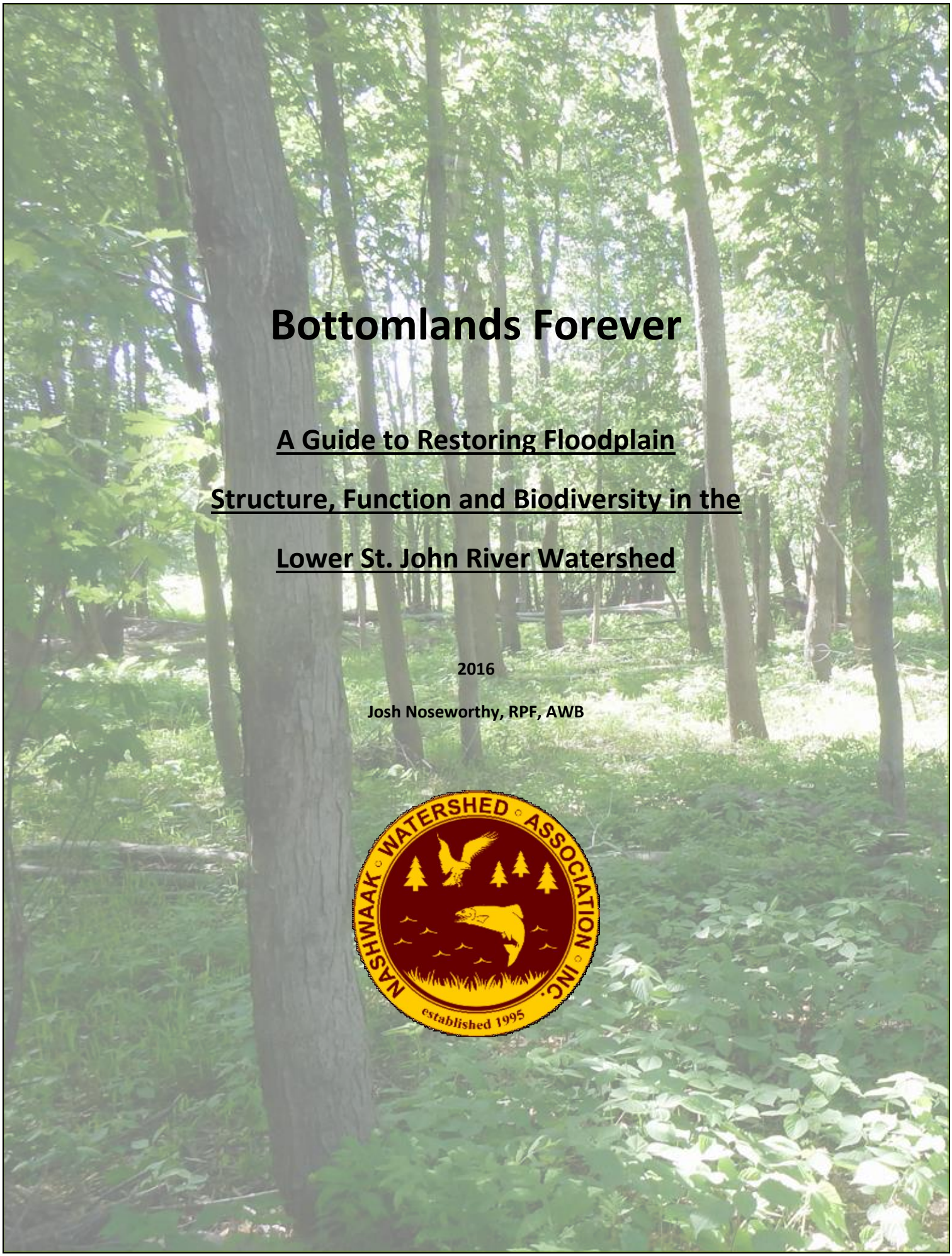

Bottomlands Forever

A Guide to Restoring Floodplain Structure, Function and Biodiversity in the Lower St. John River Watershed

2016

Josh Noseworthy, RPF, AWB

NASHWAAK WATERSHED ASSOCIATION INC.
established 1995

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Introduction

The Nashwaak Watershed Association Inc. (NWAI) is a registered non-profit organization that was founded in 1995. The NWAI aims to ensure the Nashwaak watershed is managed as a healthy ecosystem that balances a variety of economic, recreational, social and landowner interests. In doing so, the NWAI is committed to maintaining and restoring the structure, function, and biodiversity of the Nashwaak floodplain ecosystem.

It is estimated that up to 90% of the original floodplain habitat along the Nashwaak river was destroyed due to past and present land clearing for agriculture and development. Online satellite imagery suggests a similar pattern throughout the lower St. John River watershed. The unique forests that occur on floodplains in New Brunswick are highly threatened[1]. Floodplain forests are generally among the most converted and least protected ecosystems in northeastern North America[2], and yet they are known to be exceptionally biodiverse[3], potentially providing habitat for up to twice as many wildlife species as upland forests[4]. Numerous federal and provincial species-at-risk use these forests and other floodplain habitats for breeding, nesting and feeding, and they also provide a variety of important ecosystem services to local communities.

