Riparian Ecology and Restoration in Eastern Canada: A Literature Review

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1.0 INTRODUCTION

In order to formulate accurate and robust restoration targets for riparian zones in disturbed areas (e.g., agricultural grazing fields), it is necessary to sample regional reference sites to determine the vegetation composition of natural or undisturbed riparian ecosystems. The data from these field samples can then be used to identify a set of vegetation restoration targets. As the first step towards this objective, this literature review addresses riparian ecology and restoration within eastern Canada with a focus on vegetation and an emphasis on Ontario.

2.0 METHODS

A number of internet-based literature searches were conducted in order to collect relevant information in the form of papers published in journals, technical reports, and government manuals. For searches using the *Web of Science*, the search term "riparian AND Ontario" from 1980 onward was used, and the search term "riparian AND Canada" from 1990 onward was used. The following search terms were applied to both *Google Scholar* and *Google* searches: (1) "riparian Ontario" and (2) "riparian temperate". The term "riparian" was also searched on the websites for the following journals: *Journal of Applied Ecology*, *Restoration Ecology*, *Journal of Applied Vegetation Science*, *Ecology*, *Ecosphere*, *Ecological Applications*, *Conservation Biology*, *Biological Conservation*, and *Plant Ecology*.

Websites for the following provincial resource management organizations were also searched: Ontario conservation authorities, Ministry of Natural Resources and Forestry (MNRF), and the Ministry of Environment and Climate Change (MOECH). Since the federal government has very little regulatory power over provincial resource management activities, those agencies were not included in this systematic search. However, a few federal publications were found to be relevant to this study particularly some research conducted by the Canadian Forest Service and wildlife protection guidelines prepared by the Canadian Wildlife Service.

3.0 RESULTS

More than 400 documents including peer-reviewed journal articles and technical papers were obtained and evaluated for this literature review. Of these, 79 were found to be relevant to the objectives of this report, which has two main sections: part one addresses riparian vegetation ecology and part two deals with riparian restoration targets. Part one includes both government guidance documents and research papers produced by government scientists (provincial and federal), academic scientists, and scientists associated with non-profit natural resource conservation organizations. Many relevant papers from around the world are available, however the geographic focus for this study was eastern Canada, which is defined here as the region from the east coast of Canada to the western boundary of Manitoba.

3.1 RIPARIAN VEGETATION ECOLOGY AND MANAGEMENT

Both the Ontario provincial government and the Canadian federal government have produced guidance documents that address the ecology and management of riparian ecosystems. In addition, both levels of government have carried out research that focuses on the ecological, management and policy aspects of riparian zones. Universities and non-profit conservation organizations throughout eastern Canada have also investigated riparian ecology and management.

3.1.1 Ontario Provincial Government Guidance Documents

A total of 16 guidance documents addressing riparian ecosystems produced by the Ontario Ministry of Natural Resources and Forestry (OMNR) were found in this study. The only other guidance document found that included riparian ecology and management was produced by the Ontario Ministry of Agriculture and Food (OMAF) in partnership with the Ontario Cattlemen's Association and the Ontario Federation of Agriculture.

Ontario Ministry of Natural Resources and Forestry

In total, the 16 OMNR documents that provide guidance for resource management activities or that provide resource assessments, and are most relevant to riparian ecology and management were searched for their use of the term "riparian" using the Adobe pdf search function (see Appendix A). The five different contexts or uses of the term riparian are defined in Appendix A.

Of these documents, 11 had two or fewer instances of the term riparian and these uses did not include any reference to either secondary or primary data or information (see Appendix A). The only provincial guidance documents that addressed riparian ecosystems at a significant level (defined here as at least 16 instances) included the following five documents (from most to least instances). Primary data here is defined as field data collected and presented by the author of the publication.

- OMNR. 2010a. *Forest Management Guide for Conserving Biodiversity at the Stand and Site Scales – Background and Rationale for Direction*. (141 instances)

This document cites 30 field studies (secondary sources) that have addressed riparian ecology and management. Most of these field studies were not conducted in Ontario. No information addressing plant species composition or age-class structure in riparian ecosystems is provided in this document and no primary data are presented.

- OMNR. 2010b. *Natural Heritage Reference Manual*. (92 instances)

Most of the use of the term riparian in this document is in the context of management prescriptions and reference to secondary sources (scientific literature) to establish the need for riparian buffers. There is no consideration of plant species composition or age-class structure in riparian ecosystems; no primary data are presented.

- OMNR. 2000. *Significant Wildlife Habitat Technical Guide*. (19 instances)

Most of the uses of riparian in this document are descriptive as an adjectives. There are three instances where riparian is used relative to management prescriptions. No primary data are presented.

- Uhlig, P. 2009. *Ecosites of Ontario: Great Lakes-St. Lawrence Forest Region, Operational Draft*. (17 instances)

The following provides a summary of the evaluation of this document. No primary data related to riparian ecosystems is presented.

(a) total of 224 ecosites in the Great Lakes-St. Lawrence Forest Region (GLSL)

(b) no listing and definition of "riparian" in glossary

(c) no riparian ecosite types

(d) 17 ecosites that may occur in riparian zones

(e) the only riparian-related term defined is "shoreline" and only relative to large bodies of water; those not defined include beach, bluff, and coastal

(f) there are 38 coastal and shoreline types including the following: excavated bluff, active bluff, open bluff, bluff, active mineral shoreline, active bedrock shoreline, bedrock shoreline, open bedrock shoreline, active talus or historic/raised beach, talus or historic/raised beach, open talus or historic/raised beach, anthropogenic coarse shoreline, active coarse shoreline, coarse shoreline, open coarse shoreline, calcareous active bedrock shoreline, calcareous bedrock shoreline, calcareous open bedrock shoreline, calcareous active talus or historic raised beach, calcareous talus or historic raised beach, calcareous open talus or historic raised beach, calcareous anthropogenic coarse shoreline, calcareous active coarse shoreline, calcareous coarse shoreline, calcareous open coarse shoreline, active coastal cliff, open coastal cliff, coastal cliff, active coastal bedrock shoreline, open bedrock coastal shoreline, coastal bedrock shoreline, coastal bedrock shoreline, active coastal bedrock shoreline, open coastal bedrock shoreline, coastal coarse shoreline, active coastal bluff, coastal bluff, active coastal mineral shoreline

The 17 instances of the term riparian in this document are associated with the GLSL ecosites that may be found in riparian zones. Note that both swamp and fen are defined as wetlands in this publication; the instances are numbered below.

Conifer Swamp

1 - organic poor conifer swamp
2 - mineral poor conifer swamp
3 - organic intermediate conifer swamp
4 - mineral intermediate conifer swamp
5 - organic rich conifer swamp
6 - mineral rich conifer swamp

Hardwood Swamp

7 - intolerant hardwood swamp
8 - maple hardwood swamp
9 - oak hardwood swamp
10 - hardwood swamp

Thicket Swamp

11 - mineral thicket swamp
12 - organic thicket swamp
13 - sparse treed fen

Fens

14 - open moderately rich fen
15 - open extremely rich fen
16 - open shore fen
17 - shrub shore fen

- OMNR. 1998. *Code of Practice For Timber Management Operations In Riparian Areas*. (16 instances)

In this document, the term riparian is used both as a descriptive adjective and in reference to management guidelines. On page 1, it is stated that the riparian zone "is the most productive environment in the forest". There is no reference to secondary or primary information in this document.

Ontario Ministry of Agriculture and Food

The publication, *Best Management Practices: Buffer Strips* (Lane 2011) primarily addresses environmental aspects of agricultural practices in southern Ontario. It provides a definition for riparian zone, addresses the values of riparian zones, describes the impacts of agriculture on riparian areas, and provides a number of management practices designed to minimize or eliminate human impacts to riparian areas and associated water bodies.

This guidance document also identifies and briefly describes seven types of riparian zones as follows.

- *Upper Reaches, Narrow Channels* - narrow shallow valleys and deep channels; soil types range from fine sands to clays; sand and clay plains; in agricultural areas, riparian vegetation consists mostly of grassed pastures and croplands; in areas with natural vegetation, riparian areas consist of lowland deciduous trees, lowland conifers, shrub-meadow mix, and marsh/swamp plants

- *Upper Reaches, Wide Channels* - dominated by rolling landscapes, rivers with steeply sloping valleys, and medium-width shallow channels; bank and bed materials are usually cobbly or bedrock controlled; typical soils are stony or gravelly sandy to loamy soils; in central, eastern, and northern Ontario, these areas are often shallow to bedrock; in southern Ontario, these landscapes can be dominated by loamy soils; in agricultural landscapes, the riparian area is dominated by natural or nearly natural vegetation; nearly natural settings have pasture species, shrubs and trees; forest cover dominates the natural vegetation, ranging from deciduous in the south (oak-ask-hickory), to mixed conifer-deciduous in the near north (maple-beech-pine-hemlock), to jack pine-red pine-black spruce in the north

- *Middle Reaches of Rivers* - riparian areas in the middle reach zone of rivers have steep valleys and broad floodplains; the valleys have slopes over 10%; slopes are even steeper through clayey soils or bedrock faults (gorges); the floodplains are often wide (30 - 500 m), with shallow meandering channels; soils are highly variable; valley vegetation is often upland forest or pasture; natural floodplain vegetation is a combination of meadow, wetland and forest species

- *Lower Reaches of Rivers* - riparian areas of the lower reach (near the mouth of the river) consist of shallow valleys, a wide channel, broad floodplains, and delta islands and braided streams at the river mouth; soils consist of silty and fine sand materials; natural vegetation is most often grass and wetland species, with small pockets of ravine forest; local landscapes are often level and highly productive

- *Lakes: Beaches, Bluffs and Bedrock-Controlled Shorelines* - beaches are usually found in lake bays and they consist of sandy, gravelly, and stony materials; bluffs are shorelines with sizeable elevation drops, some are formed from bedrock, others are formed from silty and clayey materials; bedrock-controlled shorelines are dominated by forest cover in uplands and wetland vegetation in lower areas

- *Wetlands and Natural Ponds* - riparian vegetation is also found around wetlands and ponds, and wetlands can be found in riparian areas; the main types of wetlands include fens, bogs, swamps and marshes; riparian vegetation around ponds closely matches nearby wetland vegetation

- *Constructed Watercourses, Drains and Channelized Streams* - these are open drains or channelized streams designed and constructed to convey water from tile-drained lands, field surfaces and upstream surface waters; normally these watercourses have steep banks, shallow channels and no valleys; for most of these watercourses, riparian vegetation is restricted to grassed buffer strips and banks, trees are occasionally planted to provide shade and soil stability; they are prone to bank erosion

3.1.2 Ontario Provincial Government Research

Only two riparian studies published by Ontario provincial scientists (OMNR) were found during this literature review and neither provided primary or secondary information about plant species composition or age-class structure in riparian ecosystems. McLaughlin (2009) investigated nutrient cycling in a forested swamp and compared it to to an alder swamp in riparian zones of a boreal mixedwood landscape in northern Ontario.

Naylor et al. (2012) provided some examples of how science-based knowledge was used to plan and implement clearcutting within riparian forests. They promote the use of this approach for clearcutting riparian forests throughout central and northern Ontario. Table 2 provides an overview of the types and amount of logging allowed in riparian areas on crown land in Ontario.

3.1.3 Non-Government Research – North Bay-Mattawa Region of Ontario (~100 km radius)

Riparian ecology research in the North Bay-Mattawa region has been carried out by the North Bay-Mattawa Conservation Authority (NBMCA), Nipissing Forest Resource Management, and Ancient Forest Exploration & Research. These studies are addressed in the following sections.

North Bay-Mattawa Conservation Authority

Martens (2012) carried out a field study of disturbed riparian areas to investigate and document physical land use characteristics of the watersheds entering into Callander Bay and to identify potential sources of phosphorus and other nutrients that could be contributing to poor water quality. No vegetation sampling was conducted during these assessments.

In 2013, Stantec Consulting Ltd. produced the NBMCA *Integrated Watershed Management Strategy: Technical Background Report*. There are five instances of the term "riparian" in this report. Management prescriptions for riparian areas are found in only one instance (pg. 255) where it is stated that, "Chisholm intends to apply East Ferris policies to Mink Lake and Lake Nosbonsing as these water bodies are primarily within the jurisdiction of the municipality of East Ferris. A 30 m setback will generally be applied along these waterways to protect riparian vegetation." There are no references to the scientific riparian literature and no primary riparian information is presented.

The NBMCA (2014) *Source Water Assessment* report states that roughly 80% of the Source Water Protection Area (SP Area) is forested with the following dominant tree species: Red Pine, Eastern White Pine, Eastern Hemlock, Yellow Birch, Maple species, and Red Oak. The distribution of terrestrial and wetland land cover classes includes the following (from most to least abundant).

- Mixed Forest (37.3 %)
- Deciduous Forest (28.6%)
- Coniferous Forest (9.5%)
- Sparse Forest (4.3%)
- Treed Bog (2.3%)
- Open Bog (0.1%)
- Treed Fen (0.1%)
- Cutovers (0.3%)
- Burns (<1.0%)
- Bare Rock Bedrock Outcrop (0.1%)

Development in the SP Area including residential and agricultural activities has often resulted in alterations to shoreline (riparian) areas. Large portions of the SP Area are unpopulated with riparian areas in their natural state, however, these areas have not been surveyed. This report states that if a 100 m strip along every shoreline were to be identified as a riparian buffer, it would amount to almost 15% of the SP Area.

In the *NBMCA Integrated Watershed Management Strategy* (Stantec Consulting Ltd. 2015), the NBMCA listed the definition, identification, and evaluation of riparian areas as a priority for the entire SP Area. In addition, "priorities suggest that the greatest need is for improved mapping and monitoring." There are no references to the scientific riparian literature and no primary riparian information is presented.

Nipissing Forest Resource Management

In the report addressing High Conservation Values in the Nipissing Forest, Street et al. (2014) address the management aspects of riparian forests in the Nipissing Forest region as follows.

- "Riparian forests play a critical role in maintaining fisheries by providing bank stability, sediment control, nutrient inputs and microhabitats... [and that] Forest management activities in riparian areas on the NF are implemented in a way to minimize harmful alteration or disruption of fish habitat."

- "...protection of fisheries resources in forest management planning relies primarily upon Area of Concern planning which deals with erosion potential and watercourse disruption protection measures along with access restrictions on self-sustaining lake trout and brook trout lakes".

- "...at this time, there are no identified important [riparian] production areas that warrant increased protection from forest operations that are not already addressed in the current planning approach".

They also describe the habitat for numerous species-at-risk that have associations with riparian zones. However, they do not cite any published literature addressing riparian ecosystems and they do not provide any primary riparian vegetation information.

Ancient Forest Exploration & Research

A number of field studies focusing on riparian ecology in the Temagami region were supported by Ancient Forest Exploration & Research from 1990 through 2001. The first of these studies was conducted by Giroux (1994) for his Master's thesis at Trent University. He collected terrestrial and aquatic data at 49 stream locations to identify relationships between disturbance and three landscape components including riparian vegetation, stream chemistry, and stream invertebrate communities in old-growth Red and Eastern White Pine Forests located in the Temagami region of Ontario. He identified the following features of the riparian zone (up to 20 m from the stream bank) in these old-growth Red and Eastern White Pine forests.

- From most to least abundant, the following overstory tree species were found in the riparian zone: Eastern White Pine, Red Pine, Northern White Cedar, Black Spruce, White Spruce, Balsam Fir, Yellow Birch, Jack Pine, Poplar, Red Maple, and Cherry spp.

- From most to least abundant, the following understory plant species were found in the riparian zone: Balsam Fir, Red Maple, Alder spp., Yellow Birch, Black Spruce, Cherry spp., Black Ash, White Spruce, Blueberry spp., White Birch, Honeysuckle, White Pine, Red Pine, Beaked Hazelnut, and Jack Pine.

