^2=32.96, p=0.0001). Although, mean height growth for trees in all categories increased one year after planting (2009), the highest height increase included trees with tubes (8in), followed by no protection (7in), followed by mats (4in) and only 1in for mats and tubes combined (Figure 8).

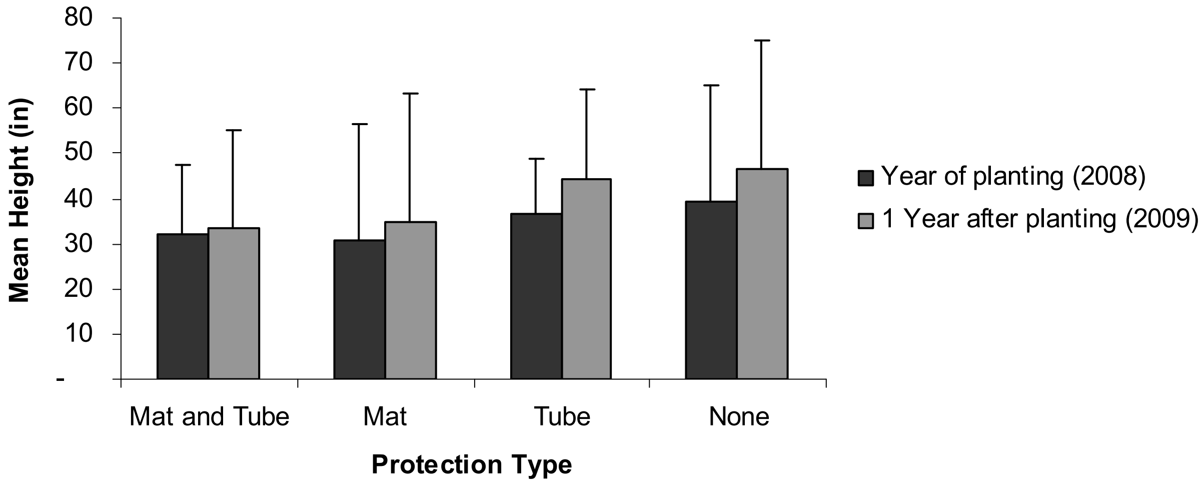

Figure 8. Mean height by tree protection type for trees that were monitored for one year, Vermont, USA, 2009.

Although mats and tubes provide the highest survival rates for planted trees, they do not promote height growth. The combination of brush mat and tree tubes may act as both a protective barrier from trampling, and choking by reed canarygrass, but it may limit photosynthesis production in the plant and therefore restrict growth.

When protection presence or absence was compared among three species, no protection was found to increase tree height significantly for ash (F=35.7, p=0.0001) and maple (F=32.9, p=0.0001) species, but was insignificant for boxelder. Ash, boxelder, and maple were the only tree species that were monitored with protection (mat and tube) and without protection for both seasons. Therefore, trees with mats and tubes do not have a height growth advantage after their first full year. In fact, first year height growth for ash and maple trees increased 65in and 23in without protection, while boxelder trees decreased by 15in (Figure 9).

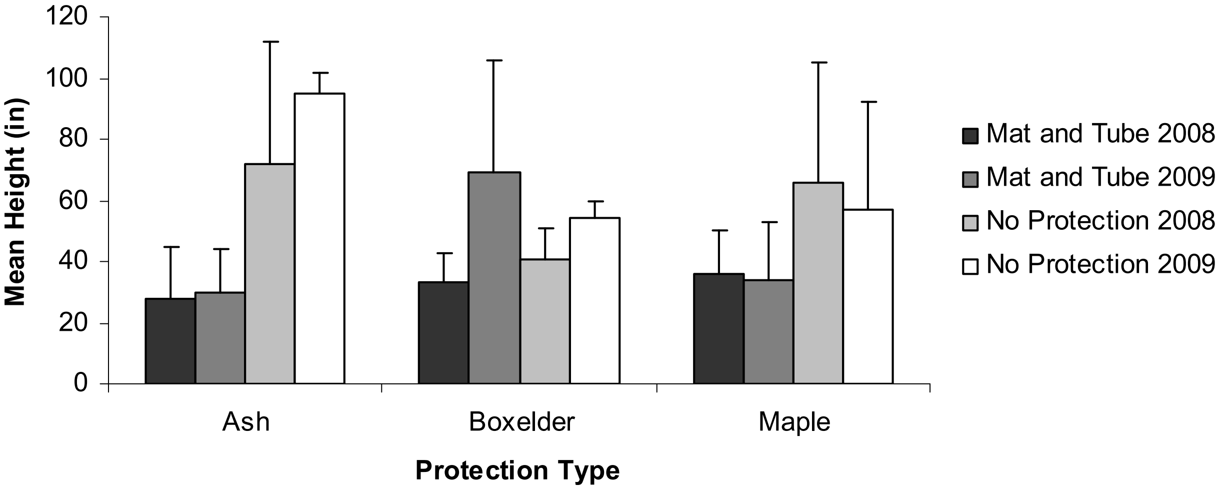

Figure 9. Change in tree height by species that were monitored with and without protection for one year, Vermont, USA 2009.