A backwater wetland on the Nashwaak floodplain in spring. Photo taken by the author.

As part of the commitment to floodplain protection and restoration, the NWAI has been actively planting trees on abandoned farmland for a number of years. As new information has become available, the restoration program has evolved to ensure that conservation principles are used to guide these practices. The following report was developed to synthesize these principles into best practices to restore floodplain habitat throughout the lower St. John River watershed, with emphasis on using only native species, of local genetic stock, whenever possible. The tools described can be used by land trusts, government agencies, watershed groups, or anyone who wishes to help conserve and restore this unique bottomland ecosystem. By disseminating this information, the NWAI hopes to increase awareness and support for bottomland conservation and restoration, for the benefit of wildlife and local communities throughout the watershed.

Stabilising Riverbanks

Restoration projects will often begin by stabilizing streambanks and riverbanks that have been cleared up to the waterline. Exposed banks are often subject to scouring and erosion, which not only has negative impacts on rivers and streams, but can also jeopardize restoration projects if banks are not stabilized. The following section provides a step-by-step procedure for stabilizing banks using native willows.

Red-tipped Willow (*Salix eriocephala*). Photo by Michael Rayner, CC by 4.0

Collecting and Processing. Although there are many types of native willow that can be used to stabilize banks, two species are recommended: Red-tipped Willow (*Salix eriocephala*) and Sandbar Willow (*Salix exigua*), both of which are common and grow vigorously within the watershed. Willow cuttings are best collected when they are dormant[5], such as in winter or early spring. Cuttings that are larger than 2cm wide at the base are recommended, because larger cuttings tend to take root much better than smaller ones[6]. Cuttings should be as long as possible when collected, and can be cut-to-length as needed when planting. All twigs and branches should be trimmed from the stem, and several inches off the top of the stem should be removed, which will encourage rooting instead of branching[5]. Cuttings can be cut at a 45° angle at the base to make planting easier, and as a way of marking the bottoms to ensure they are not planted upside-down. They can be bundled for transport, and stored in plastic in a dark, moist and cold environment, such as a snowbank[5]. Seven to ten days before planting in the spring, it is best to soak cuttings in water. This has been shown to stimulate root growth much quicker than without soaking[6]. For best results, cover them with water during this time, and to keep them well oxygenated, water can be replaced every few days[7].

The long, thin leaves of Sandbar Willow (*Salix exigua*). Photo by Susan McDougall, CC by 3.0

Grading the site. On high, steeply eroded banks, you may need to slope the soil to a shallower grade before planting willows, otherwise they may wash away during flooding. With care, banks

can be graded by hand, although silt fencing or some other means of keeping topsoil out of the river will be required. Willows will do best on a slope that is 2:1 (Figure 1[8]), but this will not always be possible to achieve, so aim to create grade as close to 2:1 as possible.

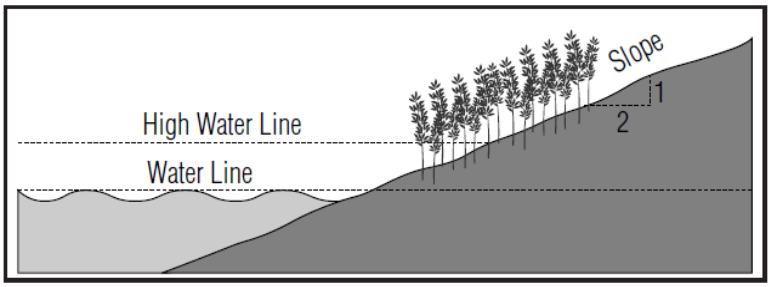


Figure 1. A 2:1 slope is ideal for willow planting, from OMNR (1995)[8].

Mowing. To prepare the site for willows, grass and other herbaceous vegetation should be mowed within 5m from the low water mark. Of course, take care not to kill any trees or woody shrubs that are already helping to hold the bank in place. It is best to mow herbaceous vegetation in the autumn. This will allow you to plant early in the spring the following year when the soil is still saturated, giving the willows a full growing season to expand their roots. If possible, mow multiple times in the summer and autumn to discourage herbaceous vegetation even more.

Planting. Willows can be planted as soon as the ground has thawed in the spring[7]. Since the water will be high, you may need to plant multiple times throughout the spring and early summer up to the low-water mark. It is suggested to plant willow stakes in a zig-zag pattern, approximately 1m apart[9,10] (Figure 2). On steep, eroded slopes, use a denser spacing of 0.5m apart, and plant stems both vertically and diagonally into the soil to better stabilize it[6]. A minimum of three rows should be planted, although five or more is suggested on bare soil or on sites that experience heavy erosion and ice scouring.