- Although understory plant biomass in the riparian zone was lowest in the old-growth condition compared with three younger forest stand categories, plant species richness in the riparian zone was highest in the old-growth condition compared with the other age categories.

- Understory plant biomass in the riparian zone was highest around stream riffles compared with stream pools, however, understory plant species richness in the riparian zone was highest around stream pools compared with stream riffles.

Later, in 1999, Quinby et al. produced a technical report describing plant community composition in a riparian zone at the east end of Blueberry Lake in Temagami. The following results were obtained from this study.

- A total of 63 plant species were found within 32 m of the stream bank.

- Of these 63 species, the abundance of 25 species (40%) was significantly correlated with distance from the stream bank (Table 3).

- Of these significant correlations, 18 species (29%) showed an decrease in abundance with increasing distance from the stream bank (Table 3).

- Of these 18 species, the presence of 14 species terminated prior to the 32 m point (Table 3), however, four plant species did not.

- The woody plant species associated with the riparian zone included Black Ash, Fly Honeysuckle, and Wild Red Raspberry.

- Understory plant biomass (total abundance) was not significantly correlated with distance from the stream bank, however, species richness decreased significantly as distance from the stream increased (Figure 1).

For a field study of 16 streams in the Cassels-Rabbit Lakes area of Temagami, Quinby et al. (2000) found a total of 122 understory (<0.5 m height) plant taxa (species and species groups) within 30 m of the stream banks (Table 4). The following woody plant species were found to be associated (statistically significant) with the riparian zone: Black Ash, Black Swamp Currant, Canada Yew, Choke Cherry, Dwarf Trailing Raspberry, Meadow-sweet, Mountain Maple, Northern Bush Honeysuckle, Speckled Alder, White Birch, Wild Red Raspberry, and Yellow Birch.

Using the same dataset as Quinby et al. (2000), Saddock (2001) analyzed plant species abundance in the shrub/sapling layer (>0.5 m height and <10 cm dbh) within the riparian areas of 16 streams in Temagami. He identified six riparian plant species in the shrub/sapling layer that explained the greatest amount of variation in distance from the streambank. These species associated with the riparian zone included Black Ash, Canada Fly Honeysuckle, Fancy Wood Fern, Mountain Maple, Sweet Gale, and Yellow Birch (Table 5). Bracken fern was used as an upland forest indicator in the analysis. Using these indicator species in the shrub/sapling layer, he found a mean riparian zone width of 37 m, which was more than twice the 16 m width found by Quinby et al. (2000) using only understory data.

Ancient Forest Exploration & Research also supported a riparian ecology field study in the Lower Spanish Forest region of Ontario (Quinby 1997), which is located roughly 200 km west of North Bay. The primary findings of this study are as follows.

- A distinct riparian vegetation zone was found along the stream sampled.

- Both species richness and biomass were significantly higher in the riparian zone compared to the upland zone.

- Logging significantly reduced lichen biomass by 76% and moss/liverwort biomass by 38%.

- The number of understory plant taxa was 16% less in the logged riparian forest compared with the ancient riparian forest.

- The number of unique understory plant taxa was 47% less in the logged riparian forest compared with the ancient riparian forest.

- The number of tree species was 40% less in the logged riparian forest compared with the ancient riparian forest.

- The number of unique tree species was 80% less in the logged riparian forest compared with the ancient riparian forest. Unique refers to taxa or species that were found in either the logged or ancient riparian areas but not the other.

3.1.4 Non-Government Research – Other Ontario Regions

Outside of the North Bay and Spanish River regions of Ontario, the only field studies that have addressed the composition and structure of natural riparian zones have been conducted in northern Ontario. Some studies in southern Ontario have assessed riparian vegetation but they focused only on a few select tree species or plant growth forms (e.g., grasses, shrubs, trees, etc.) and did not address the change in plant community composition and structure from the riparian zone through to the upland areas (Credit Valley Conservation Authority 2011, Credit Valley Conservation Authority 2013, Oelbermann and Gordon 2000, Oelbermann and Gordon 2001, O'Neill and Gordon 1994, Petrone et al. 2008, Rios and Bailey 2006).

Similarly, a few studies in northern Ontario included evaluation of riparian vegetation but only included select tree species or plant growth forms (e.g., grasses, shrubs, trees, etc.) and did not address the change in plant community composition and structure from the riparian zone through to the upland areas (Hazlett et al. 2005, Hazlett et al. 2008).

Working near the Town of White River, Ontario in the boreal mixedwood forest, Mosley et al. (2006) sampled vegetation, insects and birds in order to determine if birds prefer riparian areas over upland areas during various times of the year. Their main finding was that riparian areas had greater avian species richness and abundance and more insects than upland forests during the breeding period. They also found that riparian areas may function as movement corridors for birds.

Their habitat comparison showed that mean tree density, Trembling Aspen biomass, and upper canopy cover were all higher in upland vs riparian areas (Table 6). They also found that Alder, Leatherleaf, Sweetgale, and Wild Red Raspberry were all much more abundant in riparian areas than in upland areas (Table 7). They noted that high shrub cover was a common property of their riparian sites.

By far, the most field-based research addressing riparian vegetation in northern Ontario has been conducted by the Azim Mallik Lab at Lakehead University in Thunder Bay, Ontario. Seven papers published on riparian ecology and logging by the Mallik Lab were found to be relevant to this literature review. Each paper is addressed chronologically as follows.

Effects of beaver, Castor canadensis, herbivory on streamside vegetation in a northern Ontario watershed (Barnes and Mallik 2001)

- Five different habitats types were identified adjacent to Beaver impoundments in the Chapleau Game Reserve including:
    - Alder - dam construction
    - Trembling Aspen - primary food
    - White Birch and Willows - secondary foods
    - shrubs - occasionally used for food and dam construction
    - conifers - occasionally used for dam construction

- The authors believe that fire is required to rejuvenate Trembling Aspen, which is the preferred food of the Beaver. This could require controlled burns in order to facilitate the regeneration of preferred Beaver habitat.

The early impact of adjacent clearcutting and forest fire on riparian zone vegetation in northwestern Ontario (Lamb et al. 2003)

- They compared the riparian vegetation communities with adjacent upland areas that were burned, harvested and undisturbed northeast of Thunder Bay near Lake Nipigon. Most buffer zones were 30 m for the burned and harvested adjacent areas and 90 m or wider for undisturbed sites.

- They conclude that the vegetation community in riparian zones is not strongly affected by disturbances occurring in the upland vegetation.

- Their explanation for these findings is that lateral changes in riparian vegetation composition are due primarily to the frequency and intensity of flooding, the extent of saturated rooting zones, surficial geology, and beaver activity.

Plant species traits across a riparian-zone/forest ecotone (Lamb and Mallik 2003)

- They examined changes across a riparian-upland forest understory ecotone in nine plant traits including the presence of woody stem tissue, leaf longevity, nitrogen fixation, seed longevity, dispersal vector, pollination vector, and clonal growth form. Examining ecotones from a trait perspective has strong potential for identifying the environmental factors and associated species functional responses that encourage the development of distinct vegetation boundaries. Data were collected northeast of Thunder Bay near Lake Nipigon.

- The ecotone along the headwater streams in a boreal mixed-wood forest supported four distinct vegetation zones including streambanks, riparian, transition, and upland forest understory.

- They found distinct suites of plant species traits for each zone. Wind and insect pollination, wind and vertebrate dispersal, and deciduous and evergreen leaves showed the greatest change in prevalence between the vegetation types.

Bryophyte responses to microclimatic edge effects across riparian buffers (Stewart and Mallik 2006).

- This field experiment investigated microclimatic conditions and bryophyte growth and vitality at seven locations between the stream edge and 60 m into upland undisturbed conifer forest and at clearcut logging sites with riparian buffers at a location 30 km northwest of Thunder Bay, Ontario.

- To carry out the experiment, two Bryophyte species were transplanted in pots and placed at 10 m intervals along 60 m transects perpendicular to the stream across the buffer and undisturbed sites. Bryophyte growth, cover, and vitality, as well as microclimatic parameters and plant cover, were measured over the summer in 2003.

- Results of the study showed that both Bryophyte species responded to changes in microclimatic conditions and that vapor pressure deficit was the most important factor influencing the growth of *Hylocomium splendens*, whereas for *Polytrichum commune* growth, soil moisture was most important.

- This study confirms that interior forest Bryophytes such as *H. splendens* can be used as indicators to monitor edge effects and biodiversity recovery following logging and that the growth and vitality of these Bryophytes reflect the prevailing near-ground microclimatic conditions at the forest edges.

- In addition, abundance estimates of such Bryophytes can be used to determine the depth of edge effects across both natural ecotonal edges (e.g., riparian-upland forest edge) and edges created by human activity such as logging. Logging practices must consider depth of edge in determining the appropriate width of riparian buffers that are necessary to sustain biodiversity and associated values at the land/water interface.

Edge effects of wildfire and riparian buffers along boreal forest streams (Braithwaite and Mallik 2012)

- This study was conducted in a boreal mixedwood forest 30 to 70 km northeast of Thunder Bay, Ontario where structure of the canopy trees, understorey cover and the near-ground microclimate were assessed along 96 transects beside 24 streams.

- They compared plant communities created by post-fire residual structures at the fire edge to unburned plant communities at the riparian edge as undisturbed reference sites. They also evaluated the effect of post-fire residual structures and proximity to streams on the depth and magnitude of edge effects.

- The average microclimatic depth of edge effect extended 8 m into the reference buffer but only 2.5 m from the fire edge. Similarly, the depth of edge effect for plant life-forms extended 20 m from the reference buffer edge and 5 m from the fire edge. At the fire edge, the structural magnitude of edge effect was significantly higher, but the microclimatic magnitude of edge effect was lower than the reference buffer edge. Shrubs, shade-tolerant herbs and grasses increased at the reference buffer edge and decreased at the fire edge.

- In summary, the ecological structure at reference buffer edges and fire edges in boreal forests creates different environmental conditions, which support different plant communities. Lower structural and microclimatic depth and magnitude of edge effect at the fire edge result from (1) edge location, (2) intact shrub layer, and (3) disturbance-resilient riparian vegetation.

Understory plant community resilience to partial harvesting in riparian buffers of central Canadian boreal forests (Mallik et al. 2013)

- This study investigated the responses of understory species to gaps created by partial harvesting at up to 50% basal area removal in riparian buffers (up to 42 m wide) of boreal forests 60 km south of White River, Ontario, and compared them to nearby un-harvested buffers and riparian reference areas of undisturbed forests.

- Gaps (from 25 to 125 m^2) created by partial harvesting increased canopy openness, ground-level solar radiation, and shallow soil temperatures proportional to gap sizes. Changes were small and only consistently higher than the range of these conditions in un-harvested riparian areas when gaps were greater than 50 m^2.

- Understory plant abundance in gaps tended to be higher than in un-harvested sites but significant differences could not be detected. Species richness and diversity were higher among medium and large gaps (>20 m^2) than in small gaps, but they were not higher than in un-harvested buffers or reference riparian areas.

- Plant community composition (Table 8) was not different between harvested and un-harvested riparian areas. However, the following changes were observed: (1) gaps created by partial harvesting affected foliar morphology of selected common understory plants, (2) leaf dry matter content was higher in harvested gaps than in un-harvested buffers or reference riparian areas, and (3) specific leaf area was lower in harvested gaps. These differences were related to gap size.

Forest regeneration in gaps seven years after partial harvesting in riparian buffers of boreal mixedwood streams (Mallik et al. 2014)

- The study area was located about 60 km south of White River, Ontario on the boreal shield of central Canada, 75 km inland from the northeastern shore of Lake Superior.

- They determined the effect of partial harvesting in stream-side riparian buffers on regeneration of the following canopy species: Balsam Fir, White Birch, White Spruce, Black Spruce, and Trembling Aspen by testing the hypothesis that juvenile trees would be more abundant, species-rich, and larger in gaps than in non-harvested buffers, and that those differences would be proportional to gap size.

- Findings indicated that riparian woody plant communities in partial harvesting gaps had a higher density and were more diverse than those communities in the unharvested buffer areas. Density and diversity were higher in medium to large gaps and consisted of both shade-intolerant and early successional species. They speculate that more favorable light and soil temperature in the larger gaps are responsible for this.

- The main conclusion was that logging within the riparian zone to increase habitat complexity and early successional forest species is possible by logging up to 50% of the overstory basal area. They also recommend monitoring the effectiveness and longer-term ecological responses of riparian communities to this kind of logging at catchment and landscape levels.

3.1.5 Other Eastern Canada Regions

Studies addressing riparian vegetation ecology and management within eastern Canada and outside of Ontario were found for only three provinces including Nova Scotia, Quebec, and Manitoba.

Nova Scotia

Setbacks and Vegetated Buffers in Nova Scotia: A review and analysis of current practices and management options (Rideout 2012)

- This report presents a summary of (1) scientific literature that addresses riparian and coastal zone ecology, (2) approaches to coastal and riparian management used in North American jurisdictions, (3) management options available to the Province of Nova Scotia, and (4) the challenges of implementing a vegetated buffer or setback policy. The report is intended to clarify the complex issues related to use of vegetated buffers and setbacks in coastal and riparian zones, and to provide guidance to government staff as a basis for policy design recommendations.

- The author states that, "few studies have examined the riparian buffer widths necessary to maintain plant species diversity and abundance as they are most often recognized for their ability to protect water quality and fish habitat and their utility as wildlife corridors" (pg. 104).

- Riparian areas can support high plant heterogeneity and can play an important role in plant dispersal and many floodplain plants require regular cycles of flooding for seed dispersal and germination.

- Appendix C of the Rideout (2012) report provides an excellent 12-page review of riparian zone science (numerous tables and figures) addressing the five main ecosystem services of riparian areas: bank stability and erosion prevention, pollutant filtration, flow moderation, provision of habitat and wildlife corridors, and channel morphology control.

Quebec

An attempt to explain the distribution of the tree species composing the riparian forests of Lake Duparquet, southern boreal region of Quebec, Canada (Denneler et al. 1999)

- The objective of this study was to identify the most important environmental factors determining the distribution of ten tree species within the riparian zone of Lake Duparquet, located in the southern boreal region of Quebec.

- Occurrence and relative basal area of ten tree species were assessed within an altitudinal range of 200 cm above mean water level along 95 transects that were distributed among five geomorphological shore types including depositional flats, floodplains, beaches, terraces, and rock outcrops.

- Results of this study indicate that the elevation gradient, representing seasonal flooding, is the main factor determining the distribution of the tree species within the riparian zone. To a lesser extent, geomorphological shore types through the influence of surficial substratum, topography, aspect, and fire also at least partially explain tree species distribution (Table 9).

Importance of riparian habitats to flora conservation in farming landscapes of southern Québec, Canada (Boutin et al. 2003)

- Plants of riparian habitats located between crop fields and linear watercourses (e.g., drainage ditches, streams, small rivers) located in the Boyer River watershed of Quebec were assessed to determine the contribution of narrow riparian areas to plant biodiversity within an agricultural landscape and if these riparian zones facilitate the growth of weeds that are detrimental to agriculture.

- Twenty-nine sections (>400 m) of riparian habitats adjacent to crop fields were inventoried and grouped into five vegetation types: (1) grass-dominated and devoid of woody species, (2) forb-dominated and devoid of woody species, (3) dominated by small (<2m) shrubs, (4) dominated by tall (2 - 10 m) shrubs, and (5) dominated by mature trees (>10 m).

- Results indicated that:
  - Species composition differed considerably among the various riparian habitats when considering forest spring ephemerals, ferns, forbs, grasses, and woody vegetation.
  - Habitats with trees contained a larger number of herb and woody species than other riparian habitats, however, habitats with trees were more heterogeneous than other habitat types.
  - Substantially more native wetland species were located adjacent to watercourses than near fields.
  - More weedy and introduced species were found near crop fields.