Ash and maple species are two species that will grow the most without protection, however, this does not assure their overall survival. Although, Clatterbuck's seven-year study (1999) found a height growth advantage to trees shelters for trees that were within the height of the tube, he suggested that after emergence from the tube the height growth advantage was decreased.

Herbivory

Survival was significantly higher for trees that were not girdled (84%, n=987) than trees that were heavily girdled (21%, n=14) (X^2=40.1, p<0.0001) (Figure X). Survival was (71%, n=7) for moderately girdled trees (Figure 10).

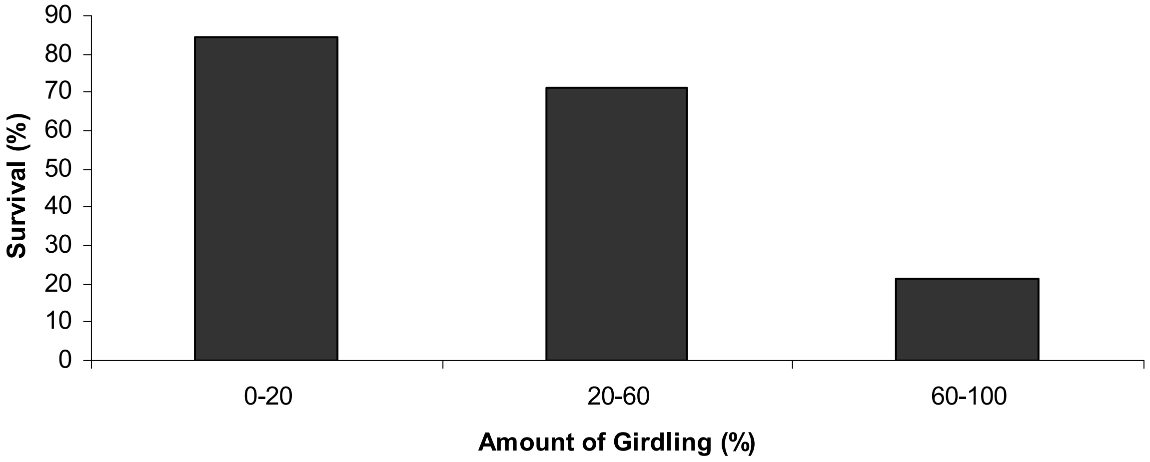

Figure 10. First year survival by girdling presence or absence for trees that were monitored in 2009, Vermont, USA.

Preliminary data demonstrates that high amounts of girdling does not affect tree height (F=1.156, p=0.31). Within one sampling year mean height increased with girdling from 36in with (0-20%) girdling to 44in with (20-60%) girdling, to 55in with (60-100%) girdling (Table 6). However, a larger sample size is needed to draw more definitive conclusions of the girdling affect on height.

Table 6. Mean tree height ± 1 standard deviation by girdling (%) for trees that were monitored in 2009, Vermont, USA.

Girdling (%)	n	Mean
0-20	832	36±24
20-60	5	44±28
60-100	3	55±41

Because planted trees are usually taller than the tree tube, the tubes do not necessarily protect the trees from girdling. It is important to understand that this data tells us how tall the trees were that were girdled, but not how girdling affected tree growth. Unfortunately, accurate girdle data was only collected for the first full year of monitoring and more monitoring is needed to assess the affects of girdling on tree growth.

A tree's height was not affected by the presence or absence of tubes, as tubes did not prevent the tree from being girdled (t=-0.7, p=0.5; t=-0.5, p=0.6) (Table 7).

Table 7. First year height ± 1 standard deviation of girdled trees with and without tubes for 2009, Vermont, USA.

Protection Type	Girdling (presence/absence)	n	Mean
No Tube	Girdling	4	37± 7
Tube	Girdling	1	35
No Tube	No Girdling	86	47±29
Tube	No Girdling	77	45±30

Two seasons of monitoring observations also identified that if tubes are not buried up to 1in the soil at time of planting, meadow voles are able to easily access the trunk base to feed. Additionally, heavy snow years allow meadow voles to feed on tree trunks above the tubes, the perfect snow year at the Brookfield 2 site provided an opportunity for girdling by meadow voles on trees planted with tubes. In fact, this site had disproportionately high amounts of girdling damage from meadow voles and was included in the "Tube" category for analysis.