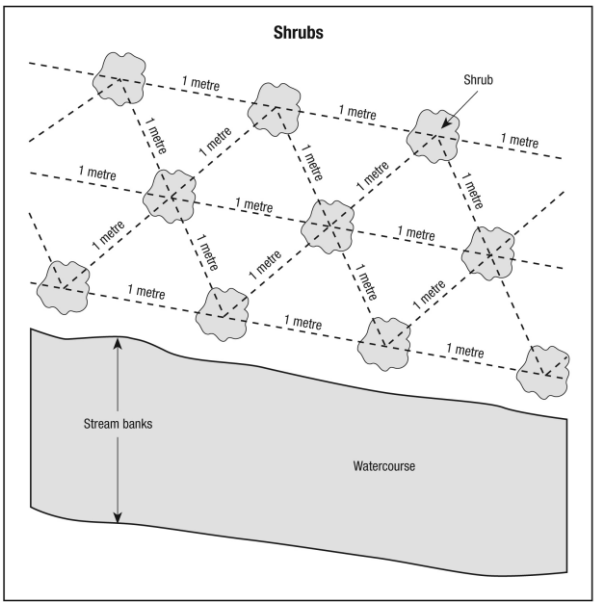


Figure 2. Suggested willow-planting design, from Bastien-Daigle et al. (1991)[10].

When planting, cuttings can be cut to length as needed, but should be at least 60cm long whenever possible[6]. As the prepared cuttings will be sharpened at the base, they can be pushed into the soil with heavy gloves, or hammered into the ground using a mallet. On steep, eroded banks, using large and long stems is recommended. In these areas, a piece of rebar can be used as a dibble to create a pilot hole[6]. Regardless of size, all cuttings should be buried at least ¾ of their length[6]. Tamp the soil around the planted cuttings, as any air pockets will kill new-forming roots.

Pruning. After stems have hardened off in autumn, it is recommended to prune between 1/3 to 1/2 of the planted cuttings. Pruning back to 5cm above the ground will encourage coppicing and root expansion the following spring[8]. Cuttings >2cm at the base can be saved and used in other stabilization projects.

Restoring Floodplain Forests

Floodplain forests throughout much of New Brunswick are typically dominated by Silver Maple (*Acer saccharinum*), alongside a variety of other tree species. The lower St. John River valley in particular harbours a unique assemblage of floodplain tree species found nowhere else in the Maritimes. Many of these trees reach their northern limit here[11], and are hundreds of kilometres away from their core populations (see Appendix A). In addition to the diversity of trees, a number of rare and at-risk tree species are associated with these floodplain forests, such as Bur Oak (*Quercus macrocarpa*), Black Willow (*Salix nigra*), and Butternut (*Juglans cinerea*). Floodplain forests provide habitat for a wide variety of wildlife, but also provide ecosystem services, such as erosion control, carbon sequestration, and flood prevention. Restoring these forests will most often involve site preparation and planting on old agricultural lands, but can also involve restoring forests that have grown up after improper logging on floodplains. The following section describes best practices for restoring these forests, including site preparation, planting, and tending in forests that have already established.

Butternut is federally designated as a Threatened species.

Site Preparation

Site preparation is done to prepare land for planting trees. Proper site prep is the most important aspect to establishing a forest on land that was cleared for agriculture, because dense sod and herbaceous field vegetation will discourage planted trees from reaching their full growth potential. The three types of site preparation discussed below are listed in order of least to most aggressive. It is generally recommended to prepare the site as aggressively as possible. This will be most effective at controlling competing field vegetation. However, it's recognized that this will not always be possible to do, particularly if areas are designated as Provincially Significant Wetland. In these areas, less aggressive techniques will have to suffice.

Mowing / Bush hogging / Mulching

Mowing and bush hogging are the most basic forms of site preparation. They can be used alone, such as when sensitive soils cannot be disturbed, or in preparation for more aggressive techniques. When mowing is the only form of site prep to be used, mowing multiple times in the summer and autumn will have the greatest effect of suppressing field vegetation. Mowing is also an important aspect of maintaining the site after planting. It is very important to maintain a mowing schedule for at least 3 years after planting[12]. This also helps to discourage rodents that would otherwise nest in dense grass and girdle young trees. Additionally, applying bark mulch in a 15-25cm radius around planted trees is an excellent way to supress herbaceous field vegetation, and can lessen the amount of mowing needed around individual trees[13].

Dense field vegetation on a Nashwaak floodplain that was cleared of forest in the past. Photo taken by the author.

Plowing and Disking

Plowing and disking is the preferred method for preparing agricultural land for tree planting[12]. Unless soils are too sensitive to allow machinery, plowing and disking should be a priority, as it has been shown to significantly increase the survival rate of planted trees on bottomlands. The method prepares the site for planting by (a) increasing soil aeration, (b) destroying competing vegetation, including deep-rooted perennials, (c) improving water infiltration, and (d) stimulating beneficial soil microbes[14]. Plowing and disking requires the use of machinery, which is not recommended in boggy soil, or near eroded banks. The method uses a plow to strip and overturn the compacted sod layer, followed by a disk harrow that cuts up and mixes the overturned clumps into the soil. Plowing and disking should occur to a depth that reaches below the compacted soil layer. In some cases, plowing and disking the site multiple times might be required on heavy clays or compacted ground. Investing in aggressive soil disturbance up front will almost always lessen the amount of weed control needed in the future.