Understory plant diversity and biomass in hybrid poplar riparian buffer strips in pastures (Fortier et al. 2011)

- Plant biomass, species richness, and canopy openness were measured in six-year old hybrid poplar riparian buffer strips in the understory of two unrelated poplar clones planted along headwater streams at three pasture sites in southern Quebec.

- Lower understory biomass was observed on sites with the Poplar clone that had less canopy openness (more crown biomass). There was some evidence that in addition to tree size, there was a clonal effect on canopy openness.

- In some plots with clone MxB-915311 at the most productive sites, the understory plant growth was so low that it could compromise important buffer functions for water quality protection such as runoff control, sediment trapping, and surface soil stabilization.

- Significant positive relationships between canopy openness and introduced species richness and cover were found, while no significant relationship was observed between canopy openness and native plant species richness and cover.

- These results suggest that planting riparian buffer strips with fast-growing trees can lead to the exclusion of shade intolerant introduced species, which are typical colonizers of disturbed habitats such as riparian areas in pastures, while having no significant effect on native plant diversity.

- A strong significant linear relationship between mean total species richness and mean introduced species richness was also observed, supporting the hypothesis that the richest communities are the most invaded by introduced species, possibly because of higher canopy openness.

- This study highlights the need for a better understanding of relationships between tree growth, canopy openness, understory biomass, and plant diversity in narrow strips of planted trees. This would be useful in designing multifunctional riparian buffer systems in agricultural landscapes.

A Comparison of the Composition and Diversity of Tree Populations along a Hydrological Gradient in Floodplains (Southern Québec, Canada) (Berthelot et al. 2015)

- The purpose of this study was to identify and characterize the effects of increased flooding frequency on the structure and composition of forest stands. The sampling sites (total of 94 quadrats) were located in riparian forests within the boundaries of flood-risk zones established by government maps.

- Results showed that there are significant differences in the composition and diversity of forest communities among the different flood recurrence zones. In the active floodplains (interval of 0–20 years), the riparian forests were clearly distinguished from other intermediate flood zones (interval of 20–100 years). See Table 10 for all tree species identified in the study and their distribution across the three flood recurrence zones.

- Differences were also found in the structure of the communities, particularly in the frequent flood zones, which are characterized by a low renewal rate, low density, and less-diversified forest stands. With expected increases in the number of flooding events in the coming decades, there may be greater tree mortality and a gradual disappearance of the forest communities in high frequency flood zones.

Manitoba

Impacts of land use on riparian forest along an urban-rural gradient in southern Manitoba (Moffatt et al. 2004)

- This study compared the vegetation of riparian forests along an urban-rural disturbance gradient using 25 sampling sites along the Assiniboine River in southern Manitoba. Each site was categorized into one of five land use categories including urban, suburban, high intensity rural, low intensity rural, and relatively high quality reference forest. See Table 11 for summary data on species richness and number of dominant species for all exotic and native herbaceous species, all shrub species, and all tree species for each land use category.

- Differences in herbaceous, shrub, and tree species composition and diversity were related to the proportion of surrounding land use, forest patch size, connectivity, and area-perimeter ratio. Urban riparian forests were more disturbed and isolated. They were smaller and characterized by drier, more alkaline soils. In addition, they had significantly lower native and overall understory species diversity, and had a higher proportion of exotic plant species.

- Suburban forests were less disturbed, faced greater development pressure, and had sandier soils. Although suburban understory diversity was similar to that of rural forests, suburban sites had a higher proportion of exotic species, especially escaped horticultural and invasive species.

- Reference sites were relatively large and exhibited greater connectivity, but there was little difference in species composition and diversity among high intensity rural, low intensity rural, and reference sites. These site types were less disturbed than either urban or suburban forests, and reference sites were characterized by hydrophilic plant species.

Understorey indicators of disturbance for riparian forests along an urban–rural gradient in Manitoba (Moffatt and McLachlan 2004)

- For this study, an urban-rural gradient was used to identify species- and guild-level indicators of riparian forest degradation along the Assiniboine River in southern Manitoba. Twenty-five sites were categorized according to urban, suburban, high-intensity rural, low-intensity rural, and relatively high quality reference land use.

- Generalists, which frequented all land use types, dominated (69%) the understory community, whereas opportunistic (15%) and vulnerable (16%) species were relatively less common. Opportunistic species, which characterized city sites, tended to be exotic, woody and annual, and effective dispersers. In contrast, vulnerable species, which characterized non-city sites, tended to be native, perennial, and ineffective dispersers.

- Indicators of disturbed forests were opportunistic and positively associated with disturbance measures including connectivity and cover of garbage, and negatively correlated with native and overall diversity. They included exotics *Solanum dulcamara*, *Rhamnus cathartica*, and *Lonicera tartarica*.

- In contrast, indicators of high-integrity forest were vulnerable, often excluded from urban sites and were negatively associated with disturbance measures and positively correlated with native and overall diversity. They included natives *Rubus idaeus*, *Carex* spp., and *Galium triflorum*.

- These results suggest that opportunistic and vulnerable species, and their associated guilds, can be used as effective indicators of disturbance and forest integrity and to identify forest patches that warrant further protection or restoration.

3.1.6 Federal Government Guidance Documents

Two guidance documents produced by the Canadian federal government that address the ecology and management of riparian areas were found during this study. One was produced by the Canadian Wildlife Service and the other was published by Agriculture and Agri-Food Canada.

The document, *How Much Habitat is Enough* (Third Edition; Canadian Wildlife Service 2013) includes three riparian habitat protection components as follows.

- "Both sides of streams should have a minimum 30-metre-wide naturally vegetated riparian area to provide and protect aquatic habitat. The provision of highly functional wildlife habitat may require total vegetated riparian widths greater than 30 metres." (pg. 13)

- "75% of stream length should be naturally vegetated." (pg. 13)

- "Urbanizing watersheds should maintain less than 10% impervious land cover in order to preserve the abundance and biodiversity of aquatic species. Significant impairment in stream water quality and quantity is highly likely above 10% impervious land cover and can often begin before this threshold is reached. In urban systems that are already degraded, a second threshold is likely reached at the 25 to 30% level." (pg. 14)

This guidance document provides an explanation of the value of riparian zones for maintaining the integrity of aquatic ecosystems, wetland ecosystems and terrestrial ecosystems. It also provides a substantial review of some of the relevant scientific literature that provides evidence for the existence and importance of riparian ecosystems. However, most of this literature focuses on associations with animal species with very little focus on plant species and vegetation. In addition, no primary data are presented.

The federal report, *Agricultural Riparian Health: Theory, Concepts and Potential Indicators* (Fortier 2014), published by Agriculture and Agri-Food Canada, "is a working tool designed to guide discussions regarding indicators that could be used to quantify agricultural riparian health. It is also intended to provoke thought and discussion on the use of the term health applied in the specific case of agricultural riparian zones" (pg. 5). This report addresses many aspects of riparian ecology and management, however, only the portions of this report pertaining to the understanding of vegetation in natural riparian areas is included in this literature review.

The author states that, "to assess the health of agricultural riparian zones in agricultural landscapes, it is important to identify the main plant species that naturally colonize the riparian zone in the absence of human disturbance" (pg. 19). These main plant species for eastern Canada are provided in Table 1. The author also states that, "with this knowledge, it is possible to determine how far a riparian zone that is disturbed by agricultural activities has moved from its natural trajectory in terms of plant succession".

Most Canadian riparian ecotones currently present in agricultural areas were initially dominated by forests. Natural riparian zones support a number of threatened and vulnerable plant species. For example, in Quebec close to half of the 375 species that are threatened, vulnerable or likely to be vulnerable are associated with wetlands or riparian zones.

At the landscape scale, the variations in hydrologic and geomorphologic conditions from one stream order to another, such as flood frequency, duration and magnitude facilitates the development of structurally and floristically distinct riparian systems for each different stream order in a given region. In addition, the existence of a lateral water saturation gradient, which varies depending on the type of alluvial deposits, affects the distribution of plant species. It is difficult for trees to colonize riparian zones that have a relatively wide floodplain and that remain almost permanently saturated with water resulting in low soil oxygen levels.

The invasion of natural (and human-altered) riparian corridors by non-native plants is a global phenomenon, in both forests and grassland landscapes. There are three factors that facilitate this invasion: (1) the proximity of the stream, which transports propagules, to areas where the non-native plants can germinate and establish, (2) the frequency and intensity of disturbances associated with floods, which create an environment where plant competition is reduced, and (3) the continuous availability of water in the soil, which promotes growth and reproduction. In general, young and more highly disturbed riparian communities have the highest rates of invasion by non-native species. Riparian patches having high edge-to-area (perimeter/area) ratios are also more susceptible to invasion by exotic plants. For example, riparian zones in agricultural areas generally have rates of invasion by non-native species due to the presence of weeds in adjacent crop fields.

3.1.7 Federal Government Research

The only research being conducted on riparian ecology and management in Ontario by the federal government is being spearheaded by the Kreutzweiser Lab at the Canadian Forest Service Great Lakes Forestry Research Centre located in Sault Ste. Marie. Work at the lab is focusing primarily on the impacts of forestry activities within the riparian zone on both aquatic and terrestrial ecosystems (see Appendix B that lists 16 publications). However, the terrestrial component, which addresses plant species composition in riparian zones, has been led by Azim Mallik at Lakehead University. The terrestrial aspects of this work will be addressed in a later section of this report.

As Kreutzweiser states in his research program description (Kreutzweiser 2015):

> "Canadian Forest Service researchers, in collaboration with the Ontario Ministry of Natural Resources, several university partners, and the forest industry, have been comparing natural disturbances in shoreline areas of forest water bodies to disturbances from forest harvesting. These disturbances not only create increased shoreline habitat complexity, but they also cause changes in the water bodies themselves that are important for sustaining aquatic ecosystem health. The research has shown that careful shoreline harvesting can be conducted in some areas to increase shoreline habitat complexity and minimize harmful effects in water bodies.
>
> New forest management regulations in Ontario and elsewhere across Canada are beginning to allow, or even encourage, some degree of forest harvesting closer to water than the conventional riparian buffers allowed. Ongoing research will be looking at when and where to use intentional shoreline harvesting, and to ensure that the effects of shoreline harvesting will in fact emulate natural disturbance effects while still adequately protecting water resources and aquatic habitats."

Thus, from a broad landscape conservation perspective, this group of collaborating scientists is taking the approach that it is preferable to promote logging (simulates natural disturbance) within the very narrow riparian buffers (rarely wider than 30 m) rather than to cut less upland forest leaving more natural upland forest in order to facilitate conditions that would be more conducive to maintaining natural disturbance regimes. They also contend that most riparian forests protected from logging will accumulate too much old-growth forest, which is an unhealthy ecological condition that should be remedied through logging (Sibley et al. 2012).

3.2 RIPARIAN RESTORATION TARGETS

The most effective way to evaluate the effectiveness of ecological restoration is to compare the restored area to natural, undisturbed ecosystems in nearby landscapes with similar habitat conditions. The following studies address the need for restoration reference sites and for the use of metrics to evaluate restoration effectiveness.

Ecological properties for the evaluation, management, and restoration of temperate deciduous forest ecosystems (Keddy and Drummond 1996)

- Many of the original deciduous forests of North America have disappeared over the last few centuries, thus our challenge is to preserve remnant forests, restore altered forests, and harvest managed forests in a sustainable manner. To do so, we need to identify macro-scale properties that can easily monitor the condition of the eastern deciduous forest as a whole.

- In this paper, the authors offer ten possible properties for monitoring forests including: (1) tree size, (2) canopy composition, (3) quantity and quality of coarse woody debris, (4) number of spring ephemeral species in the herbaceous layer, (5) number of typical corticulous bryophyte species (grow on bark), (6) density of wildlife trees, (7) fungi, (8) avian communities, (9) number of large carnivores, and (10) forest area.

- For this study, the authors assigned to each property a control or normal value, an intermediate value, and a heavily altered value, which were based on the existing literature. Using these 10 properties relative to forested areas would:

- allow us to recognize, rank, and protect high-priority forest sites for conservation
- tell us whether changes in a forest are in the direction of restoration or toward further alteration
- enable us to evaluate different harvesting methods so we can select those that cause the least alteration to forests

Canopy Composition and Forest Structure Provide Restoration Targets for Low-Order Riparian Ecosystems (Rheinhardt et al. 2009)

- Many programs are in place to protect and restore low order streams and riparian zones. However, information on riparian zone forests is sparse for many biogeographical regions, especially compositional and structural data that would provide useful targets for restoration.

- This study provides quantitative data on riparian zone composition and forest structure from three physiographic provinces of the southeastern United States. Data from 219 low-order (first- to fourth-order) forested reaches were arranged by three basal area categories meant to represent successional categories and variations in forest structure.

- Many early to mid-successional disturbed stands were similar in composition to late-successional reference stands in the same physiographic sub-region. At these sites, natural successional processes would likely be sufficient to restore the compositional and structural attributes inherent in late-successional stands if provided long-term protection.

- Other sites with dissimilar compositions may have been recovering from more intensive types of alterations, such as mechanized land clearing. At such sites, restoration to historic compositions could benefit functionally by planting oaks (*Quercus* spp. L.) and other heavy mast species.

Best Management Practices: Buffer Strips (Lane 2011)

- This publication provides an excellent chapter titled, "Establishing and Managing Buffer Strips" that addresses the potential functions of restored riparian buffers, design principles, plant species selection, and a step-by-step guide for establishing and managing a riparian restoration project.

- An accurate site assessment is one of the most important first steps and should focus on soil type, slope, shape of the watercourse, adjacent land uses and their potential impacts, and riparian type such as lakeshore, wetland, small stream, large stream, river, etc.

- Width is also a key consideration as wider buffers are more effective at filtering contaminants, encouraging infiltration, and providing a diversity of wildlife habitat. However, in general, the greater the buffer width, the more expensive and time consuming the project will be.

- Riparian areas can be restored to many different kinds of vegetation including grasses, wildflowers/herbaceous plants, shrubs, or trees, or any combination of these. The plants species selected should reflect the desired buffer function, local native vegetation composition, growth rate, wildlife value, economic value, and local site conditions including climate, soil type, soil drainage, soil pH, and risk of flooding. Non-native and invasive plant species should be avoided.

- This publication includes three tables that list suggested hardwood trees species (7), conifer tree species (7), and shrub species (7) for riparian restoration in Ontario. Each species is described in terms of frost zone, soil type, drainage, flood tolerance, rooting, growth rate, height, shade tolerance, wildlife value, and economic value.

Using reference conditions in ecosystem restoration: an example for riparian conifer forests in the Pacific Northwest (Pollock et al. 2012)

- Quantifying the attributes of reference sites is a crucial problem in the restoration of ecosystems, driving both the evaluation of current conditions and the setting of management targets for specific points in the future. This study provides a three-step process to assess the effects of proposed riparian ecosystem restoration efforts: (1) identify reference sites (2) quantify metrics that describe the reference sites, and (3) use models to predict the likely effects of restoration actions relative to reference conditions.

- To apply this approach the authors identified 117 natural, late-successional conifer dominated stands from existing forest inventories in the Pacific Northwest for the purpose of establishing reference conditions. This was done to establish quantitative metrics for structural attributes essential to the maintenance of biodiversity in these forests, and to assess whether there were any important quantitative differences between upland and riparian forests or whether upland and riparian forest reference sites could be used interchangeably.

- Quantitative metrics for comparison included diameter, height and species of each live and dead tree in the stand, live and dead tree biomass, density, and stand age.

- Tree species richness was 34% higher in riparian forests compared with upland forests and all tree species except for Douglas Fir had higher densities in riparian forests.