Tree Planting Experience

Tree survival was significantly increased when trees were planted by volunteers versus professionals (X^2=29.174, p<0.0001). Volunteer tree planters had the highest mean survival (92±6), while professional tree planters had a mean survival of (81±34) (Table 8).

Table 8. First year mean survival ± 1 standard deviation by tree planter across sites for 2009, Vermont, USA.

Tree Planter Type	**n**	**Mean**
Professional	259	81±34
Volunteer	180	92±6

Volunteer tree planters may increase tree survival because they are not being paid for their time and they typically are members of the community in which the tree planting is taking place. They are investing their free time into a project they want to succeed, because they have a stake in the outcome. Paid professional tree planters are more likely to be less connected with the project and are seeking to complete the job within a proposed timeframe.

Survival by Prior Land Use

Survival decreased by 2% for agricultural land (X^2=19.23, p<0.0001), 7% for fallow land (X^2=3.67, p=0.05), and 8% for livestock pasture (X^2=52.01, p<0.0001), and 30% for both livestock pasture and agricultural crops combined (Figure 11).

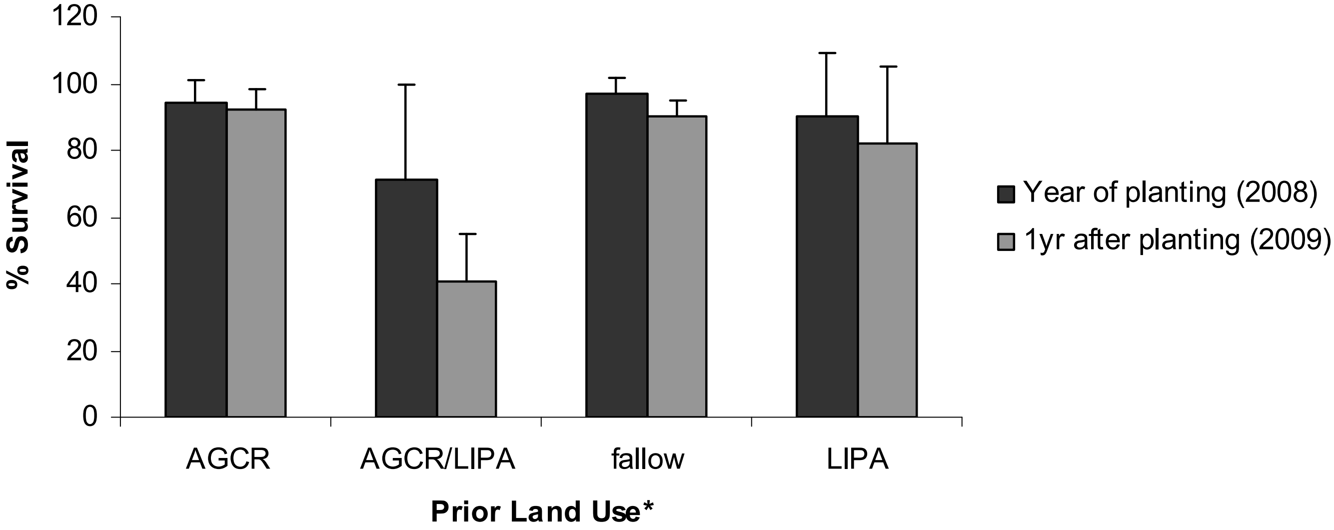

Figure 11. Percent survivorship by prior land use* for trees that were monitored at varied planting years, Vermont, USA.

Prior Land Use*:AGCR=agricultural crop; LIPA=livestock pasture; AGCR/LIPA=land that is used for a combination of livestock pasture and cropland; fallow=land that has not been used in the past 10 years.

In the first year following planting, survival was highest for fallow land, followed closely by agricultural crops, and livestock pasture, with cropland combined with livestock dropping below 40% in the second monitoring season. Agricultural cropland may provide the best survival due to the lack of competition from other plant species on the land. Agricultural land has a history of cultivation and when trees are planted the land is primarily bare soil. Similarly, land that has lied fallow for the past ten years would have already begun the natural community successional process and planted trees may fit well into this process. Of course these observations are only speculative, and more data over a longer monitoring period will demonstrate if these trends continue.

Monitoring at Older Sites

Survival, Species and Growth

Survival varied significantly across planting years with older sites generally having higher survival rates than sites planted within the past three years. However, this data was inconclusive because dead trees were almost impossible to find for older planting years, and planting plans were not accurate enough to ascertain location and species of every tree planted at these older sites. Baseline monitoring is necessary immediately following planting to identify initial height and tree condition.

Causes of tree death at older sites were similar to first year planting sites with the most common cause being unidentifiable, but when identified included competition from reed canarygrass, flooding, bank erosion, mowed by farmer or trampled by wildlife/humans, girdled by tree tubes, girdling by meadow voles, and browsed by deer.