Pit and Mound Creation

Although not considered an essential part of floodplain forest restoration, creating pit and mound topography can add structural complexity to the site, which can increase the diversity of wildlife that use it. Pit and mound topography naturally occurs in undisturbed forests as trees tip over from wind or ice. The upended root mass decomposes into a mound feature, which sits

adjacent to the associated pit. Artificially creating these features can create important habitat until the planted forest matures and undergoes the process naturally. This method of site prep can be used in addition to plowing and disking, or on its own, and requires machinery with a bucket or scoop. It is suggested to create pits and mounds a year before planting begins, to allow the mounds to settle. Below is the recommended number and size for pits and mounds, with the aim of covering between 10-15% of the restored area[15,16]:

Pit and mound restoration on abandoned farmland.
Photo taken from Trees Ontario, 2012[15]

- Approximately 150 pits / hectare that are 2 - 3m^2 in area and 15 - 20cm deep;
- Approximately 150 mounds / hectare that are < 1m high.

Planting

The NWAI currently plants bare-root stock that are grown in the NWAI nursery. Container grown or bare-root are the preferred stock for planting on floodplains. When digging holes, it is important to match the right size and depth to the root ball. Planting in holes that are too small or too shallow can result in root-bound trees that dry out. Conversely, holes that are too large or deep can create air pockets that will kill expanding root systems.

Freshly planted Silver Maple on a Nashwaak floodplain.
Photo taken by the author.

Generally, it is best to plant trees that are taller than 30cm, with sturdy stems and well-developed root systems[12]. However, trees that are taller than 1m, with well-developed root systems, will provide the highest rate of survival[17]. This is especially important if planting on sites that can only be mowed, and only trees >1m tall should be used in this case.

Blanket Planting

Blanket planting refers to planting open areas (such as a field) in a uniform spacing. Generally, trees should be spaced close together so that canopy closure occurs as quickly as possible. This not only shades out field vegetation, but also encourages the trees to grow upward, rather than turning into branchy, poorly formed stems[12]. Blanket planting should be spaced at 2m x 2m (2,500 trees / ha). However, if machinery is needed to mow, a 3m x 1.5m spacing (~2,200 trees / ha) can facilitate this. Planting in irregular or crooked rows is considered a best practice for restoration, as it more closely resembles natural forest succession.

Fill Planting

Fill planting is done in forests that are already established, either naturally or planted. One of the main benefits of fill planting is the opportunity to add less common tree species into the mix (see Appendix A), increasing tree diversity over time. Fill planting usually occurs in one of three scenarios:

1) Replacing dead trees on newly planted sites.

2) Planting canopy openings in existing floodplain forests.

3) Planting patches that are cut for the purpose of planting, in degraded forests or plantations (see patch cutting on page 10).

Fill planting is ideal in natural openings such as this one. Photo taken by the author.

Generally, most floodplain tree species cannot grow under the shade of a forest, and require partial sunlight to survive. However, it is not recommended to cut in floodplain forests. Instead, trees can be fill planted in natural canopy openings that permit sunlight to reach the forest floor. Since there will be shade from the surrounding forest for at least a portion of the day, spacing does not need to be as dense as blanket planting. A spacing of 3m x 3m (~1,100 trees / ha) is recommended when fill planting in mature forests. However, if replacing dead trees in areas that were freshly planted, continue to use the 2m x 2m spacing.

Tending

Tending refers to working in forests that have already established, either naturally or through planting. Tending is used either to promote any floodplain tree species that are already

present, or to create openings to fill plant when they are absent. The three tending treatments are pruning, crop-tree release and patch cutting.

Pruning

Pruning should be implemented on planted trees after their third growing season, and every 2-3 years afterward as needed[12]. This gives the trees adequate time to establish a healthy root system, which allows them to quickly recover after pruning. Although the spacing between planted trees should generally limit the need for pruning[18], if forking and branching is observed, pruning can improve growth and form significantly. The main priority of pruning is to remove multiple leaders, favoring the healthy, dominant one. If trees begin to sprout at the base of the stem, pruning these sprouts will also encourage upward growth, as opposed to having multi-stemmed trees that are bushy and poorly formed. It is recommended to prune in winter when trees are dormant.

Crop Tree Release

An optional treatment in planted areas is to select between 50 – 120 trees / hectare that will be designated as crop-trees[19]. Crop-trees can include rare tree species to ensure they reach maturity and produce seed, and also common species that have exceptional form and vigour. For example, it has been shown that a healthy Silver Maple can triple its wood volume in the 10 years that follow a crop-tree release[20]. This not only quickens the development toward mature forest conditions, but also reduces crowding amongst trees, and improves tree health and seed production. A crop-tree release is implemented using the crown-touch method (Figure 3), which removes adjacent trees that touch the crowns of crop-trees[21]. Crop-tree release is best used after trees reach an average diameter of 10cm or larger[22]. It is suggested to pre-select crop-trees once they reach this size, and implement a release when the crowns begin to compete with adjacent trees. When implementing a release in mature forest, it is suggested to use a mix of girdling and felling to create a diversity of snag and log habitat that will benefit wildlife (see Appendix B for details).