- Both upland and riparian forest types were generally similar, but riparian stands had higher average live tree wood volumes and basal areas, suggesting they may be growing on sites that are more productive. Both riparian and upland forests had abundant large diameter (>50 cm) live trees and snags.

- Models of the growth of young conifer stands that had been logged showed that, if left untreated, the stands followed a trajectory towards developing forest structure similar to the average reference condition. In contrast, the restoration treatment (thinning) followed a developmental trajectory along the outside range of reference conditions.

Gallery Forest or Herbaceous Wetland? The Need for Multi-Target Perspectives in Riparian Restoration Planning (Weisberg et al. 2013)

- Riparian herbaceous wetlands have declined dramatically as a result of river regulation and agricultural development, leading to losses of important habitats and ecosystem services that differ from those provided by gallery forests, which have been the primary choice for riparian restoration.

- Rather than focusing primarily on the restoration of gallery forests, the authors advocate restoration of diverse and dynamic habitat mosaics in the context of natural variability of flow and sediment regimes for riparian restoration projects. This includes increasing the amount of fluvial marshes, sloughs, wet meadows, alkali meadows, off-channel ephemeral ponds, and other critical floodplain communities associated with herbaceous plant dominance.

- Models are needed to match life history requirements of particular wetland herbaceous plant species with details of flow and sediment transport regimes so that riparian forests are not planted in ecologically inappropriate sites.

- Indicators of riparian restoration success should be broadly inclusive of a range of plant and animal species, habitat types, and ecosystem components.

Indicators of restoration success in riparian tropical forests using multiple reference ecosystems (Suganuma and Durigan 2015)

- Using a chronosequence from 4 to 53 years of 26 riparian forest undergoing restoration in the Brazilian Atlantic Forest, this study used modeling to evaluate how forest structure, tree species richness and composition, and the proportion of plant functional guilds change through time including 20 attributes (Table 12). They also estimated the time required for these variables to reach different types of reference ecosystems: old-growth forest, degraded forest, and secondary forest.

- Attributes that followed a predictable trajectory over time included tree basal area, canopy cover, tree density, tree species richness, and proportions of shade tolerant and slow growing species or individuals. Most of the variation in density of pteridophythes, lianas, shrubs and phorophythes, proportion of animal-dispersed individuals, rarefied richness and floristic similarity with reference ecosystems were unexplained by the analysis.

- Results also showed that the estimated time to reach the reference ecosystems condition was shorter for structural attributes than for species composition or proportion of functional guilds. The recovery time varies among the three types of reference ecosystems for most attributes. For example, tree species richness and proportion of shade tolerant species became similar to secondary forests in about 40 years and about 70 years or more to reach the old-growth forest condition.

- The authors state that within the same ecological region, forest restoration by planting trees results in a standard trajectory, predictable for most attributes of structure, richness, and functional guilds, which should guide the establishment of targets for restoration. However, floristic composition is not predictable.

- This study also showed a high probability of success in restoring forest structure and related ecosystem services by planting nursery-raised seedlings. However, the probability of restoring the historical species composition and life forms other than trees is very low and should not be disregarded when setting restoration goals.

- They recommended that reference ecosystems used for setting final restoration goals should represent the entire range of histories and regimes of disturbance within a given ecological region.

- Due to their ecological relevance and predictability, canopy cover, basal area, understory density, and understory richness were recommended as ecological indicators for monitoring forest restoration success.

    - *Canopy cover*: is directly related to the recovery of biomass, shelter for wildlife and relevant ecosystem services, such as the recovery of microclimate, nutrient cycling, erosion control, and regulation of water resources. It is a good indicator for the first 10 years after initiation of restoration when changes clearly linked with age.

    - *Basal area*: is a classic indicator of biomass, representing the recovery of forest structure and carbon sequestration. Basal area can be also a surrogate for most of the ecosystem services related to canopy cover. As only trees above 5 - 10 cm dbh are usually measured, this is not an indicator to be applied during the first years after planting, when basal area is highly influenced by the density of seedlings planted.

    - *Understory density*: the density of trees naturally regenerating is the most direct indicator of the recovery of natural biological processes. Among the size classes examined, saplings provided a more predictable response than seedlings, which are more subject to stochastic mortality factors.

    - *Understory richness*: the number of tree species in naturally regenerating in the restoration area is the best indicator of the effective recovery of diversity and persistence of species on the landscape. However, it is not a good indicator during the initial stages of restoration.

4.0 SUMMARY

This summary highlights the most relevant aspects of the findings of this literature review addressing riparian ecology and restoration focusing on the four broad areas of government guidance, government research, non-government research, and restoration targets.

4.1 Government Guidance Documents

Six Ontario provincial guidance documents addressed riparian ecosystems at a significant level; five of these were produced by the OMNR and one was published by the OMAF. The OMNR documents address primarily forest management, natural heritage, wildlife management, logging in riparian areas, and ecological land classification.

The *Forest Management Guide for Conserving Biodiversity at the Stand and Site Scales – Background and Rationale for Direction* (OMNR 2010a) cites 30 field studies (secondary sources) that have addressed riparian ecology and management, however, most of these field studies were not conducted in Ontario. In addition, this document is void of information or data addressing plant species composition or age-class structure in riparian ecosystems.

In the *Natural Heritage Reference Manual* (OMNR 2010b), most of the use of the term riparian is in the context of management prescriptions and reference to secondary sources (scientific literature) to establish the need for riparian buffers. There is no consideration of plant species composition or age-class structure in riparian ecosystems in this document. Similarly, most of the uses of the term riparian in the *Significant Wildlife Habitat Technical Guide* (OMNR 2000) and in the *Code of Practice For Timber Management Operations In Riparian Areas* (OMNR 1998) are descriptive (adjective modifiers of other terms) and there are only a few instances where the term riparian is used relative to management prescriptions. There is no reference to information or data addressing plant species composition or age-class structure in riparian ecosystems.

A total of 224 ecosites are identified and described in the document, *Ecosites of Ontario: Great Lakes-St. Lawrence Forest Region, Operational Draft* (Uhlig 2009). However, there are no riparian ecosites included in this guide. In fact the term riparian is not listed and defined in the glossary. The guide does state that 17 ecosites (swamps and fens) may occur in riparian zones and it does include 38 coastal and shoreline types, which often include bluffs, exposed bedrock, talus, and sandy beaches.

The OMAF publication, *Best Management Practices: Buffer Strips* (Lane 2011), primarily addresses environmental aspects of agricultural practices in southern Ontario. It provides a definition for riparian zone, addresses the values of riparian zones, describes the impacts of agriculture on riparian areas, and provides a number of management practices designed to minimize or eliminate human impacts to riparian areas and associated water bodies. It also identifies and briefly describes seven types of riparian zones including narrow and wide channels in upper reaches (of rivers); middle reaches; lower reaches; beaches, bluffs and bedrock-controlled shorelines of lakes; wetlands and natural ponds; and constructed watercourses. Finally, it provides a detailed section on how to establish and manage a riparian restoration project including information on the potential functions of restored riparian buffers, design principles, and plant species selection.

Two guidance documents produced by the Canadian federal government that address the ecology and management of riparian areas were found during this study. One was produced by the Canadian Wildlife Service and the other was published by Agriculture and Agri-Food Canada.

The document, *How Much Habitat is Enough* (Third Edition; Canadian Wildlife Service 2013) states that both sides of a stream should have protection zone of at least 30 meters, at least 75% of a stream length should be naturally vegetated, and that urbanizing watersheds should maintain less than 10% impervious land cover. This document addresses the value of riparian zones for maintaining landscape integrity and reviews scientific evidence for the importance of riparian ecosystem to wildlife. However, there is very little focus on plant species and vegetation and no primary data are presented.

The report, *Agricultural Riparian Health: Theory, Concepts and Potential Indicators* (Fortier 2014), states that it is essential to protect and study natural riparian zones in order to use them as baselines to evaluate the impacts of agriculture. It provides a short list of the most common riparian plant species in eastern Canada and addresses the importance of natural riparian zones as habitat for a number of threatened and vulnerable plant species. It also recognizes that the invasion of natural (and human-altered) riparian corridors by non-native plants is a global phenomenon and that in general, young and more highly disturbed riparian communities have the highest rates of invasion by non-native species.

4.2 Government Research

Two riparian studies published by Ontario provincial scientists were found during this literature review and neither provided primary or secondary information about plant species composition or vegetation age-class structure in riparian ecosystems.

The only research being conducted on riparian ecology and management in Ontario by the federal government is being spearheaded by the Kreutzweiser Lab at the Canadian Forest Service (CFS) in Sault Ste. Marie in collaboration with a number of other scientists. However, the terrestrial component, which addresses plant species composition and vegetation age-class structure in riparian zones, has been led by Azim Mallik at Lakehead University.

The Kreutzweiser lab focuses primarily on the impacts of forestry activities within the riparian zone on both aquatic and terrestrial ecosystems. In particular, the lab is taking the approach that logging (according to their prescription) should be promoted within riparian buffers in order to simulate natural disturbance, which they feel is important in order to maintain riparian ecosystems.

4.3 Non-Government Research in Ontario

Although numerous non-governmental researchers have addressed riparian ecology in Ontario, only two groups have documented the nature of plant species and vegetation within Ontario riparian zones. Ancient Forest Exploration & Research has conducted a number of field studies in and near the North Bay-Mattawa region and the Mallik Lab at Lakehead University has conducted many riparian vegetation field studies, primarily located in the Thunder Bay region of Ontario.

Ancient Forest Exploration & Research

Four field studies focusing on riparian ecology in the Temagami region and one in the Lower Spanish Forest were carried out and/or supported by Ancient Forest Exploration & Research from 1990 through 2001. The first of these studies was conducted by Giroux (1994); his main findings for the riparian zone in Temagami old-growth Red and Eastern White Pine forests included the following.

- From most to least abundant, the following overstory tree species were found in the riparian zone: Eastern White Pine, Red Pine, Northern White Cedar, Black Spruce, White Spruce, Balsam Fir, Yellow Birch, Jack Pine, Poplar, Red Maple, and Cherry spp.

- From most to least abundant, the following understory plant species were found in the riparian zone: Balsam Fir, Red Maple, Alder spp., Yellow Birch, Black Spruce, Cherry spp., Black Ash, White Spruce, Blueberry spp., White Birch, Honeysuckle, White Pine, Red Pine, Beaked Hazelnut, and Jack Pine.

- Although understory plant biomass in the riparian zone was lowest in the old-growth condition compared with three younger forest stand categories, plant species richness in the riparian zone was highest in the old-growth condition compared with the other age categories.

- Understory plant biomass in the riparian zone was highest around stream riffles compared with stream pools, however, understory plant species richness in the riparian zone was highest around stream pools compared with stream riffles.

At the east end of Blueberry Lake in Temagami, Quinby et al. 1999 found that:

- 63 plant species were found within 32 m of the stream bank and the abundance of 25 of these species (40%) was significantly correlated with distance from the stream bank;

- Of these significant correlations, 18 species (29%) showed an decrease in abundance with increasing distance from the stream bank;

- Of these 18 species, the presence of 14 species terminated prior to the 32 m point;

- The woody plant species associated with the riparian zone included Black Ash, Fly Honeysuckle, and Wild Red Raspberry; and

- Understory plant biomass (total abundance) was not significantly correlated with distance from the stream bank, however, species richness decreased significantly as distance from the stream increased.

For 16 first and second order stream draining into Cassells and Rabbit Lakes, Quinby et al. (2000) found a total of 122 understory (<0.5 m height) plant taxa (species and species groups) within 30 m of the stream banks and the following woody plant species were found to be associated (statistically significant) with the riparian zone: Black Ash, Black Swamp Currant, Canada Yew, Choke Cherry, Dwarf Trailing Raspberry, Meadow-sweet, Mountain Maple, Northern Bush Honeysuckle, Speckled Alder, White Birch, Wild Red Raspberry, and Yellow Birch.

In 2001, Saddock identified six plant species in the shrub/sapling layer that explained the greatest amount of variation in distance from the streambank including Black Ash, Canada Fly Honeysuckle, Fancy Wood Fern, Mountain Maple, Sweet Gale, and Yellow Birch. Using these indicator species in the shrub/sapling layer, he found a mean riparian zone width of 37 m.

The primary findings of a field study in the Lower Spanish Forest region of Ontario (Quinby 1997) included the following.

- Both species richness and biomass were significantly higher in the riparian zone compared to the upland zone.

- Logging significantly reduced lichen biomass by 76% and moss/liverwort biomass by 38%.

- The number of understory plant taxa was 16% less in the logged riparian forest compared with the ancient riparian forest.

- The number of unique understory plant taxa was 47% less in the logged riparian forest compared with the ancient riparian forest.

- The number of tree species was 40% less in the logged riparian forest compared with the ancient riparian forest.

- The number of unique tree species was 80% less in the logged riparian forest compared with the ancient riparian forest.

Mallik Lab at Lakehead University

Seven papers published on riparian ecology and logging by the Mallik Lab were found to be relevant to this literature review. Barnes and Mallik (2001) identified five different habitats types adjacent to Beaver impoundments in the Chapleau Game Reserve including Alder for dam construction, Trembling Aspen as the primary food source, White Birch and Willows as secondary foods, shrubs used occasionally for food and dam construction, and conifers used occasionally for dam construction.

Lamb et al. (2003) conclude that the vegetation community in riparian zones is not strongly affected by disturbances occurring in the upland vegetation. Their explanation is that lateral changes in riparian vegetation composition are due primarily to the frequency and intensity of flooding, the extent of saturated rooting zones, surficial geology, and beaver activity.

Also published in 2003, Lamb and Mallik identified four distinct vegetation zones including streambanks, riparian, transition, and upland forest understory in the ecotone along the headwater streams in a boreal mixed-wood forest. In each zone, they found distinct suites of plant species traits. The traits that showed the greatest change between zones included plants with wind and insect pollination, plants with wind and vertebrate dispersal, and deciduous and evergreen leaves.

In a field experiment, Stewart and Mallik (2006) found that both Bryophyte species responded to changes in microclimatic conditions and that vapor pressure deficit was the most important factor influencing the growth of *Hylocomium splendens*, whereas for *Polytrichum commune* growth, soil moisture was most important. Interior forest Bryophytes such as *H. splendens* can be used as indicators to monitor edge effects and biodiversity recovery following logging and abundance estimates of such Bryophytes can be used to determine the depth of edge effects across both natural ecotonal edges and edges created by human activity such as logging.

For a study of edge effect, Braithwaite and Mallik (2012 found that the average microclimatic depth of edge effect extended 8 m into the reference (undisturbed) buffer but only 2.5 m from the edge of the burned area. Similarly, the depth of edge effect for plant life-forms extended 20 m from the reference buffer edge and 5 m from the fire edge. The ecological structure at reference buffer edges and fire edges in boreal forests creates different environmental conditions, which support different plant communities. Lower structural and microclimatic depth and magnitude of edge effect at the fire edge result from edge location, an intact shrub layer, and disturbance-resilient riparian vegetation.

Mallik et al. (2013) found that gaps from 25 to 125 m^2 created by partial harvesting resulted in increased canopy openness, ground-level solar radiation, and shallow soil temperatures proportional to gap sizes. Species richness and diversity were higher among medium and large gaps (>20 m^2) than in small gaps, but they were not higher than in un-harvested buffers or reference riparian areas. Plant community composition was not different between harvested and un-harvested riparian areas. However, the following changes were observed: (1) gaps created by partial harvesting affected foliar morphology of selected common understory plants, (2) leaf dry matter content was higher in harvested gaps than in un-harvested buffers or reference riparian areas, and (3) specific leaf area was lower in harvested gaps.