Condition data was discernable at older sites based on documenting those trees that were present. The highest percentage of vigorous trees (38%) occurred during the 2002/2003 planting seasons, followed by 1997/1998 seasons, while, the 2007 and 2009 planting seasons actually had the lowest percentage of vigorous trees (Table 9). This demonstrates that nursery supplied trees do not usually arrive in vigorous condition, but are mostly healthy (2009 trees had 48% healthy trees, which was the highest for all years). The 2008 planting year had the highest percentage of very unhealthy trees (8%), followed by the 1997/1998 (7%) planting year. Dead trees that were found were recorded as such and can be monitored in future years, but it was presumed that many dead trees were not found at older sites because they had already decomposed.

Table 9. Mean survival ± 1 standard deviation and condition of planted trees monitored at sites planted in 1997/1998, 2002/2003, 2007, 2008 and 2009, Vermont, USA.

Year Planted	n	Mean	Vigorous	Healthy	Moderate	Unhealthy	VUnhealthy	Dead
1997/1998	119	88±14	25	28	21	6	7	12
2002/2003	337	81±23	38	31	8	2	2	1
2007	336	74±22	6	39	13	10	6	26
2008	518	80±18	7	26	20	17	9	21
2009	257	98±2	6	48	32	6	6	2

Monitoring at older planting sites, demonstrates the importance of tree survival in the first few years following planting. If trees survive this timeframe, they are likely to do well over the long term. The monitoring completed at older sites will enable planners to track future survival and condition of existing trees.

Results for long term monitoring showed a significant variation in tree height, with the 2002/2003 planting year having the tallest average trees, followed by 1997/1998 (F ratio=261.3, p<0.0001) (Table 10).

Table 10. Measurements of tree height (in) ± 1 standard deviation by planting year, Vermont, USA.

Year Planted	n	Mean
1997/1998	119	106±73
2002/2003	337	127±66
2007	336	50±25
2008	518	35±24
2009	257	29±14

Generally, older sites have taller trees. However, it is unknown why trees planted in 1997/1998 are shorter on average than trees planted in 2002/2003. More data is needed with similar population sizes to begin to make inferences regarding height growth for older populations. Also of interest, is the fact that many of the tallest trees at 2002/2003 sites included vigorous green ash trees, which emphasizes the importance of these trees as early successional species. Across all planting years, ash trees had the tallest average height of all tree species (n>30) planted followed by boxelder, oak, black willow, maple, while balsam fir were the shortest. Shrub willow and dogwood were the two most common shrub species (n>30) and of these willows were commonly taller.

Protection

Trees planted with tubes significantly affected height growth for all planting years (F ratio=11.08, p<0.0001) (Table 11). Older trees were generally taller, but overall 2002/2003 trees were the tallest (156in). Mean height for 1997/1998 was 145in with a tree tube, 85in in 2007 with a tube, 40in in 2008, and 34in in 2009. Trees with no protection were the shortest for most planting years except 1997/1998, which was 105in for no protection and for trees with mats. The 2009 tree data in this table only tells us baseline information for the height of trees at the time of planting and their protection mechanism if any.

Table 11. Mean height (in) ± 1 standard deviation by protection type for year planted, Vermont, USA.

	Height (in) by Year Planted				
	1997/1998	**2002/2003**	**2007**	**2008**	**2009**
	Mean, n	**Mean, n**	**Mean, n**	**Mean, n**	**Mean, n**
Mat and Tube		122±66, 101	49±22, 162	22±10, 71	31±13, 85
Mat	105±95, 22	155±59, 33	67±39, 27	33±26, 139	25±11, 97
Tube	145, 1	156±65, 28	85±44, 5	40±13, 98	34±15, 8
None	105±67, 77	112±65, 88	43±17, 48	42±31, 99	34±22, 14

Observation at older planting sites showed that tubes on trees planted seven and eight years ago showed no signs of disintegration. In fact, Blue-x tubes and white spiral tubes were found to be girdling otherwise healthy mature trees (Figure 12).

Blue-X tube beginning to girdle a green ash tree at a 2003 planting site.

Spiral tube that girdled a red maple at a 2002 planting site.

Figure 12. Signs of tube girdling at monitoring sites planted in 2002 and 2003, Vermont, USA.

These results are similar to Clatterbuck (1999) and Marquis' (1977) studies, which found no sign of tree shelter degradation even after six growing seasons. This data demonstrates that management is required to insure planted tree survival and assure that tree shelters are properly installed and removed. No older planting sites used Tubex tree shelters and therefore no data was collected to determine whether these tubes also girdle trees. The twin-walled design and laserline perforations of Tubex shelters are advertised to split apart to prevent fast growing trees from being constricted, additionally these tubes include bird netting to prevent birds from getting trapped in shelters (Forestry Suppliers, 2010). Results from older planting sites support tree shelter removal when the tree is between 2” and 3” in diameter.