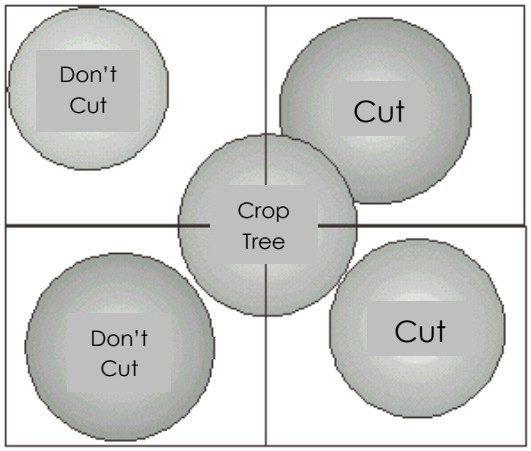


Figure 3. Crop-tree release.

Patch Cutting

In some cases, floodplain forests may have been cut and converted to conifer plantations, or replaced by early successional boreal tree species such as White Spruce (*Picea glauca*), birches

(*Betula* sp.) or poplars (*Populus* sp.). In other cases, abandoned agricultural land and clearcuts may grow back as alder thickets. In all cases, restoring floodplain forests will require cutting these areas in patches, and fill planting the patches with floodplain tree species. Since most floodplain tree species are intolerant of intense shade, these patches should be a minimum of 300m^2, but preferably larger. When implementing patch cuts in forested areas, it is suggested to use a mix of girdling and felling to create a diversity of snag and log habitat that will benefit wildlife (see Appendix B for details).

Restoring Wetlands

Restoring wetlands on floodplains refers to creating vernal pools on past agricultural land. Vernal pools are seasonal wetlands that are recharged with floodwater each year. They are naturally small, shallow, and disconnected from the river after flooding subsides, which means they rarely support fish. This makes them very important breeding and foraging habitat for a variety of wildlife, including turtles, amphibians, invertebrates, waterfowl and wading birds[23]. Although labour intensive, creating vernal pools as part of floodplain restoration can provide enormous benefits to wildlife.

Wood Turtle (*Glyptemys insculpta*).
Photo by Alain Belliveau.

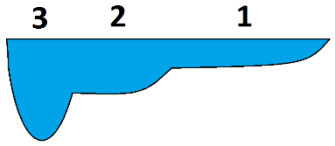
Bottomland vernal pools were commonly filled in and leveled when converted to agricultural land[24]. Light green depressions in old fields are a good indication that there was once a vernal pool before the soil was tilled, and these areas are good starting points for restoration. Using earth-moving machinery, a vernal pool can be dug to meet the size and shape of the depression. If there are no indicators like this on the restoration site, vernal pools can be created in low-lying areas. Since the process will require earth-moving machinery, it is best to create vernal pools when the soils have dried.

The light green vegetation represents a wet depression where sedges have colonized instead of grasses. This area was most likely a vernal pool before the land was cleared and tilled. Photo taken by the author.

The recommended steps for constructing vernal pools are as follows:

1. If there are no wet depressions with an obvious boundary, choose a low-lying area and stake out the shape and size of the pool to be excavated. Vernal pools are generally larger than 400 m^2 (~0.1 acres), but less than 4,000 m^2 (~1 acre)[25]. Although any shape can be used, irregular shapes have greater edge perimeter, which can provide more habitat than circular shapes of the same area.
2. Remove all sod and topsoil from the target area and pile it nearby. Once the vernal pool depression is completed, the topsoil can be spread back into the depression to add nutrients and organic matter. Sod can be piled to create mound features.
3. Excavate a depression in the subsoil that is no more than 1m deep at the deepest point. A suggested configuration is to use three different depths, which will provide habitat for a wider array of wildlife than a single depth[26]:

Tier	Depth (cm)	Area Covered (%)
1	15	50
2	40	30
3	100	20



Cross-section of a suggested vernal pool tier configuration

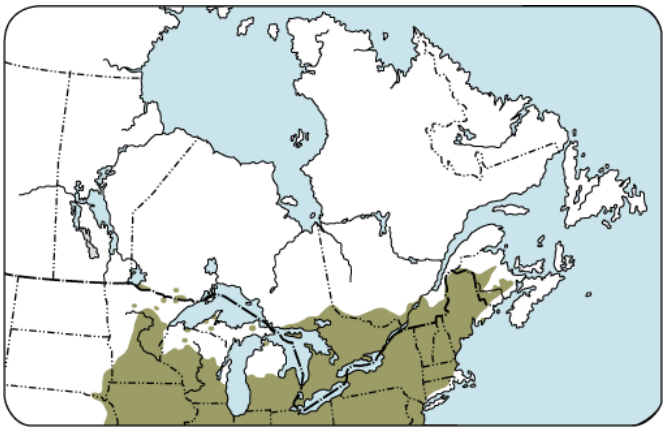
4. The perimeter of the pool should be graded to a 1:4 slope or shallower[27]. This provides a gradual entry / exit for amphibians, turtles and other smaller wildlife.
5. The sod and subsoil that is removed from the depression can be used to create mounds that will add structural diversity to the site. Linear mounds between 15 – 60cm high can be placed along the lower edge of the pool to encourage water storage for longer periods[26]. Any extra subsoil can be mounded elsewhere.
6. Once the depression is completed, spread a layer of topsoil evenly throughout the excavated area.
7. Willow stakes can be planted around the perimeter and on mounds to stabilize the soil and create edge habitat. It is recommended to plant trees beyond the willow stakes soon after completing construction for long-term stabilization.
8. Although there is no set number of wetlands that should be created per unit area, it is generally recommended to cover between 10 - 15% of a floodplain restoration project in wetland habitat[26]. In some cases, wetland creation may not be necessary because natural wetlands already meet this area target. However, as stated before, much of this habitat was destroyed when the land was cleared for agriculture in the past, and where indicators suggest their former extent, these wetlands should be restored. The total number of wetlands that are created will depend on the amount of area needed to meet the 10 - 15% target, and the size of the wetlands being created.

A vernal pool on the Nashwaak floodplain. Note the mound on the left bank and the shallow grade on the right bank. Photo taken by the author.

Appendix A: Floodplain Trees of the lower St. John River watershed

Silver Maple (*Acer saccharinum*)

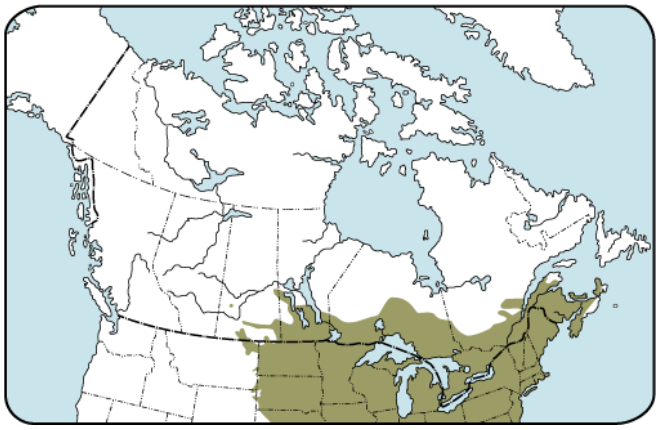
Silver Maple is the dominant tree in the floodplain forests of the Nashwaak watershed, and is the most flood-tolerant of all the native tree species in New Brunswick. NB represents the most northern limit to this species range in North America[28]. Unlike most tree species, Silver Maple produces seed in spring rather than autumn, which allows them to be distributed in flood waters, and also provides an important early food source for a variety of wildlife. They are fast growing, hardy, and can survive across a range of soil moisture conditions, making it an ideal species to blanket plant when restoring floodplain forest. Silver Maple is particularly susceptible to sprouting, and may need to be pruned more often than other species.



Silver Maple range (Natural Resources Canada, Canadian Forest Service).

White Elm (*Ulmus americana*)

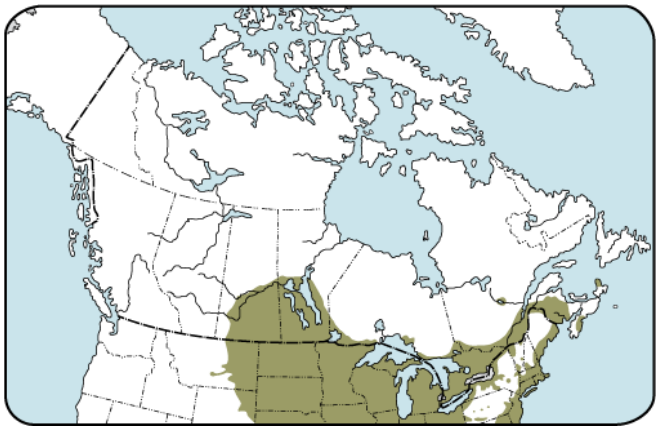
White Elm was once abundant throughout the floodplain forests of eastern Canada, but has declined due to the exotic Dutch Elm disease. Because of the disease, White Elm is considered a species of conservation concern in New Brunswick[29]. However, resistant strains are becoming available, and in the future, it is expected that resistant genetic stock from within the St. John River watershed will be available. If / when this occurs, emphasis should be placed on restoring this species throughout the watershed. Like Silver Maple, White Elm can also withstand significant flooding, and produces seeds in spring to take advantage of flood waters for dispersal. If growing White Elm for restoration purposes, it is recommended to collect seed from live, healthy trees that are >65cm wide at the base, as these trees would have existed before the disease was introduced, and may be resistant[30].



White Elm range (Natural Resources Canada, Canadian Forest Service).