Lastly, Mallik et al. (2014) determined that riparian woody plant communities in partial harvesting gaps had a higher density and were more diverse than those communities in the un-harvested buffer areas. Density and diversity were higher in medium to large gaps and consisted of both shade-intolerant and early successional species. They speculate that more favorable light and soil temperature in the larger gaps are responsible for this. The main conclusion was that logging within the riparian zone to increase habitat complexity and early successional forest species is possible by logging up to 50% of the overstory basal area.

4.4 Non-Government Research in Other Eastern Canada Regions

Field-based primary research focusing on riparian vegetation has been conducted in only two other provinces in addition to Ontario; four studies in Quebec and two in Manitoba.

Quebec

In the southern boreal region of Quebec, Denneler et al. (1999) found that the elevation gradient, representing seasonal flooding, is the main factor determining the distribution of the tree species within the riparian zone of a large lake. To a lesser extent, geomorphological shore types through the influence of surficial substratum, topography, aspect, and fire also at least partially explain tree species distribution.

Boutin et al. (2003) evaluated the value of riparian habitats for conserving plant species in agricultural landscapes of southern Quebec species composition differed considerably among the various riparian habitats when comparing abundance of the following plant guilds: forest spring ephemerals, ferns, forbs, grasses, and woody vegetation. Habitats with trees contained a larger number of herb and woody species than other riparian habitats, however, habitats with trees were also more heterogeneous than other habitat types. More weedy and introduced species were found near crop fields.

Examining hybrid poplar riparian buffer strips along headwater streams in pastures, Fortier et al. (2011) found that understory biomass was lower on sites with the Poplar clone that had more crown biomass and that at some sites, the understory biomass was so low that it could compromise important buffer functions for water quality protection such as runoff control, sediment trapping, and surface soil stabilization. They also discovered significant positive relationships between canopy openness and the prevalence of introduced species, and a strong relationship between mean total species richness and mean introduced species richness. These findings are useful for designing multifunctional riparian buffer systems in agricultural landscapes.

In a study to identify and characterize the effects of increased flooding frequency on the structure and composition of forest stands, Berthelot et al. (2015) found that there were significant differences in the composition and diversity of forest communities among the different flood recurrence zones. Differences were also found in the structure of the communities, particularly in the frequent flooding zones, which are characterized by a low renewal rate, low density, and less-diversified forest stands. With expected increases in the number of flooding events in the coming decades due to climate change, there may be greater tree mortality and a gradual disappearance of the forest communities in high frequency flood zones.

Manitoba

Using one dataset to produce two studies Moffatt et al. (2004) and Moffatt and McLachlan (2004) compared the vegetation including plant species of riparian forests along an urban-rural disturbance gradient using 25 sample sites along the Assiniboine River in southern Manitoba. Each site was categorized into one of five land use categories including urban, suburban, high intensity rural, low intensity rural, and relatively high quality reference forest.

For the first study, differences in herbaceous, shrub, and tree species composition and diversity were related to the proportion of surrounding land use, forest patch size, connectivity, and area-perimeter ratio. Urban riparian forests were more disturbed and isolated, smaller, and characterized by drier, more alkaline soils. In addition, they had significantly lower native and overall understory species diversity, and had a higher proportion of exotic plant species. Although suburban understory diversity was similar to that of rural forests, suburban sites had a higher proportion of exotic species, especially escaped horticultural and invasive species. There was little difference in species composition and diversity among high intensity rural, low intensity rural, and reference sites.

For the second study, they found that generalist plant species, which frequented all land use types, dominated the understory community, whereas opportunistic and vulnerable species were relatively less common. Opportunistic species, which characterized city sites, tended to be exotic, woody and annual, and effective dispersers. In contrast, vulnerable species, which characterized non-city sites, tended to be native, perennial, and ineffective dispersers. Indicator species of disturbed forests were opportunistic and positively associated with disturbance measures. Indicators of high-integrity forest were vulnerable, often excluded from urban sites and were negatively associated with disturbance measures and positively correlated with native and overall diversity.

4.5 Riparian Restoration Targets

A number of ecologists have recognized the need to use assessment information and data from undisturbed reference sites to develop targets for the restoration of terrestrial ecosystems (e.g., Rheinhardt et al. 2009, Pollock et al. 2012, Mallik et al. 2013, Weisberg et al. 2013). However, less work has been done on identifying the most effective metrics to use in order to describe and monitor changes in terrestrial ecosystems from the early stages of restoration through to the final stages in order to assess success and/or failure.

Using the loss and fragmentation of temperate deciduous forest ecosystems in North America as a case study, Keddy and Drummond (1996) identified ten possible properties for monitoring changes in forest conditions including tree size, canopy composition, quantity and quality of coarse woody debris, number of spring ephemeral species in the herbaceous layer, number of typical corticulous bryophyte species (grow on bark), density of wildlife trees, fungi, avian communities, number of large carnivores, and forest area. Assessment of these forest characteristics (1) facilitates the recognition, ranking, and protection of high-priority forest sites for conservation; (2) identifies if a forested area is moving towards restoration or toward further alteration, and (3) will enable evaluation of different logging methods so we can select those that cause the least alteration to forests.

With a focus on riparian areas in the Brazilian Atlantic Forest, Suganuma and Durigan (2015) evaluated the effectiveness of 20 forest attributes for monitoring the success of forest restoration and identified four attributes as the most effective. These included the following.

- *Canopy cover*: is directly related to the recovery of biomass, shelter for wildlife and relevant ecosystem services, such as the recovery of microclimate, nutrient cycling, erosion control, and regulation of water resources. It is a good indicator for the first 10 years after initiation of restoration when change is clearly linked with age.

- *Basal area*: is a classic indicator of biomass, representing the recovery of forest structure and carbon sequestration. Basal area can be also be a surrogate for most of the ecosystem services related to canopy cover. As only trees above 5 - 10 cm dbh are usually measured, this is not an indicator to be applied during the first years after planting, when basal area is highly influenced by the density of seedlings planted.

- *Understory density:* the density of trees naturally regenerating is the most direct indicator of the recovery of natural biological processes. Among the size classes examined, saplings provided a more predictable response than seedlings, which are more subject to stochastic mortality factors.

- *Understory richness:* the number of tree species naturally regenerating in the restoration area is the best indicator of the effective recovery of diversity and persistence of species on the landscape. However, it is not a good indicator during the initial stages of restoration.

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TABLES 1-12

Table 1 - Common woody plants found in riparian areas of Eastern Canada (from Fortier 2014)

Region of Canada	Latin name	Common name
Eastern Canada	*Acer Rubrum*	Red maple
	Acer saccharinum	Silver maple
	Alnus incana subsp. rugosa	Speckled alder
	Betula papyfera	White birch
	Cornus stolonifera	Red-osier dogwood
	Fraxinus nigra	Black ash
	Fraxinus pennsylvanica	Red ash
	Larix laricina	Tamarack
	Myrica gale	Sweet gale
	Picea glauca	White spruce
	Picea mariana	Black spruce
	Pinus strobus	White pine
	Populus balsamifera	Balsam poplar
	Populus deltoides	Eastern cottonwood
	Populus x Jackii (BxD)	Jackii poplar
	Quercus bicolor	Swamp white oak
	Salix sp.	Willow
	Thuja occidentalis	Eastern white cedar
	Ulmus americana	American elm

Table 2 - Types and amount of logging allowed in riparian areas on crown land in Ontario (HPS = high potential sensitivity, MPS = moderate potential sensitivity, LPS = low potential sensitivity; from Naylor et al. 2012)

Variable	Water feature	Direction
Shoreline disturbance	Large lakes (≥1000 ha)	A maximum of 10% of riparian forest may be clearcut
	Medium lakes (100–999 ha)	A maximum of 25% of riparian forest may be clearcut
	Small lakes (8–99 ha) and HPS or MPS ponds	A maximum of 50% of riparian forest may be clearcut
	LPS ponds	Up to 100% of riparian forest may be clearcut
	Rivers	Riparian forest on 1 side of rivers may be clearcut
	HPS or MPS streams	Mature forest with ≥60% canopy cover retained within 15 m of water on both sides of streams
		Remainder of forest in riparian buffer (see below) may be clearcut on 1 side only
	LPS streams	Riparian forest on both sides of streams may be clearcut
Riparian trees	Lakes, rivers, and HPS or MPS ponds	Retain 10 dominant or codominant trees/100 m of clearcut shoreline
Restrictions on harvest, renewal, and tending operations to protect fish habitat and water quality	All water features	No trees felled into water features
		No disturbance of the forest floor within 3 m of water features (no machine travel, no trees felled into or extracted through this zone)
		Minimal disturbance of shrubs and saplings within 3 m of water features
		No ruts within 15 m of water features
		Minimal exposure of mineral soil (<5%) within 15 m of water features
		No ruts that channel water to within 15 m of water features
	All HPS features	No roads[a], landings, or aggregate pits within 30–90 m of water features based on slope (30-, 50-, 70-, and 90-m riparian buffers for slopes of 0–15, 16–30, 31–45, and >45%, respectively)
	All MPS features	No roads[a], landings, or aggregate pits within 30 m of water features
	All LPS features	No roads[a], landings, or aggregate pits within 15 m of water features

[a] Roads permitted if there are no practical or feasible alternatives and appropriate mitigative measures are taken to minimize risk of sediment transport to water features.

Table 3 - Plant species significantly correlated with distance from the stream bank at Blueberry Lake, Temagami (r=correlation; p=probability; included only those species with presence in 6+ quadrats; bold=species presence that terminated prior to the 32 m point; from Quinby et al. 1999)

Decrease with Distance Away from the Stream

Species	r	p
black ash	-.5725	.001
blue bead lily	-.7913	.000
Canada mayflower	-.4820	.005
dwarf raspberry	-.5366	.002
false Solomon's seal	-.4466	.010
fly honeysuckle	-.4669	.007
grasses	-.4563	.009
ground pine	-.6114	.000
lady fern	-.4101	.020
nodding trillium	-.4596	.008
northern beech fern	-.6169	.000
oak fern	-.4673	.007
sedges	-.5141	.003
shining club-moss	-.4933	.004
spinulose wood fern	-.3528	.048
upright wood-sorrel	-.6701	.000
violets	-.4529	.009
wild red raspberry	-.5133	.003

Increase with Distance Away from the Stream

Species	r	p
balsam fir	.3769	.033
common ploypody	.4707	.007
interrupted club-moss	.5655	.001
lichens	.4858	.005
mosses	.7731	.000
starflower	.4183	.017
white birch	.3846	.030

Table 4 - List of Plant Species in the Riparian Zone of the Cassels-Rabbit Lakes Area and their Correlation with Distance from the Streambank (species in bold face represent the most significant correlations and were used to generate the regression model; * means that the correlation was significant but too low to be included in the regression model; from Quinby et al. 2000)

SPECIES NAME	CORRELATION COEFFICIENT
Abies balsamea (basam fir)	.09
Acer pensylvanicum (striped maple)	-.35
Acer rubra (red maple)	.07
Acer saccharum (sugar maple)	-.19
Acer spicatum (mountain maple)*	-.37
Acetaea rubra (baneberry)	-.29
Adiantum pedatum (maiden hair fern)	-.32
Alnus incana (speckled alder)*	-.43
Alnus viridis (green alder)	.31
Amelanchier spp. (serviceberry)	-.21
Anemone candensis (Canada anemone)	-.26
Aralia nudicaulis (wild sarsaparilla)	.29
Aralia racemosa (spikenard)	.00
Aster macrophyllus (large-leaved aster)	**.74**
Athyrium filix-femina (lady fern)	**-.74**
Betula alleghaniensis (yellow birch)	**-.77**
Betula papyrifera (white birch)*	-.45
Botrychium virginianum (rattlesnake fern)*	-.43
Chimaphila umbettula (princes pine)	.00
Cicuta maculata (Cicuta maculata (water hemlock)	-.27
Circaea alpina (drawf enchanter's nightshade)	**-.69**
Clintonia borealis (blue bead lily)	**.64**
Coptis trifolia (goldthread)	**.57**
Cornus canadensis (bunchberry)	**.81**
Cornus rugosa (round-leaved dogwood)	-.08
Cornus stolonifera (red osier dogwood)	.16
Coryllus cornuta (beaked hazelnut)	-.03
Cypripedium acuale (pink lady's slipper)	-.16
Cystopteris bulbifera (bulbet fern)	**-.58**
Diervilla lonicera (nothern bush honeysuckle)*	.39
Dirca palustris (leatherwood)	.12
Drosera rotundifolia (round-leaved sundew)	-.22
Dryopteris carthusiana fancy (fancy wood fern)	-.32
Dryopteris carthusiana toothed (toothed wood fern)	-.34
Dryopteris marginalis (marginal wood fern)*	-.51
Epigaea repens (trailing arbutus)	-.01
Epilobium angustifolium (fireweed)*	-.36
Equisetum scirpoides (drawf scouring rush)	-.20
Equisetum sylvaticum (woodland horsetail)*	-.50
Eupatorium maculatum (Joe-Pye weed)	**-.66**
Fragaria vesca (woodland strawberry)	-.29
Fraxinus nigra (black ash)	**-.83**
Galium asprellum (rough bedstraw)*	-.40
Galium triflorum (fragrant bedstraw)*	-.55
Gaultheria hispidula (creeping snowberry)*	.37

Table 4 (con't)

Gaultheria procumbens (wintergreen)	**.60**
Goodyera repens (rattlelsnake plantain)	.20
Gymnocarpium dryopteris (oak fern)*	-.51
Huperzia lucidula (shining clubmoss)	.06
Hypericum virginicum (marsh St. Johnswort)	**-.62**
Impatiens capensis (spotted touch-me-not)*	-.55
Kalmia angustifolia (sheep laurel)*	.45
Lactuca spp. (wild lettuce)	.25
Larix laricina (tamarack)	.00
Lichen spp.	-.01
Linnaea borealis (twinflower)	.25
Lonicera canadensis (Canada fly honeysuckle)	-.35
Lycopodium annotinum (stiff clubmoss)*	.43
Lycopodium clavatan (wolfs claw club-moss)	**.59**
Lycopodium dendroideum (ground pine)	**.72**
Lycopus americanus (water horehound)	**-.60**
Maianthemum canadense (Canada mayflower)*	.54
Matteuccia struthiopteris (ostrich fern)*	-.55
Medeola virginiana (cucumber root)*	.55
Mentha arvensis (wild mint)*	-.47
Mitchella repens (partridge berry)	.26
Mitella nuda (naked mitrewort)	**-.62**
Monotropa hypopitys (pinesap)	.14
Monotropa uniflora (indian root)	.10
Moss/Liverwort spp.*	.49
Myrica gale (sweet gale)	-.32
Nemopanthus mucronatus (mountain holly)	.13
Onoclea sensiblis (sensitive fern)	**-.71**
Osmorhiza claytoni (sweet cicely)	.04
Osmunda claytoniana (interrupted fern)	-.05
Osmunda regalis (royal fern)*	-.48
Oxalis montana (wood sorrel)*	-.49
Phegopteris connectilis (northern beech fern)	**-.85**
Picea glauca (white spruce)	-.19
Picea mariana (black spruce)*	.50
Pinus bankisiana (jackpine)*	.37
Pinus resinosa (red pine)	-.01
Pinus strobus (white pine)	-.23
Plantanthera hyperborea (northern green orchid)	-.19
Plantanthera orbiculata (round-leaved orchid)	.27
Poaceae spp. (grass)	**-.71**
Polygonatum canaliculatum (true solomon's seal)*	-.41
Polygonum cilinode (black fringed bindweed)	-.19
Polypodium virginianum (rock fern)	.00
Populus balsamifera (balsam poplar)	-.22
Populus spp.*	.50
Potentilla palustris (marsh cinquefoil)	-.30
Prunus pensylvanica (pin cherry)	.09
Prunus virginiana (choke cherry)	**-.67**
Pteridium aquilinum (bracken fern)	**.82**
Pyrola spp.	-.04
Quercus rubra (red oak)	-.26
Ribes glandulosum (skunk currant)	.08
Ribes lacustre (black swamp currant)*	.39