Data collected at older restoration sites also identified the most commonly used types of tree tubes. Blue-X shelters were most common for planting projects within the past eight years, followed by Tubex shelters. White spiral tubes were found on two sites planted in 2002/2003.

Natural Regeneration

We found 22 different species of naturally regenerating trees at restoration sites with the most common being shrub willow (n=34), boxelder (n=27), dogwood (n=20), green ash (n=12), and the invasive common buckthorn (*Rhamnus cathartica*) (n=10) (Figure 13). However, this data is not representative of all regenerating species because in some circumstances so many species were found naturally regenerating that we could not collect point data on all of them, this was particularly true for silver maples and boxelder.

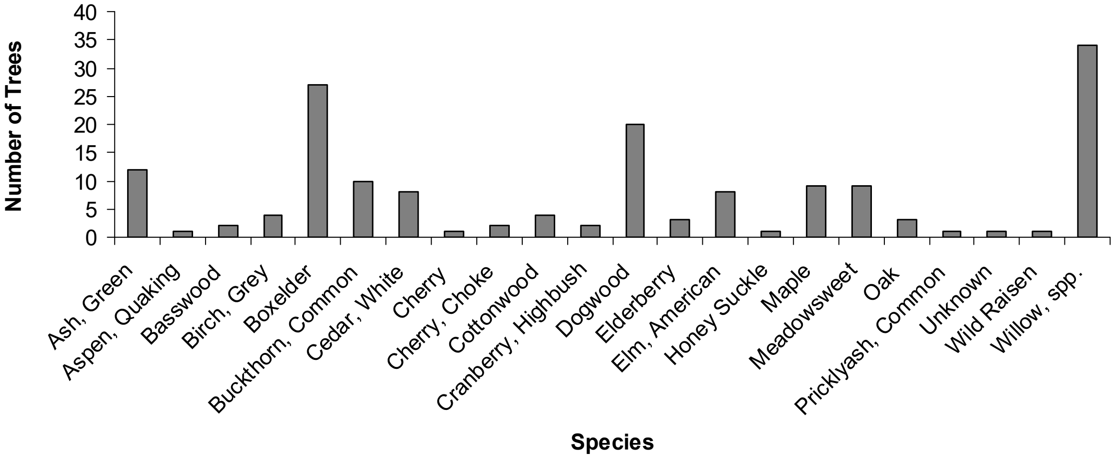

Figure 13. Number of trees by species naturally regenerating on restoration sites in Vermont, USA.

This data is of interest to restoration planners primarily because it identified which species are capable of natural regeneration. Planners can use this information to identify if local seed sources from these species are available at sites to plan for natural recruitment as well as tree planting.

Recommendations

Overall survival rates for planted trees in 2008 and 2009 where high and planners should be happy with riparian tree planting success in Vermont. The decrease in survival and condition data over the first growing season demonstrates the need for restoration planners to achieve higher survival rates (>88%) the year of planting to compensate for the potential (8%) loss over the first full growing season when survival dropped to (80%). Although, restoration planners do not currently have an exact percentage for what is deemed adequate survival for riparian planting projects, it is evident that planners are always striving for higher survival. The Vermont NRCS specification guide sheet for riparian forest buffers recommends a planting density for forest communities between 200 and 300plants/ac (VT NRCS), which translates to an average of 250plants/ac, 80% survival is approximately 200plants/ac. Generally, 80% survival or 200plants/ac is good after the first growing season, but the following recommendations are ways to consider improving potential loss. Many of the identifiable reasons for tree death are avoidable with proper monitoring and management for future years.

Planners realize the importance of planting to replicate the historic natural community, and have made every effort to achieve this goal, but common constraints include working within a limited budget, providing the landowner with plants that they like, and working with nurseries for native tree availability. One strategy for improvement might include planting more species identified in this study with high survival rates in smaller stock sizes. Examples of tree and shrub species with high rates of survival and growth in this study include ash (95%), maple (94%), dogwood (90%), and shrub willow (90%). For species not known to be as vigorous practitioners may want to plant less in quantity, but spend money on larger stock. Although, many people are concerned about the future of ash trees in the U.S. due to the emerald ash borer (an insect that has devastated ash populations across the U.S.) (www.nature.org, 2010). Due to this insect, some restoration planners including Vermont's chapter of The Nature Conservancy who have made the choice to no longer plant green ash trees at their restoration sites because they predict it will not survive (M. Droege, personal communication July 24, 2009; M. McHugh, personal communication February 23, 2010). The success of ash species in this study is obvious and because of these results, I would encourage future planting of ash, at any restoration site where this species was historically. Data demonstrates the important biological significance of this species for riparian buffer restoration.