Red Ash (*Fraxinus pennsylvanica*)

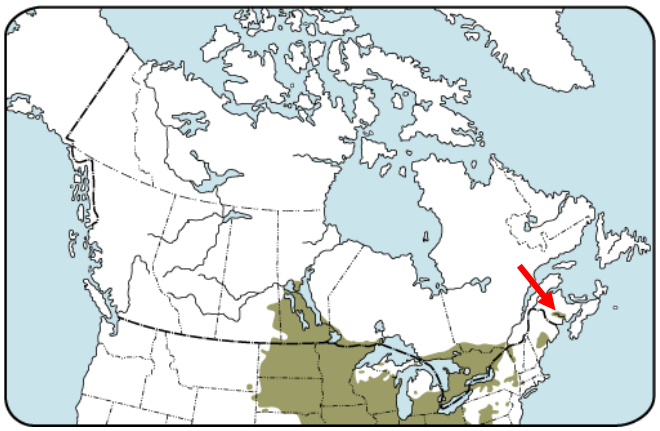
Also considered a species of conservation concern in New Brunswick[29], Red Ash (also known as Green Ash) has a limited distribution in the Maritimes. Red Ash can withstand weeks of flooding, and can grow across a range of floodplain soil conditions, from sandy shorelines, to deep alluvial clays and loams[28]. In the lower St. John River watershed, it has also been observed colonizing old fields next to rivers, which may make it particularly good for restoration purposes. As an early and prolific seeder, Red Ash provides an important food source for a variety of wildlife. The Emerald Ash Borer, an invasive insect moving east towards New Brunswick, may further threaten Red Ash. If the borer does reach the Maritimes, it will be important to identify any trees that may be resistant to the insect. Seed from any potentially resistant trees should be collected and propagated for restoration.



Red Ash range (Natural Resources Canada, Canadian Forest Service).

Bur Oak (*Quercus macrocarpa*)

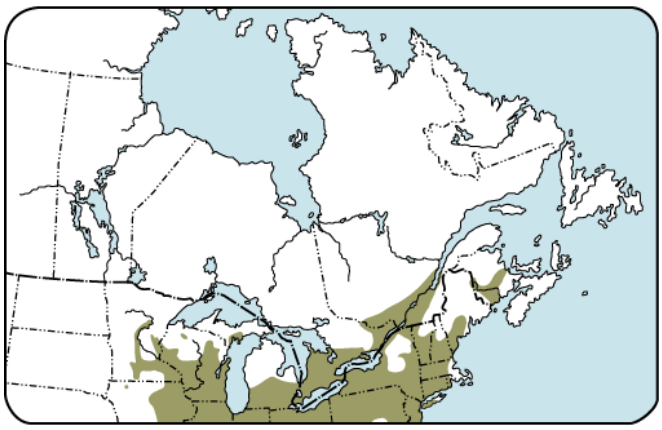
In the Maritimes, Bur Oak is restricted to the lower St. John River watershed, and is not found again until southern Maine. Because of this restriction and the loss of habitat from land clearing in the past, it is considered a species of conservation concern in New Brunswick[29]. The population of Bur Oak in New Brunswick continues to shrink as waterfront property is cleared, and restoration has been suggested by scientists from the Canadian Forest Service[31]. Bur Oaks over 400 years old have been recorded to still produce acorns[28], which are an excellent source of food for both people and wildlife. Bur Oak can be planted throughout the flood zone, but will do best in areas that are flooded for less than 2 weeks during the growing season[28]. If planting Bur Oak for restoration purposes, it is very important to use only genetic stock from within the St. John River watershed to maintain local genetic diversity[30].



Bur Oak range (Natural Resources Canada, Canadian Forest Service).

Butternut (*Juglans cinerea*)

Butternut is an endangered species in Canada[32], and a species of conservation concern in New Brunswick[29]. One of the biggest threats to Butternut is the Butternut Canker – an exotic fungal disease that has infected all known populations. Although there has been preliminary success in locating and breeding resistant trees in the United States[33], resistance has not yet been found in the New Brunswick population. If resistant trees are found, emphasis should be placed on restoring this species throughout the floodplain forests of the watershed. Although it can withstand some flooding, it is best planted in the upper edge of the flood zone on well drained soils. When planting, care should be taken to minimize root stress, as seedlings will form a tap root followed by a deep and widespread root network that can be easily damaged.



Butternut range (Natural Resources Canada, Canadian Forest Service).

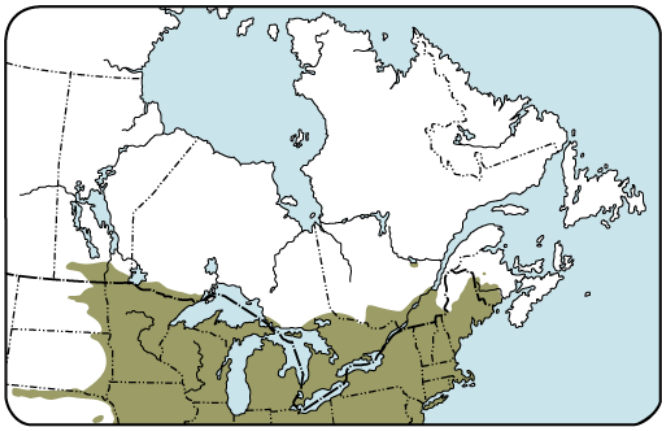
Black Willow (*Salix nigra*)