Table 4 (Con't)

Ribes triste (swamp red currant)	-.22
Rubus idaeus (wild red raspberry)*	-.50
Rubus pubescens (drawf trailing raspberry)	**-.61**
Salix spp. (willow)	**.68**
Sambucus canadensis (Canada eldeberry)	.04
Sanicula marilandica (black snake root)	-.20
Scutellaria galericulata (marsh scullcap)	**-.56**
Sedge spp.	**.68**
Smilacina racemosa (false solomon's seal)	-.19
Solidango canadensis (Canada goldenrod)	-.25
Sorbus americana (American American mountain ash)	-.19
Spiraea alba (meadow-sweet)*	-.50
Streptopus roseus (rose twisted stalk)	.19
Taxus canadensis (Canada yew)	**-.59**
Thalictrum polygamum (tall meadow rue)	**-.64**
Thuja occidentalis (eastern white cedar)	.27
Tiarella cordifolia (foam flower)*	-.43
Trientalis borealis (starflower)*	.38
Trillium cernuum (nodding trillium)	.08
Vaccinium angustifolium (low sweet blueberry)	**.81**
Vaccinium myrtilloides (velvet leaf blueberry)	.33
Viburnum cassinoides (wild raisin)	-.03
Viola spp.	**-.70**

Table 5 - Plant species used as indicators in the regression analysis to predict distance from the streambank for riparian zones at 16 streams in the Cassels-Rabbit Lakes area of Temagami, Ontario (from Saddock 2001)

Species	0-2.5	2.5-5	5-7.5	7.5-10	10-12.5	12.5-15	15-17.5	17.5-20	20-22.5	22.5-25	25-27.5	27.5-30
Pteridium aquilinum – braken fern	0	0.01	0	0.01	0.07	0.14	0.04	0.38	0.18	0.21	0.22	0.45
Fraxinus nigra - black ash	1.53	0.85	1.16	0.25	0.33	0.18	0.06	0.10	0.07	0.14	0.01	0.05
Lonicera canadensis – Canada fly honeysuckle	0.16	0.09	0.09	0.09	0.15	0.11	0.09	0.09	0.01	0	0.06	0.05
Acer spicatum - mountain maple	14.59	19.47	17.50	15.80	14.99	12.37	10.15	10.17	12.57	12.84	8.61	12.01
Dryopteris carthusiana - fancy wood fern	0.22	0.14	0.16	0.18	0	0.03	0.01	0.07	0.14	0.08	0.03	0.04
Myrica gale - sweet gale	0.03	0.01	0.01	0.04	0.01	0	0.01	0	0	0	0	0
Betula alleghaniensis – yellow birch	1.46	1.80	1.44	0.83	0.77	0.65	0.35	0.49	0.33	1.03	0.60	0.47

Table 6 - Habitat characteristics per hectare for 18 riparian and 18 upland sites near White River, Ontario (from Mosley et al. 2003)

	Riparian		Upland			
Habitat characteristic	Mean±SE	CV (%)	Mean±SE	CV (%)	$t_{[34]}$	*p*
Total tree density	587.5±61.7	44.6	800.0±65.6	34.8	–2.356	**0.024**
Canopy height (m)	18.3±0.5	11.4	17.5±0.7	16.8		0.350*
Basal area (m^2/ha)						
Coniferous species						
Balsam fir (*Abies balsamea* (L.) Mill.)	2.5±0.7	115.4	2.2±0.5	102.0		0.962*
Black spruce (*Picea mariana* (Mill.) BSP)	5.6±1.1	82.3	6.0±1.5	109.7		0.681*
Jack pine (*Pinus banksiana* Lamb.)	1.2±1.0	372.6	2.3±1.4	250.8		0.903*
White spruce (*Picea glauca* (Moench) Voss)	0.8±0.5	228.0	0.0±0.0	424.8		0.127*
Subtotal	10.2±1.3	54.4	10.5±1.7	67.5	–0.152	0.880
Deciduous species						
Trembling aspen (*Populus tremuloides* Michx.)	0.7±0.4	271.0	4.5±2.1	202.0		**0.023***
White birch (*Betula papyrifera* Marsh.)	4.0±1.2	125.3	5.6±1.0	74.1		0.114*
Subtotal	4.7±1.3	114.6	10.3±2.3	94.6		**0.025***
Total	19.0±1.9	43.4	24.5±1.9	32.7	–2.035	**0.050**
Cover (%)						
Canopy (>5 m)	34.2±3.1	38.3	46.1±2.7	24.8		**0.018***
Sapling (2–5 m)	34.2±5.5	68.1	31.9±4.0	53.2	–0.510	0.960†

Note: Calculations were made using independent *t* tests except where otherwise noted. Significant *p* values are shown in bold. Red maple (*Acer rubrum* L.) and eastern larch (*Larix laricina* (Du Roi) K. Koch) were found in small proportions on some sites and are included in appropriate totals.
*Calculations made using Mann–Whitney *U* test.
†Data were $\log_{10}$ transformed to meet the assumptions of *t* test.

Table 7 - Herbaceous cover and shrub density and cover of 18 riparian and 18 upland sites near White River, Ontario (from Mosley et al. 2003)

	Riparian		Upland			
	Mean±SE	CV (%)	Mean±SE	CV (%)	$t_{[34]}$	*p*
Shrub density (stems/ha)						
Coniferous species						
Balsam fir (*Abies balsamea* (L.) Mill.)	526.7±107.8	86.8	668.9±141.7	89.9		0.475
Black spruce (*Picea marina* (Mill.) BSP)	208.9±67.3	136.8	113.3±42.4	158.9		0.309
Subtotal	740.0±111.2	63.8	822.2±161.8	83.5		0.987
Deciduous species						
Alder (*Alnus* spp.)*	1093.3±398.3	154.5	131.1±100.8	326.0		**0.006**
Beaked hazel (*Corylus cornuta* Marsh.)	257.8±153.2	252.1	415.6±231.9	236.8		0.920
Bush honeysuckle (*Diervilla lonicera* Mill.)	306.7±152.2	210.6	426.7±192.1	209.2		0.427
Labrador tea (*Ledum groenlandicum* Oeder)	482.2±237.8	209.2	104.4±62.4	253.4		0.212
Leatherleaf (*Chamaedaphne calyculata* (L.) Moench)	1468.9±728.5	210.4	0±0	0		**0.018**
Mountain ash (*Sorbus americana* Marsh.)	131.1±34.5	111.6	164.4±38.0	98.0		0.491
Mountain maple (*Acer spicatum* Lam.)	313.3±143.6	194.4	528.9±183.1	146.9		0.874
Serviceberry (*Amelanchier* spp.)	308.9±102.9	141.4	324.4±98.4	126.7		0.886
Sweet gale (*Myrica gale* L.)	1006.7±433.2	182.6	0±0	0		**0.018**
White birch (*Betula papyrifera* Marsh.)	375.6±199.8	225.7	128.9±57.8	190.3		0.565
Wild red raspberry (*Rubus idaeus* L. var. *strigosus* (Michx.) Maxim.)	286.7±129.8	192.1	0±0	0		**0.001**
Subtotal	6644.4±1344.2	85.8	3728.9±479.1	80.5		**0.005**
Total	7384.4±1330.3	76.4	3346.7±466.7	59.1		**0.012**
Cover (%)						
High shrub (0.5–2 m)	51.8±4.8	39.7	51.7±3.8	31.1	0.018	0.986
Low shrub (0–0.5 m)	56.4±3.8	28.8	52.8±3.8	30.5	0.670	0.508
Herbaceous	59.1±6.0	42.8	47.5±4.0	35.5		0.194

Note: Calculations were made using Mann–Whitney *U* tests except where otherwise noted. Significant *p* values are shown in bold.
*Green alder (*Alnus crispa* (Ait.) Pursh) and speckled alder (*Alnus rugosa* (Du Roi) Spreng.).

Table 8 - Mean (±SE) %cover of understory species used in the community composition analyses in large (L), medium (M), and small (S) gaps, un-harvested buffers (B) and in reference riparian areas (R) in Northern Ontario (from Mallik et al. 2013)

Taxa	L	M	S	B	R
Abies balsamea	27.5(7.6)	20.4(4.9)	26.8(13.1)	15.7(7.2)	30.0(15.2)
Acer spicatum	1.3(1.3)	7.2(4.4)	0	3.5(3.5)	0
Alnus crispa	1.2(1.2)	0.4(0.4)	0	0	0
Alnus incana	3.0(2.3)	6.2(3.4)	2.5(2.5)	0	0
Amelanchier sp.	2.7(0.9)	9.4(2.7)	15.5(8.2)	11.2(4.6)	3.0(2.6)
Aralia nudicaulis	4.3(2.5)	3.8(1.3)	0	7.2(5.9)	10.3(6.5)
Aster macrophyllus	2.1(1.4)	5.4(3.1)	0	3.9(2.5)	0.3(0.3)
Athyrium filix-femina	0	1.3(0.9)	5.6(4.3)	2.9(2.9)	0
Betula papyrifera	10.5(3.5)	5.9(2.4)	0	1.4(0.7)	0
Brachythecium sp.	5.0(1.5)	8.4(2.0)	5.6(2.5)	4.3(1.1)	14.6(4.5)
Calamagrostis canadensis	4.5(4.5)	0.5(0.4)	0	0	0
Carex sp.	4.8(3.6)	4.3(2.4)	1.8(1.8)	0.8(0.6)	0
Cinna latifolia	0	0.2(0.2)	0	1.6(1.6)	0
Cladina rangiferina	1.5(0.7)	0.8(0.4)	0	0.2(0.2)	1.0(1.0)
Cladonia sp.	2.7(1.0)	1.3(0.5)	0.2(0.2)	2.2(1.4)	2.0(1.2)
Clintonia borealis	18.4(4.0)	9.6(2.2)	11.8(4.7)	11.8(3.4)	11.0(3.0)
Coptis trifolia	3.2(1.7)	3.4(0.9)	2.5(1.8)	0.8(0.6)	2.0(1.6)
Cornus canadensis	26.6(5.2)	30.7(3.7)	18.7(7.3)	17.5(4.2)	24.6(9.1)
Cornus stolonifera	0	1.2(0.7)	0	0	0
Corylus cornuta	0.9(0.9)	0.3(0.2)	0	8.1(5.6)	0
Deschampsia flexiosa	0.9(0.6)	1.1(0.6)	0	0	0
Dicranum flagellare	0	0.1(0.1)	1.8(1.8)	0.8(0.8)	0
Dicranum montanum	4.3(1.0)	2.8(2.3)	0	3.1(3.1)	0.6(0.6)
Dicranum ontariense	0.4(0.4)	0.2(0.2)	5.0(5.0)	2.5(2.2)	1.0(1.0)
Dicranum polysetum	2.6(1.1)	3.7(1.1)	2.5(1.8)	4.1(2.2)	8.6(3.3)
Diervilla lonicera	13.8(6.4)	9.2(2.9)	18.1(12.0)	11.6(3.6)	15.6(6.6)
Epigea repens	2.5(1.7)	10.6(2.3)	10.0(6.6)	3.5(2.2)	0
Fungi	0	0.2(0.1)	0	0.6(0.2)	0.1(0.1)
Gaultheria hispidula	0	0.7(0.4)	0	0.4(0.4)	0
Gaultheria procumbens	2.3(2.3)	0	0	0	0
Goodyera repens	0	0.2(0.1)	0	0.8(0.5)	0
Ledum groenlandicum	4.8(4.0)	2.8(1.6)	3.2(3.1)	0.6(0.6)	0
Linnaea borealis	7.5(3.9)	4.7(1.3)	1.2(0.8)	5.4(2.8)	4.0(2.1)
Liverworts	0.1(0.1)	1.2(0.9)	0	0.6(0.3)	0.6(0.6)
Lycopodium annotinum	0.1(0.1)	0.4(0.3)	2.5(2.5)	0	0
Lycopodium dendroideum	1.3(0.9)	0.7(0.5)	0	0.2(0.2)	2.0(1.6)
Lycopodium lucidulum	1.4(0.6)	6.6(2.6)	6.8(4.9)	2.1(1.6)	5.3(3.3)
Mainthemum canadense	14.3(3.7)	9.1(1.7)	10.0(3.8)	9.1(3.5)	11.3(1.8)
Picea glauca	2.2(2.2)	5.1(3.7)	0	0.2(0.2)	0
Picea mariana	5.1(3.5)	2.7(1.4)	5.6(3.9)	10.4(4.6)	15.6(5.1)
Pleurozium schreberi	10.7(2.8)	22.2(4.8)	19.3(7.8)	17.1(8.3)	11.0(6.1)
Populus tremuloides	1.9(1.9)	1.7(1.0)	0	0	0.1(0.1)
Prunus pensylvanica	1.5(1.3)	1.5(1.5)	5.0(5.0)	0	0
Pteridium aquilinum	1.5(1.1)	3.6(1.6)	1.2(0.8)	6.8(6.8)	2.6(1.7)
Ptilium crista castrensis	0.3(0.2)	0.3(0.2)	0	2.9(1.8)	0.6(0.6)
Rubus idaeus	0	3.8(1.5)	10.6(10.6)	0	0
Rubus pubescens	0	2.0(0.8)	0	0	0
Salix sp.	0.7(0.7)	0.2(0.2)	0	2.9(2.0)	0
Sorbus decora	4.5(3.8)	2.6(1.1)	0	0	1.6(1.6)
Sphagnum girgensohnii	1.3(1.3)	1.8(1.4)	0	0	0
Streptopus roseus	0	0.7(0.4)	0	0.8(0.8)	1.0(0.6)
Trientalis borealis	0.4(0.2)	1.1(0.5)	0.6(0.6)	0.2(0.2)	0.6(0.6)
Vaccinium angustifolium	22.6(4.8)	24.5(4.5)	14.3(6.5)	20.2(5.2)	17.3(5.0)
Vaccinium myrtilloides	7.5(3.1)	6.6(2.6)	2.5(1.8)	0.6(0.6)	8.6(6.7)
Viola sp.	0.2(0.2)	0.8(0.6)	0.6(0.6)	2.5(2.5)	0

Table 9 - Regression results for tree species and geomorphological shore types at Lake Duparquet, southern boreal region of Quebec (from Denneler et al. 1999)

Shore type *Species*	Plots	rBA* [%]	Step 1 Variable	Step 1 Partial $r^{\dagger}$	Step 2 Variable	Step 2 Partial $r^{\dagger}$
Depositional flats	69					
Fraxinus nigra	37	71.7	Exposure (E_DG)‡	–0.429	—	
Larix laricina	26	72.6	Exposure (E_DG)‡	0.457	—	
Picea mariana	11	22.8	Horizontal distance	0.448	—	
Salix spp.	10	22.7	Aspect SE	0.357	—	
Thuja occidentalis	20	69.7	Peat	0.334	Elevation	0.285
Floodplains	33					
Fraxinus nigra	25	63.3	—		—	
Thuja occidentalis	10	49.8	Elevation	0.348	—	
Beaches	45					
Abies balsamea	21	47.8	Elevation	0.338	Exposure (E_FI)‡	–0.279
Populus balsamifera	10	61.7	—		—	
Thuja occidentalis	22	81.7	—		—	
Terraces	66					
Abies balsamea	18	39.5	Elevation	0.372	—	
Betula papyrifera	11	49.1	Horizontal distance	0.357	—	
Fraxinus nigra	11	58.1	Elevation	–0.387	—	
Thuja occidentalis	50	83.1	—		—	
Rock outcrops	28					
Thuja occidentalis	24	93.1	—		—	

*Mean of the relative basal area, using only plots where the corresponding species was present.
†$P \leq 0.009$.
‡Calculated with direct (D) or effective (F) fetch and wind exceedance during the growing season (G) or the ice-free period (I), respectively.