The more local the seed stock is to the planting site the better. Although, quantitative data on tree origin was not available for this study, trees grown locally are likely to have increased chances for survival, because trees that are grown locally have less travel time between harvest and planting, and have less of a climatic adjustment to make when they are planted. Trees grown locally are better adapted to the outside variables that may affect their growth and survival (i.e. weather, insects, herbivores, and length of growing season) (Dorner, 2002). Bringing trees in from other states or regions heightens the potential for introduced pathogens and invasive species transfer (i.e. emerald ash borer, Asian longhorn beetle, wooly adelgid, and beech bark scale disease) (Inoue, 2010). Regarding willow species, locally collected willows may provide the best stock for a restoration site because they have evolved in the same region with the landscape, whereas most nursery willows are so hybridized it is difficult to identify or differentiate between species (A. Tursini, personal communication, July 29, 2008).

Care and handling prior to planting can have a tremendous impact on tree survival. For example, bareroot seedlings need to be planted as soon as possible after harvest, and if immediate planting is not possible these trees need to be watered and stored in a dark, and cool place until planting can commence.

The more outside variables planners can identify and minimize prior to tree planting the greater the chances of restoration success. Some restoration planners have already adjusted planting plans to include details on historic natural community, soil type, native species, prior land use, nursery provider, height of trees to be planted, tree planting technique (seed, bareroot, tubeling, container grown), date of planting, date of nursery pick-up, protection measures used, experience tree planters background, landowners involvement, and follow-up monitoring (F. Pendleton, personal communication January 7, 2010).

Results from this monitoring effort and more general field observations have encouraged restoration planners to take proactive steps to improve quality of tree plantings by providing a hands-on tree planting training session to all contracted (i.e. professional) tree planters to insure in hopes to reduce this variable as a factor in seedling survival (C. Smith, personal communication, December 6, 2010).

Restoration managers may want to consider only using tree tubes where reed canarygrass is established and or where known populations of meadow voles, rabbits, beavers, and deer are considerable or mowing from farmers and or trampling from livestock is likely. In sites where the added cost of these protection devices is an issue planners may want to increase plant density to heighten survival versus the use of protection devices. Similarly, using brush mats without tubes may offer enough protection from reed canarygrass while at the same time making the plant more visible to promote survival and not preclude tree height growth.

Although browse data was collected for this study, the data was inconclusive due to lack of detail in identifying specific browse types. The monitoring protocol had now been updated to include the amount of browse, location of browse, and species suspected of browsing. Our data found two most common types of browse (leaf browse from insects, and stem browse from deer). We noticed that leaf browse rarely influenced tree health, while the amount of stem browse appeared to have a greater impact on tree health. Unfortunately, this data could not be analyzed in this study, but is recommended for future monitoring and analysis.

Results demonstrate that increased girdling decreases chances of tree survival and tree tubes do not necessarily protect trees from girdling. Based on these results, restoration planners need to consider other forms of tree protection measures to impede girdling such as staining the trunk of the tree with a mixture of paint and sand (Materkowski, 2009). In addition, planters need to make certain that tree tubes are properly installed by burying the bottom portion a minimum of 1in in the ground.

Contrary to some research, which suggests that planting grass in buffers provides protection to tree seedlings by making seedlings more difficult to find and reducing environmental pressures like drought and wind (Stange & Shea, 1998). I found that many grasses including the invasive reed canarygrass actually outcompete seedlings and strangle them or make them more likely to be trampled in the future by concealing their location. Because invasion from reed canarygrass was potentially a common cause of seedling mortality, post planting restoration management in the form of invasive species control and general management is something planners should consider incorporating into landowner contracts. Additionally, invasive species could be controlled prior to planting as part of initial site preparation and as a preventative measure to help assure planted tree survival. Unfortunately, controlling these species requires lots of time, effort, and sometimes even repeated herbicide applications. If herbicides are needed this requires application by a licensed professional, and is not ideal adjacent to water (Holton and Plumb, 2010). The more trees we can keep alive during the first and second growing seasons will assure the long-term success of riparian restoration, and ultimately provide buffer corridors with healthy riparian forests.

Because we only began monitoring planted trees in 2008, it is necessary to monitor these projects for more years, while adding other baseline projects to develop stronger patterns of tree planting success and therefore provide more information to restoration planners. Unfortunately, monitoring for this study was only able to occur at each site once within the growing season. Trees that were monitored in May at the beginning of the growing season might have had very different results than trees monitored in late September. Although it is impossible for one monitor to visit all sites within the same timeframe, it is important to return to the same sites at the same time in the growing season each year. It is essential to monitor trees immediately following planting to record baseline condition, height, and location. Additionally, if at all possible this monitoring should be completed before the herbaceous layers has reached full height or after the herbaceous layer had died off to insure finding all trees that were planted. This data provides a strong foundation of restoration trends that should steer planners in the right direction to improve tree establishment success, and demonstrates that monitoring is a necessary component the restoration process, without which planners have no way of knowing whether they are achieving desired restoration results.