Within the Maritimes, Black Willow is only found in the lower St. John Watershed, and is not found again until southern Maine. Even within it`s range, which includes all watersheds south of the Keswick River, it is uncommon, making it a species of conservation concern in New Brunswick[29]. Black Willow prefers wet soils but cannot tolerate shade, so it is best to plant along the rivers edge, or in open areas along backwater wetlands and oxbows. Black Willow can be easily propagated from cuttings, and is ideal for streambank stabilization under the right growing conditions. It is commonly used for this purpose in the central United States[34]. For restoration, it is important to use only genetic stock from within the St. John River watershed to maintain local genetic diversity. It is also important to note that Black Willow looks very similar to Crack Willow (*Salix fragilis*) - a non-native species in New Brunswick.

Black Willow range (Natural Resources Canada, Canadian Forest Service).

Basswood (*Tilia americana*)

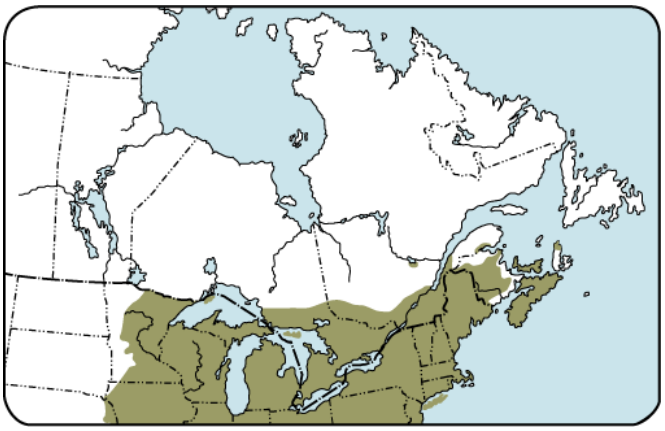
In the Maritimes, Basswood is generally restricted to rich soils in southwestern New Brunswick, making it a species of conservation concern in the province[29]. Although not strictly a floodplain species, the rich, moist but well drained soils that Basswood requires are generally found on the upper edges of floodplains within the lower St. John River watershed. Although very nutrient demanding, Basswood has been successfully planted on abandoned farmland in Ontario where proper site preparation and weed control was maintained[28]. When planting, care should be taken to minimize root stress, as seedlings will form a tap root up to 20cm long during their first year's growth. Basswood is also a vigorous sprouter, and may need to be pruned more often than other species.



Basswood range (Natural Resources Canada, Canadian Forest Service).

Red Oak (*Quercus rubra*)

Although not considered a floodplain species, within the lower St. John River watershed, Red Oak is commonly found along the upper margins of the flood zone. Red Oak grows best on deep, well-drained soils, but can tolerate a range of soil moisture and nutrient conditions[28]. Similar to Bur Oak, it appears that Red Oak can also withstand minor flooding, making it ideal for restoring transitional areas between floodplain and upland forests. Red Oak may also be an ideal species to plant on floodplains that are influenced by estuarine conditions, as salt-tolerance has been observed in some New Brunswick populations. Red Oak has successfully been planted on abandoned farmland[12], but competing vegetation must be aggressively controlled. When planting, care should be taken to minimize root stress, as seedlings will rapidly form a tap root that that can be easily damaged.



Red Oak range (Natural Resources Canada, Canadian Forest Service).

Appendix B. Structural Diversity.

When implementing restoration in areas that are already forested, it is important to create deadwood habitat, which is a recognized approach to promoting biodiversity in general[35]. Deadwood is created as snags and downed logs, although emphasis should be placed on creating snags, as these will become downed logs over time, and fill the ecological role of both.

Snags

Girdling is used to create dead standing trees (*i.e.* snags), which provide critical habitat for a variety of wildlife. When selecting trees to be removed during crop-tree release or patch cutting, girdle approximately 30 trees per hectare that are >25cm in diameter where possible[36]. Additionally, having at least one snag per hectare that is >50cm in diameter is ideal[37]. In many cases, meeting these criteria may not be possible, so as a general rule, large trees should be favored over small trees when creating snags. For information on different tools used for systematic tree girdling, see the USDA publication *Tree Girdling Tools*[38]. When girdling, the following guidelines should be followed:

- The girdle should consist of a single or double band around the entire stem, with a minimum width of 2cm per band that removes the bark and cambium layers entirely.
- The girdle should occur below the lowest live limb on the stem.
- A tree should not be girdled if it is within tree-length of an access road or trail.

Downed Logs

Felling trees is the typical method of implementing silviculture, and will be the dominant form of deadwood created during restoration treatments. In addition to smaller trees that are cut during treatments, it is recommended to create downed logs that are >30cm in diameter where possible[39]. Similar to snags, large trees make the best habitat, so if these size criteria cannot be met, try to fell at least 10 of the largest logs per hectare that are >2m in length[37].

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