Table 10 - All tree species identified in 94 quadrats (10 m × 20 m) in the three zones (FFz = 0–20 yrs, MFz = 20–100 yrs, NFz = no-flood zones; from Berthelot et al. 2015)

Tree Species	Species Code	Total Tree Stems			Tree Species	Species Code	Total Tree Stems		
Flood zones (FFz and MFz) and no-flood zones (NFz)		FFz	MFz	NFz			FFz	MFz	NFz
Abies balsamea (L.) Mill.	ABBA	101	87	358	*Ostrya virginiana* Mill.	OSVI	–	3	13
Acer negundo L.	ACNE	81	3	–	*Picea glauca* (Moench)	PIGL	–	4	1
Acer saccharinum L.	ACRI	16	1	–	*Picea mariana* (Mill.)	PIMA	1	1	3
Acer rubrum L.	ACRU	28	35	161	*Picea rubens* Sarg.	PIRU	–	9	9
Acer saccharum Marsh.	ACSA	117	44	51	*Pinus strobus* L.	PIST	–	–	31
Betula alleghaniensis Britt.	BEAL	42	34	22	*Populus balsamifera* L.	POBA	3	7	–

Table 10 (con't)

Tree Species	Species Code	Total Tree Stems			Tree Species	Species Code	Total Tree Stems		
Betula papyrifera Marsh.	BEPA	2	4	13	*Populus deltoides* Bartr.	PODE	1	4	3
Betula populifolia Marsh.	BEPO	18	17	2	*Populus grandidentata* Michx.	POGR	3	4	6
Carpinus caroliniana Walt.	CACA	–	61	–	*Populus tremuloides* Michx.	POTR	67	18	11
Cornus altenifolia L.	COAL	3	–	–	*Prunus serotina* Ehrh.	PRSE	71	45	14
Corylus cornuta Marsh.	COCO	–	2	–	*Quercus rubra* L.	QURU	–	9	3
Fagus grandifolia Ehrh.	FAGR	1	13	10	*Salix* sp.	SALI	3	1	–
Fraxinus americana L.	FRAM	–	11	5	*Thuja occidentalis* L.	THOC	32	10	15
Fraxinus nigra Marsh.	FRNI	74	95	66	*Tilia americana* L.	TIAM	39	13	–
Fraxinus pennsylvanica Marsh.	FRPE	252	76	8	*Tsuga canadensis* (L.) Carr.	TSCA	0	20	123
Juglans cinerea L.	JUCI	–	1	–	*Ulmus americana* L.	ULAM	6	5	–
Larix laricina (Du Roi) Koch	LALA	2	3	–	*Ulmus rubra* Mühl.	ULRU	56	8	7
Malus pumila Mill.	MAPU	4	–	–	Unknown	UKN	10	5	12
Total of trees		741	487	696			292	166	251
Number of tree species		14	16	10			12	17	14

Table 11 - Species richness and number of dominant species for all exotic and native herbaceous species, all shrub species, and all tree species for each land use category in Southern Manitoba (P values are from one-way ANOVA, and means of diversity measures are separated using Tukey's multiple means comparison tests; from Moffatt et al. 2004)

			Urban			Suburban			High rural			Low rural			Reference			P[1]
Herbaceous	Overall	N_0	33.2	+/-4.1	b	71.2	+/-2.4	a	67.0	+/-5.9	a	67.8	+/-3.2	a	72.6	+/-6.3	a	< 0.0001
		N_2	4.8	+/-0.9	b	11.9	+/-3.0	ab	9.0	+/-2.3	ab	14.8	+/-1.7	a	11.6	+/-2.0	ab	0.0320
	Exotic	N_0	13.0	+/-2.0		13.2	+/-0.6		10.4	+/-1.4		12.8	+/-2.3		7.6	+/-1.0		NS
		N_2	3.0	+/-0.30		3.4	+/-0.47		2.5	+/-0.47		2.3	+/-0.29		2.9	+/-0.59		NS
	Native	N_0	20.2	+/-3.9	b	58.0	+/-2.3	a	56.6	+/-4.7	a	55.0	+/-2.6	a	68.5	+/-5.5	a	< 0.0001
		N_2	3.4	+/-1.4	b	9.5	+/-2.3	ab	9.4	+/-1.6	ab	13.7	+/-1.6	a	11.3	+/-2.2	ab	0.0125
Shrub	Overall	N_0	8.4	+/-0.6	b	15.8	+/-1.4	a	15.4	+/-1.3	a	12.8	+/-1.3	ab	14.8	+/-1.0	a	0.0012
		N_2	3.3	+/-0.5	b	6.7	+/-0.8	a	5.9	+/-0.7	ab	4.9	+/-0.8	ab	6.0	+/-0.7	ab	0.0261
Tree	Overall	N_0	5.0	+/-0.7		6.6	+/-0.5		7.2	+/-1.0		7.0	+/-0.8		7.0	+/-0.6		NS
		N_2	2.9	+/-0.3		2.8	+/-0.6		4.3	+/-0.7		3.8	+/-0.5		3.6	+/-0.7		NS

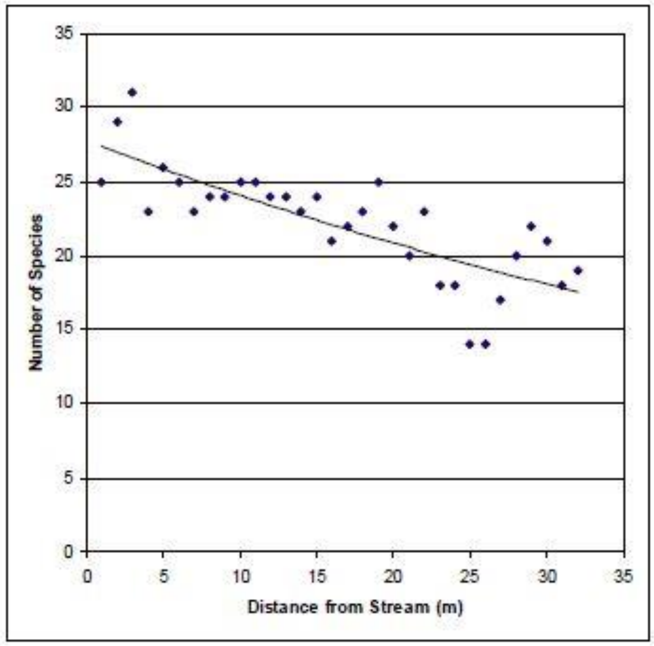
[1]NS, not significant ($P > 0.05$).

Table 12 - Mean values for the attributes of riparian forest communities in three types of reference ecosystems (Old-growth Forest, Degraded Forest, Secondary Forest) in the region of Semideciduous Tropical Forest, Brazil, and estimated time (years) for communities undergoing restoration to reach those values (from Suganuma and Durigan 2015)

	Old-growth Forest (n = *3*)		*Degraded Forest* (n = *3*)		*Secondary Forest* (n = *3*)	
	Mean ± *SE*	*Time*	*Mean* ± *SE*	*Time*	*Mean* ± *SE*	*Time*
Forest structure						
Basal area (m^2 ha^{-1})	31.7 ± 4.6	15	20.5 ± 2.6	8	24.7 ± 1.6	10
Canopy cover (%)	89 ± 2	36	87 ± 2	32	83 ± 2	24
Total density of tree species (ind. ha^{-1})	11,180 ± 914	51	9,963 ± 1,646	37	9,927 ± 1,737	37
Density of the whole understory (ind. ha^{-1})	9,990 ± 805	51	8,743 ± 1,596	37	8,207 ± 1,781	32
Density of saplings (ind. ha^{-1})	2,693 ± 427	71	2,650 ± 187	68	2,913 ± 487	87
Density of pteridophytes (ind. ha^{-1})	10,913 ± 1,312[a]	—	690 ± 571[b]	—	170 ± 47[b]	—
Density of lianas (ind. ha^{-1})	2,273 ± 90 [b]	—	4,407 ± 720 [a]	—	3,547 ± 595[ab]	—
Density of phorophytes (ind. ha^{-1})	173 ± 19[a]	—	127 ± 3[a]	—	30 ± 6[b]	—
Density of shrubs (ind. ha^{-1})	273 ± 155	—	873 ± 559	—	1,237 ± 537	—
Richness (tree species in 1,000 m^2)						
Total richness	78 ± 7	70	57 ± 6	23	51 ± 10	16
Overstory richness	41 ± 3 [a]	—	30 ± 6[ab]	—	20 ± 4 [b]	—
Richness of the whole understory	71 ± 6	77	49 ± 3	29	48 ± 9	27
Richness of saplings	42 ± 11	86	39 ± 4	69	32 ± 9	43
Rarefied richness for 100 individuals naturally regenerating	33 ± 3	39	25 ± 2	34	25 ± 5	34
Functional guilds (tree species)						
Proportion of animal-dispersed species	0.67 ± 0.02	49	0.64 ± 0.01	29	0.65 ± 0.05	35
Proportion of animal-dispersed individuals	0.54 ± 0.11	—	0.42 ± 0.14	—	0.57 ± 0.13	—
Proportion of shade tolerant species	0.81 ± 0.04	61	0.82 ± 0.02	64	0.77 ± 0.05	51
Proportion of shade tolerant individuals	0.93 ± 0.01	75	0.92 ± 0.04	73	0.73 ± 0.12	40
Proportion of slow growing species	0.41 ± 0.04	36	0.45 ± 0.02	45	0.40 ± 0.05	34
Proportion of slow growing individuals	0.66 ± 0.08	270	0.64 ± 0.13	247	0.37 ± 0.06	46

Values followed by the same letter or not followed by letters in a line do not differ statistically by ANOVA followed by Tukey test ($p < 0.05$). For attributes where there are no time values, these values are omitted because they show no predictable trajectories over time.

Figure 1 - Species richness in the riparian zone at Blueberry Lake, Temagami, Ontario (from Quinby et al. 1999)



APPENDIX A

RESULTS OF A SEARCH FOR THE USE OF THE TERM "RIPARIAN" IN ONTARIO MINISTRY OF NATURAL RESOURCES DOCUMENTS THAT ADDRESS ISSUES IN NATURAL RESOURCES MANAGEMENT

Interpretation of Types of Word Usage for "Riparian"

Page numbers reflect the sequencing determined by the pdf search function. The five types of word usage of the term "riparian" are as follows: (1) used as an adjective to denote the concept only - shown as "word only"; (2) used in the context of management and/or policy aspects - shown as "management prescriptions"; (3) used in a full bibliographic citation within a literature cited section - shown as "ref cite"; (4) reference to secondary source information from the literature - shown as "lit rev"; and (5) primary information about riparian ecosystems (field data) collected by the author - shown as "primary".

Manuals - Number of Instances of the Term "riparian" with Explanations

- OMNR. 1993. *Northern Ontario Wetland Evaluation Manual*. 0 instances

- OMNR. 1998a. *Code of Practice For Timber Management Operations In Riparian Areas*. 16 instances; some as descriptive adjectives and some relative to management guidelines; quote: the riparian zone "is the most productive environment in the forest" (pg. 1)

- OMNR. 1998b. *Algonquin Park Master Plan*. 2 instances - once in text to refer to the Riparian Timber Management Guidelines and once in the references cited section for same

- OMNR. 2000. *Significant Wildlife Habitat Technical Guide*. 19 instances

1-3 - use of word only (pg. 70)
4 - "In some of the most densely populated municipalities of southern Ontario, these riparian areas may be the most important remaining animal movement corridors." (pg. 72)
5 - "Maintain corridors that provide several benefits. For example, riparian corridors permit animal movement and help to ensure stable soils, necessary inputs of organic matter, and good water quality. Often these corridors are diverse natural areas because of fertile soils, a variety of habitat structure, a dependable source of water, abundant insect and plant foods, and several different microclimates." (pg. 73)
6 - "...in many areas, riparian areas that not only support rare vegetation communities, but often other significant wildlife habitats, are disappearing because of shoreline development along some lakes and rivers." (pg. 75)
7-19 - use of word only (pgs. 96, 115, 119, 120, 122, 126, 128)

- OMNR. 2003a. *Old Growth Definitions*. 1 instance (pg. 32); as a word only

- OMNR. 2003b. *Old Growth Policy*. 1 instance (pg. 20); as a word only

- OMNR. 2003c. *Guide to Stewardship Planning for Natural Areas*. 0 instances

- OMNR. 2009a. *Rare Vascular Plants of Ontario*. 1 instance (pg. 123); as a word only

- OMNR. 2009b. *Forest Management Planning Manual for Ontario's Crown Forests*. 0 instances

- OMNR. 2009c. *Ontario's Natural Heritage Areas: Their Description and Relationship to the IUCN Protected Areas Classification System (A Provisional Assessment)*. 0 instances

- OMNR. 2009d. *Ontario Protected Areas Planning Manual*. 0 instances
- Uhlig, P. 2009. *Ecosites of Ontario: Great Lakes-St. Lawrence Forest Region, Operational Draft*. Ministry of Natural Resources and Forestry, Sault Ste. Marie, Ontario.

17 instances - these are the GLSL ecosites that may be found in riparian zones; both swamp and fen are defined as wetlands in this publication; the instances are numbered below

Conifer Swamp
1 - organic poor conifer swamp (pg. 355)
2 - mineral poor conifer swamp (pg. 357)
3 - organic intermediate conifer swamp (pg. 359)
4 - mineral intermediate conifer swamp (pg. 361)
5 - organic rich conifer swamp (pg. 363)
6 - mineral rich conifer swamp (pg. 365)

Hardwood Swamp
7 - intolerant hardwood swamp (pg. 367)
8 - maple hardwood swamp (pg. 369)
9 - oak hardwood swamp (pg. 371)
10 - hardwood swamp (pg. 373)
Thicket Swamp
11 - mineral thicket swamp (pg. 375)
12 - organic thicket swamp (pg. 377)
13 - sparse treed fen (pg. 379)

Fens
14 - open moderately rich fen (pg. 387)
15 - open extremely rich fen (pg. 389)
16 - open shore fen (pg. 399)
17 - shrub shore fen (pg. 401)

Summary of document evaluation

(1) total of 224 ecosites in GLSL
(2) no listing and definition of "riparian" in glossary
(3) no riparian ecosite types
(4) 17 ecosites that may occur in riparian zones
(5) the only riparian-related term defined is "shoreline" and only relative to large bodies of water; those not defined include beach, bluff, and coastal
(6) there are 38 coastal and shoreline types including the following: excavated bluff, active bluff, open bluff, bluff, active mineral shoreline, active bedrock shoreline, bedrock shoreline, open bedrock shoreline, active talus or historic/raised beach, talus or historic/raised beach, open talus or historic/raised beach, anthropogenic coarse shoreline, active coarse shoreline, coarse shoreline, open coarse shoreline, calcareous active bedrock shoreline, calcareous bedrock shoreline, calcareous open bedrock shoreline, calcareous active talus or historic raised beach, calcareous talus or historic raised beach, calcareous open talus or historic raised beach, calcareous anthropogenic coarse shoreline, calcareous active coarse shoreline, calcareous coarse shoreline, calcareous open coarse shoreline, active coastal cliff, open coastal cliff, coastal cliff, active coastal bedrock shoreline, open bedrock coastal shoreline, coastal bedrock shoreline, coastal bedrock shoreline, active coastal bedrock shoreline, open coastal bedrock shoreline, coastal coarse shoreline, active coastal bluff, coastal bluff, active coastal mineral shoreline