A standardized protocol has been created as a result of this monitoring effort and is available both as a word document with associated data spreadsheets and electronically to allow the general public and agencies to access an easy to use, assessment of riparian restoration methods (Appendix 1). The protocol has been and will continue to be shared with local watershed groups, landowners, and federal and state agencies. The compilation of this data gives planners a model for future restoration and identifies a protocol that is most effective for long-term monitoring.

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APPENDICES

Appendix 1: Riparian Revegetation Monitoring Protocol

Riparian Revegetation Monitoring Protocol

This protocol is designed for monitoring tree survival at riparian restoration projects. By setting up permanent transects and recording information about specific trees (species, mat, tube, etc.), we can return to the sites in the future to evaluate tree survival.

1) Before going to the field

A) Call FWS to get tree tags. Frank Pendleton (802) 872-0629 ext 13

B) Make a map of the project site, and decide how many transects you want. Transects run perpendicular to the stream, and should extend a few feet beyond the extent of the planted trees. The first transect should be at least 50 feet from the project boundary (Figure 1). A reasonable number of transects is 3 for a small site (1 acre) and 5 for a larger site. Transects should be at least 200 ft apart and equally distributed throughout the project area.

C) Make sure you have all the things you need on the check list included in the spreadsheet.

D) Determine what nursery the trees are from, and who planted the trees. If a planting plan is available it may have this information. The NRCS contact for the county may know this information or be able to refer you to someone. Be aware that trees ordered from one nursery may have been grown at another. For example, if I order trees from the Intervale and they don't have all the trees I want, they may order them from another nursery.

2) Transect set up

A) Pound a stake at each end of the transect and GPS the stake. Number each transects (1, 2, 3, etc) and write the number on the stake. Run a tape measure between the stakes and take a photograph along the length of the transect showing the tape (Figure 1).

B) Collect data on all trees within 10 feet of the tape (both sides) for the entire length of the transect. If planted trees are sparse, you should go beyond the 10 feet and count a minimum of 10 planted trees.

C) To prevent confusion, monitor all the trees on one side of the tape before going to the other side.

2) Data Collection

A) Place a tree tag at the base of each tree and take a GPS point. Place a measuring stick next to the tree and take a photo (Figure 2). It will help you keep track of photos if you take an occasional photo of a tree tag just before you take the photo of that tree.

B) Record the tree data (See 3. Description of Tree Variables)

C) Record any natural regeneration of trees and shrubs within 10 feet of the tape. Do not go beyond 10 feet for natural regeneration. Just record the variables that apply to natural regeneration (GPS Waypoint, Species, Height, Condition, Girdled, Browse, Notes)

D) If you don't have a GPS (they're cheap these days), draw a map as you go, realizing someone will try to get back to those same trees one day (See Map worksheet).

3) Descriptions of Tree Variables:

Tree ID: This is the number on the tree tag. It provides a unique ID for each plant.

Species: Use common names. Be as specific as you can, but just call it Unknown, Maple, Ash etc., if you can't tell exactly which species it is.

Planting technique: Bare root, tubling, seed, live stake, fascine, natural regeneration.
You may need to talk to the person who ordered or planted the trees to get this information. The NRCS contact for the county may know this information or be able to refer you to someone.

Mat: Yes/No

Tube: None / Blue-X / Yellow Mesh / Hardware Cloth / Hard Plastic / Other (describe in notes)

Height in inches: Measure to the highest leaves or buds (do not count dead leaders).

Condition: There are 6 categories based on % of live foliage (Figure 2).
-Vigorous (0-5%) of foliage damaged or missing.
-Healthy (6-25%)
-Moderate (26-50%)
-Unhealthy (51-75%)
-Very Unhealthy (76-99%)
-Dead (100%)

Girdled: This is most often caused by rodents eating the bark around the base of the tree. If they remove the bark from the entire circumference, the tree will die. This field only covers the percentage of the diameter that has been girdled; make a note if the girdling has affected more than two inches of the sapling's height.
10% classes (0, 1-10%, 11-20% etc.)

Browse: Note any browsing that has occurred. This is to help us get an idea of how much pressure the trees are getting from animals eating their leaves. Note if stems have been bitten off or if only leaves have been browsed. Also note if it looks like deer or insects. (Figure 3)
10% classes (0, 1-10%, 11-20% etc.)

Inches Below Tube: This field is just for trees that are shorter than the tube they are planted in. Measure from the top of the tube to the highest live part of the sapling.

Notes: Put any additional observations on an individual's health or status in the Notes field. For example, if a plant is mostly dead but has a few remaining buds, you might categorize that individual as Very Unhealthy (76-99%) and note that it was, "nearly dead with buds only."

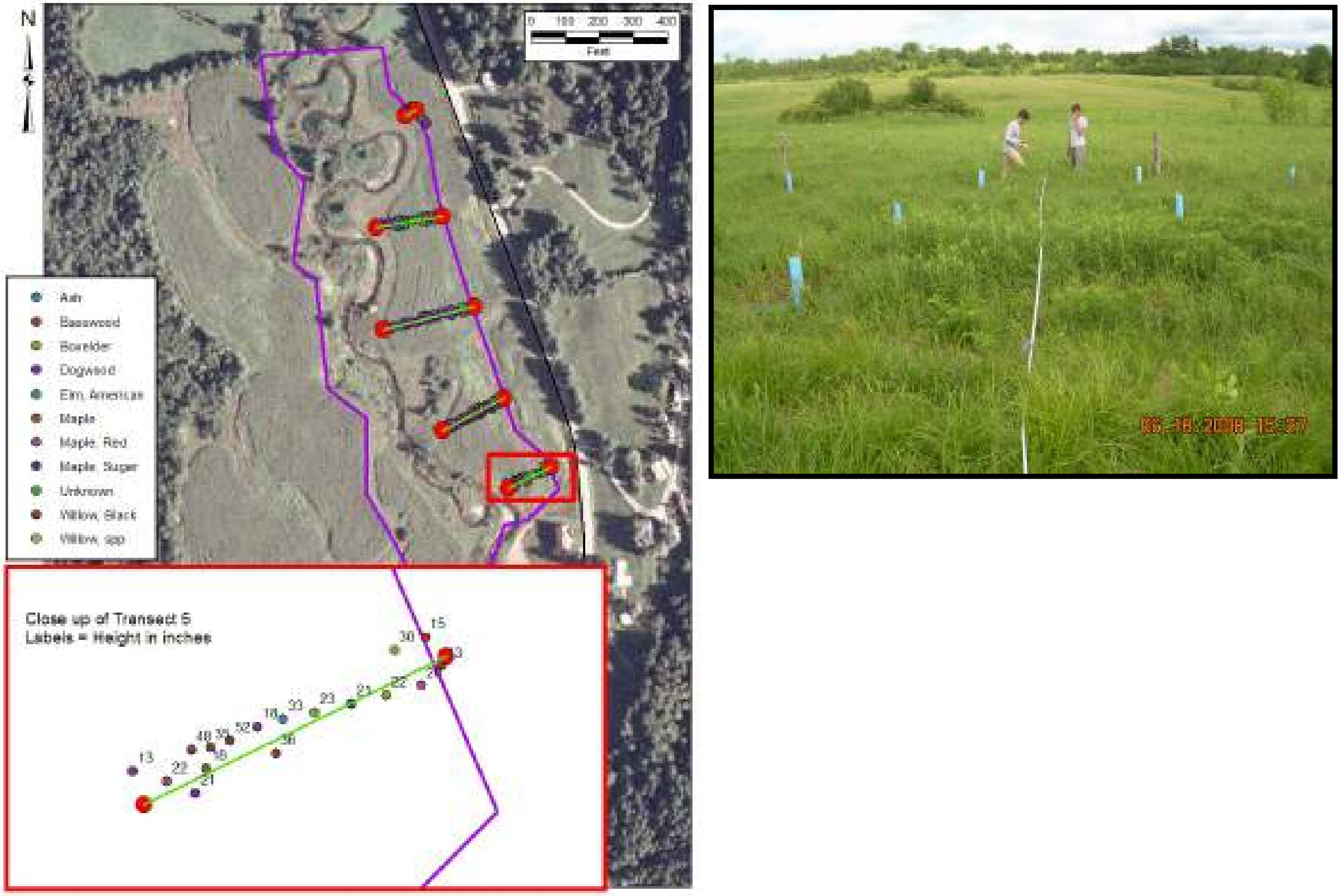

Figure 1: Aerial map showing project boundary, transect locations, transect close-up, and a photo of transect.

Vigorous (0-5% damage)

Healthy (6-25% damage)

Moderate (26-50% damage)

Unhealthy (51-75% damage)

Very Unhealthy (76-99% damage)

Dead (100% Damage)

Figure 2: Examples of Plant Condition

Girdled 100%

Girdled 50%

Stem Browse 100%

Stem Browse 50%

Leaf Browse (20%)

Figure 3. Photos of tree girdling and browse.