- OMNR. 2010a. *Natural Heritage Reference Manual*. 92 instances

1 - 6; use of word only (pgs. 6, 22, 37, 45, 88, 90)
7 - "riparian vegetation greater than 30 m in width on each side of surfacewater features should be considered significant" (pg. 90)
8 - "Restoration of riparian vegetation should be considered, wherever possible, to provide a buffer for surrounding land, to provide natural linkage along valleylands and to enhance existing natural areas." (pg. 91)
9 - " areas where restoration will provide a minimum 30 m corridor of riparian vegetation on each side of surfacewater features" (pg. 91)
10-12 - use of word only (pgs. 105, 110, 117)

13 - 19; "While not listed as a specific fish habitat water feature, riparian areas – lands adjacent to watercourses, lakes, ponds and wetlands, which are also referred to as "riparian zones" – are transitional areas between aquatic and upland habitats and as such can provide natural features, functions and conditions that support fish life processes and protect fish habitat as defined by the Fisheries Act. Adjacent lands should be identified to encompass areas with important ecological functions, such as riparian areas. As transitional areas between aquatic and upland habitats, riparian areas represent a small percentage of most watersheds but can provide natural features, functions and conditions that support fish life processes and protect fish habitat as defined by the Fisheries Act. To avoid potential negative impacts of development on fish habitat (see section 13 and appendix C), adjacent lands studies (e.g., EIS) should identify the exact extent of riparian area that may be set aside for no development or site alteration. MNR recommends the establishment and/or retention of natural vegetated cover (see section 4.5) for the protection of fish habitat. Based on current scientific literature (Castelle et al, 1994; Environment Canada, 2004 – see section 16). MNR-recommended minimum distances to be maintained or rehabilitated as natural vegetated cover adjacent to identified fish habitat, as defined by the Fisheries Act, are provided in table 11-3. Recommendations in table 11-3 are consistent with other guidance such as the distances contained in the document Best Management Practices: Buffer Strips developed by OMAFRA (2004) in partnership with the federal government and various provincial stakeholder groups. The document contains detailed approaches for the composition and design of riparian area buffer strips (i.e., area maintained or rehabilitated as natural vegetated cover) on farms that go beyond the scope of the manual but can be useful for land use planning purposes. Planning authorities may consider the need for greater distances for natural cover for reasons such as the following: a water feature is highly stressed; an endangered or threatened aquatic species is present; enhancement of functions including detrital input, bank stabilization, pollutant removal and wildlife habitat/corridors are identified as further objectives; another feature or area that has ecosystem-based planning importance (e.g., natural heritage system, floodplain or significant valleyland) is present." (pg. 117)
20 - word only (pg. 138)
21 - "Riparian linkages support and enhance the ecological functioning of aquatic features by, for example, helping to maintain water quality and thermal regime, and detaining flow in storm events." (pg. 138)
22-30; lit rev; Chagrin River Watershed Partners, Inc. (2006). Why Riparian Setbacks? Willoughby, Ohio. http://www.crwp.org. "In this report, Chagrin River Watershed Partners Inc. provides a summary of research (including references) on riparian area functions and develops a model riparian setback regulation." Information from the USA publications (pgs. 149, 150)
31 - lit rev; Environment Canada. (2004). How much habitat is enough: a framework for guiding habitat rehabilitation in Great Lakes areas of concern (2nd ed.). Canadian Wildlife Service. Pp. 80. "This federal guidance document specifies that streams should have a minimum naturally vegetated adjacent lands area 30 metres wide on both sides, or wider depending on site-specific conditions... In its conclusion, the report also notes that there is increasing scientific support for the 30 metre guideline to be expanded to 50 metres and that it may be changed accordingly in the future." (pg. 150)
32 - lit rev; Environmental Law Institute. (2003). Conservation Thresholds for Land Use Planners. Washington, D.C. Pp. 55. "The majority of studies estimate edge influence to be 230 metres or less." (pg. 150)
33-36 - lit rev; Fischer, Richard A. (2000). Width of Riparian Zones for Birds. Ecosystem Management and Restoration Research Program Technical Notes Collection (EMRRP-SI-09), U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi. http://el.erdc.usace.army.mil/elpubs/pdf/si09.pdf. "He cites several studies on the minimum widths necessary to sustain bird populations and found a range of recommendations (50 to 175 m), noting that narrow riparian zones may appear to have high diversity but the species present tend to be forest-edge species. Fischer concludes that riparian zones should be at least 100 metres wide (this applies to both sides for larger rivers and to total width for lower-order streams and rivers) if avian habitat is a management objective." (pgs. 150, 151)
37-41 - lit rev; Fischer, Richard A., and J. Craig Fischenich. (2000). Design Recommendations for Riparian Corridors and Vegetated Buffer Strips. Ecosystem Management and Restoration Research Program Technical Notes Collection (EMRRP-SR-24), U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi. http://el.erdc.usace.army.mil/elpubs/pdf/sr24.pdf. "They conclude that [riparian] buffers wider than 10 metres should be promoted, but note that widths of 100 metres or more are usually needed to ensure protection of values related to wildlife habitat." (pgs. 151, 154)
42-43 - lit rev; Semlitsch, Raymond D., and J. Russell Bodie. (2003). Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conservation Biology 17(5):1219-1228. "The authors found that core terrestrial habitat ranged from 159 to 290 metres for amphibians and from 127 to 289 metres for reptiles, from the edge of the aquatic site.... [they] conclude that buffers of 15 to 30 metres, which are used to protect

wetland species in many states, are inadequate for amphibians and reptiles. ... a 50 metre terrestrial buffer at the outer edge [was also recommended]". (pg. 154, 155)
44-54 - lit rev; Wenger, Seth. (1999). A Review of the Scientific Literature on Riparian Buffer Width, Extent and Vegetation. Office of Public Service and Outreach, Institute of Ecology, University of Georgia. Found that riparian buffers up to 275 m are required to protect some animal species. (pgs. 155, 156)
55 - use of word only (pg. 156)
56 - ditto 31 (pg. 156)
57, 58 - use of word only (pgs. 156, 161)
59-66 - impacts of clearing in riparian areas including mitigation measures (pgs. 163, 164, 173, 200, 201)
67 - impacts of roads and water crossings on riparian areas including mitigation measures (pg. 201)
68 - impacts of human residential development on riparian areas including mitigation measures (pg. 201)
69-92 - works cited (pgs. 231-245)

- OMNR. 2010b. *Forest Management Guide for Conserving Biodiversity at the Stand and Site Scales – Background and Rationale for Direction*. 141 instances

1 - ref cite (pg. 18)
2-4 - word only; descriptive (pg. 28)
5 - ref cite (pg. 36)
6-7 - word only; descriptive (pg. 87)
8 - word only; descriptive (pg. 88)
9 - word only; descriptive (pg. 110)
10-12 - lit rev; Macdonald et al. 2006 (pg. 113)
11 - lit rev; Perkins and Hunter 2006b (pg. 113)
12-13 - lit rev; Monkkonen and Mutanen (2003) (pg. 113)
14 - lit rev; Hagan et al. 2006 (pg. 113)
15 - lit rev; Lamb et al. 2003 (pg. 113)
16 - word only; management prescriptions (pg. 115)
17 - word only; management prescriptions (pg. 123)
18 - lit rev; riparian zones as animal movement corridors; numerous references (pg. 123)
19 - word only; management prescriptions (pg. 124)
20 - lit rev; fire and riparian trees; Andison and McCleary 2002, Keeton and Franklin 2004 (pg. 126)
21 - ref cite (pg. 128)
22-25 - ref cite (pg. 129)
26-32 - ref cite (pg. 130)
33-37 - ref cite (pg. 131)
38-45 - ref cite (pg. 132)
46-50 - ref cite (pg. 133)
51-55 - ref cite (pg. 134)
56-60 - ref cite (pg. 135)
61-63 - ref cite (pg. 136)
64-67 - ref cite (pg. 137)
68-69 - ref cite (pg. 138)
70-71 - ref cite (pg. 139)
72-74 - ref cite (pg. 140)
75-81 - ref cite (pg. 141)
82 - word only; descriptive (pg. 146)
83 - ref cite (pg. 151)
84-85 - ref cite (pg. 152)
86-90 - ref cite (pg. 153)
91-97 - ref cite (pg. 154)
98-102 - ref cite (pg. 155)
102-106 - ref cite (pg. 156)
107 - ref cite (pg. 168)
108 - ref cite (pg. 172)
109 - ref cite (pg. 173)

110 - ref cite (pg. 178)
111 - ref cite (pg. 187)
112 - word only; descriptive (pg. 212)
113-114 - ref cite (pg. 214)
115 - lit rev; loss of riparian forest; (Marks et al. 1994) (pg. 258)
116 - lit rev; nests found in riparian forest (Marks 1986) (pg. 259)
117 - lit rev; restricting operations in riparian areas; (Hickie 1985) (pg. 306)
118 - word only; descriptive (pg. 320)
119 - lit rev; Beaver influence on riparian vegetation; (Johnston and Naiman 1990, Donkor and Fryxell 1999, Barnes and Mallik 2001) (pg. 320)
120 - word only; management prescriptions (pg. 323)
121-123 - ref cite (pg. 324)
124 - ref cite (pg. 325)
125 - word only; descriptive (pg. 352)
126 - word only; descriptive (pg. 353)
127-128 - word only; descriptive (pg. 354)
129 - word only; descriptive (pg. 360)
130-131 - word only; descriptive (pg. 381)
132 - lit rev; Butternut habitat; (Rink 1990) (pg. 419)
133 - lit rev; Louisiana Waterthrush habitat; (Craig 1985, Murray and Stauffer 1995, Prosser and Brooks 1998, Stucker 2000) (pg. 469)
134-136 - ref cite (pg. 472)
137 - word only; management prescriptions (title: Code of Practice for Timber Management Operations in Riparian Areas); (pg. 505)
138 - ditto 137; (pg. 507)
139-141 - ref cite (pg. 577)

- OMNR. 2011a. *The Forest Resources of Ontario 2011*. 2 instances (pgs 164, 165); both for an example of a 30 m timber buffer at Garden Lake - showing two photos

- OMNR. 2011b. *State of Ontario's Protected Areas Report*. 0 instances

APPENDIX B

Canadian Forest Service Publications - Ontario Riparian Related
(only Ontario-based scientists Kreutzweiser, Hazlett, Mosely, and Broad work shown)

(from: http://cfs.nrcan.gc.ca/publications/advanced?keywords=riparian&title=&subject=&issued_by=&type=&availability=&author=&from=&to=&sort=0&order=DESC&process=Search; accessed June 8, 2015)

Emulation of natural disturbance (END) for riparian forest management: synthesis and recommendations. Sibley, P.K.; Kreutzweiser, D.P.; Naylor, B.J.; Richardson, J.S.; Gordon, A.M. Year: 2012; Catalog ID: 33302 Available from: Great Lakes Forestry Centre; CFS Availability: PDF (request by e-mail); Available from the Journal's Web site. DOI: 10.1899/11-094.1

The effects of logging in riparian areas. Frontline Express 56. Kreutzweiser, D.P. Year: 2012; Catalog ID: 33363 Available from: Great Lakes Forestry Centre; CFS Availability: PDF (download)

Merging END concepts with protection of fish habitat and water quality in new direction for riparian forest in Ontario: a case study of science guiding policy and practice. Naylor, B.J.; Mackereth, R. W.; Kreutzweiser, D.P.; Sibley, P.K. Year: 2012; Catalog ID: 33303 Available from: Great Lakes Forestry Centre; CFS Availability: PDF (request by e-mail); Available from the Journal's Web site.
DOI: 10.1899/11-035.1

Introduction and a theoretical basis for using disturbance by forest management activities to sustain aquatic ecosystems. Kreutzweiser, D.P.; Sibley, P.K.; Richardson, J.S.; Gordon, A.M. Year: 2012; Catalog ID: 33300 Available from: Great Lakes Forestry Centre; CFS Availability: PDF (request by e-mail)

Effects of upland clearcutting and riparian partial harvesting on leaf pack breakdown and aquatic invertebrates in boreal forest streams. Kreutzweiser, D.P.; Muto, E.A.; Holmes, S.B.; Gunn, J.M. Year: 2010; Catalog ID: 31860 Available from: Great Lakes Forestry Centre; CFS Availability: PDF (request by e-mail); Available from the Journal's Web site. DOI: 10.1111/j.1365-2427.2010.02410.x

Operational and economic feasibility of logging within forested riparian zones. Holmes, S.B.; Kreutzweiser, D.P.; Hamilton, P.S. Year: 2010; Catalog ID: 31859 Available from: Great Lakes Forestry Centre CFS Availability: PDF (request by e-mail).

The influence of riparian vegetation on leaf litter inputs to Boreal Shield streams: implications for partial harvest logging in riparian reserves. Muto, E.A.; Kreutzweiser, D.P.; Sibley, P.K. Year: 2009; Catalog ID: 31170 Available from: Great Lakes Forestry Centre; CFS Availability: PDF (request by e-mail)

Stream temperature responses to partial harvest logging in riparian buffers of boreal mixedwood forest watersheds. Kreutzweiser, D.P.; Capell, S.S.; Holmes, S.B. Year: 2009; Catalog ID: 29375 Available from: Great Lakes Forestry Centre; CFS Availability: PDF (request by e-mail)

Sediment deposition in streams adjacent to upland clearcuts and partially harvested riparian buffers in boreal forest catchments. Kreutzweiser, D.P.; Capell, S.S.; Good, K.P.; Holmes, S.B. Year: 2009; Catalog ID: 31176 Available from: Great Lakes Forestry Centre; CFS Availability: PDF (request by e-mail); Available from the Journal's Web site. DOI: 10.1016/j.foreco.2009.07.005

The importance of catchment slope to soil water N and C concentrations in riparian zones: implications for riparian buffer width. Hazlett, P.W.; Broad, K.; Gordon, A.M.; Sibley, P.K.; Buttle, J.M.; Larmer, D. Year: 2008; Catalog ID: 28155 Available from: Great Lakes Forestry Centre; CFS Availability: Order paper copy (free)

Non-target effects on aquatic decomposer organisms of imidacloprid as a systemic insecticide to control emerald ash borer in riparian trees. Kreutzweiser, D.P.; Good, K.P.; Chartrand, D.T.; Scarr, T.A.; Thompson, D.G. Year: 2007; Catalog ID: 28592 Available from: Great Lakes Forestry Centre; CFS Availability: PDF (request by e-mail)

Songbird diversity and movement in upland and riparian habitats in the boreal mixedwood forest of northeastern Ontario. Mosley, E.; Holmes, S.B.; Nol, E. Year: 2006; Catalog ID: 28586 Available from: Great Lakes Forestry Centre; CFS Availability: PDF (request by e-mail)

Stand carbon stocks and soil carbon and nitrogen storage for riparian and upland forests of boreal lakes in northeastern Ontario. Hazlett, P.W.; Gordon, A.M.; Sibley, P.K.; Buttle, J.M. Year: 2005; Catalog ID: 28157 Available from: Great Lakes Forestry Centre; CFS Availability: Order paper copy (free)

Macroinvertebrate community responses to selection logging in riparian and upland areas of headwater catchments in a northern hardwood forest. Kreutzweiser, D.P.; Capell, S.S.; Good, K.P. Year: 2005; Catalog ID: 25847 Available from: Great Lakes Forestry Centre; CFS Availability: PDF (request by e-mail)

Large woody debris characteristics and contributions to pool formation in forest streams of the Boreal Shield. Kreutzweiser, D.P.; Good, K.P.; Sutton, T.M. Year: 2005; Catalog ID: 26446 Available from: Great Lakes Forestry Centre; CFS Availability: PDF (request by e-mail)

Fine sediment deposition in streams after selective forest harvesting without riparian buffers. Kreutzweiser, D.P.; Capell, S.S. Year: 2001; Catalog ID: 20524 Available from: Great Lakes Forestry Centre; CFS Availability: PDF (request by e-mail)