Current Regulations, Guidelines and Best Management Practices Concerning Forest Harvesting and Riparian Zone Management.

Buffer Zone Working Group
Literature Review
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1.0 Introduction

Canada's forests comprise 10% of the world's forest and stretches across all provinces and territories. As the forest industry grows in this country so does the demand for trees. Forests are both ecologically and commercially valuable and it is important to maintain both of these values through proper management. This can be achieved through Sustainable Forest Management, which can be defined as, "Management to maintain and enhance the long-term health of forest ecosystems, while providing ecological, economic, social and cultural opportunities for the benefit of present and future generations." (von Mirbach 1999). Ecologically, forests are essential because they provide habitat for two-thirds of Canada's 140,000 species of plants and animals (Anon 2002a), help moderate climate through carbon storage, and cycle air, water and nutrients (Barnes et al. 1998). Commercially, the forestry industry creates approximately 373, 000 jobs and contributes $20.8 billion to Canada's Gross Domestic Product (GDP) (Anon, 2002a).

There are 417.6 million hectares of forest in Canada, 234.5 million hectares of this are considered to be commercial forest. Commercial forest are areas where the trees can be harvested and have a market value, be it as pulpwood or lumber. Currently, 119 million hectares of the commercial forest is being managed by the forest industry. Within the managed forest approximately 19%, or 22.6 million hectares, is not harvested because it is considered as the protective riparian zone or key wildlife habitat (Anon 2002a). Riparian zones are considered the interface between the terrestrial and aquatic environments and are very productive areas with ecological functions characteristic to both environments (Anderson and Masters 2002). Although 51% of Canada forest is currently managed only 0.4% is removed each year by harvesting therefore sustainability is obtainable.

Composition of forested land in Canada is 67% softwoods, 18% mixed woods, and 15% hardwoods. Softwoods are the dominant forest type in Canada's boreal ecoregion which covers 299.2 million hectares of land (Hall, 1995). Eighteen percent of Canada boreal forest is considered to be old-growth or late-successional forest that is often referred to as steady-state because it dominated by climax species. Old-growth forest have four features, 1) the presence of large living trees, 2) large standing, dead trees referred to as snags, 3) fallen logs and debris on the forest floor contributing to the duff layer, and 4) logs and debris in neighboring streams and ponds (Hosie, 1990). Also, old-growth forest contain large quantities of biomass and is the reason they are in high demand by the forest industry. In Canada, boreal forest consists of extensive monoculture stands of conifers such as spruces, pines, and balsams firs. Deciduous stands of white birch and trembling aspen also exist within the boreal forest ecosystem (Hall, 1995).

Newfoundland and Labrador is covered by 22.5 million hectares of forests which comprises 5.4% of Canada forests. These forests are predominantly softwoods (91%) while mixed woods (8%) and hardwoods (1%) are significantly less abundant (Anon 2002a). The largest demand for this province's timber comes from the pulp and paper industry. The second greatest demand on forest comes from domestic firewood harvesting, only 8% of timber ends up at 1,800 licensed saw mills while less than 1% is harvested for furniture and flooring production (Young, 1994). Currently, 3 pulp and paper mills are operating on the island portion of the province and this has increased the demand for softwood forest. The traditional method of harvesting has been clear-cutting which is the most invasive method (Decker et al. 2002). Newfoundland and Labrador contributes approximately 1.2% to Canada forest industry and this is directly linked to the pulp and paper industry (Table 1). The major export from Newfoundland and Labrador's forest industry is paper and the largest markets for our paper is the United States and the European Union.

Table 1. A comparison of Newfoundland and Labrador's forest industry to the national forest industry.

	Canada	Newfoundland & Labrador
Value of Exports	\$47.4 billion	\$684.8 million (1.4%)
Number of Establishments	12, 630	158 (1.2%)
Direct Jobs	373, 326	4, 121 (1.1%)
Wages/Salaries	\$11.8 billion	\$114.0 million (0.97%)
Annual Allowable Cut	232.8 million m^3	2.7 million m^3 (1.2%)

Riparian protection is a common practice across all provinces and territories. Forestry regulations and guidelines for Newfoundland and Labrador, and from other areas across Canada, will be discussed in Section 4.0. The objectives of this literature review are to 1) examine the role of riparian buffers in minimizing the impacts of forestry operations, 2) review the current regulation and guidelines of forest harvesting and riparian zone management across Canada and 3) obtain optimal design objectives for harvesting within riparian buffers in Newfoundland and Labrador.

2.0 Best Management Practices

Best Management Practices (BMP) for forestry activities refer to the practice, or combination of practices that are thought to be the most effective and practical means of preventing or reducing the impacts on the chemical, physical and biological integrity of both the aquatic and terrestrial environments (MFC 2000, Flynn 1999, Lynch and Corbett 1990). BMP for forest harvesting activities were first introduced in the 1970's with the purpose of protecting water quality (Brandrup 2002, Flynn 1997, Belt et al. 1992). Since that time BMP have been improved and modified to include many different parameters including wildlife protection, site productivity, regeneration, and riparian buffers. A major consideration for BMP in North America is non-point source (NPS) pollution entering watercourses. NPS pollution refers to any pollution in which the specific point of generation and the exact point of entry into a watercourse are undetermined (Phillips et al. 2000). NPS pollution from forest harvesting operations can be excess sediment and/or nutrients that enter the aquatic environment, the majority of which comes from access roads. BMP have been proven to limit the impacts from forest harvesting. Park et al

(1994) found that implementation of BMP to an entire watershed reduced sediment and nutrient concentration within watercourses by 20% and 40%, respectively. Wang et al (2002) found that trout populations within Wisconsin streams improved after BMP implementation because of stream temperature moderation, introduced brown trout populations began spawning naturally due to cooler water temperatures. Prior to BMP implementation in western Washington, Grosse (1989) found fish production significantly declined and salmon runs were considerably reduced.

2.1 Access Roads

Access roads for forest harvesting operations are considered the largest contributors of excess sediment entering a watercourse. The potential impacts of sedimentation will be discussed further in Section 3.1. The basic principle behind most BMP is to direct water from access roads to areas of undisturbed vegetation so that the vegetation can act as a filter and remove some of the sediment. BMP are particularly important for stream crossings, these areas are most prone to excessive sedimentation and siltation from access roads. Arthur et al (1998) found that suspended sediment flux was 16 times higher in streams where BMP were not used. Conductivity and nutrient concentrations were also higher in streams without BMP. To limit the potential impacts from access roads there are many BMP that can be followed.

Proper pre-harvest planning for all roads and skid trails using topographic maps, aerial photographs, and soil survey maps to find the least threatening paths for roads and minimize the number of roads required to harvest a site is the key to BMP (Collins et al. 2000, Anon. 1993, ODNR undated). Both access roads and skid trails should be as short as possible to minimize the impacts on the soils and local productivity. Skid trails should not exceed 1km in distance (UME 1997). In western Washington, Grosse (1989) found that sedimentation increased 30 to 300 fold when roads are constructed through a forest depending on local geology. Finer soils are easily transported by water and wind therefore sites dominated by fine soils should be avoided as much as possible. Areas dominated by bedrock and large rocks are the best areas to place access roads. Roads should also avoid all watercourses and sensitive area such as wetlands as much as possible.

Keeping roads as high as possible where the soil is the driest due to increased drainage is another important component of BMP for access roads (UNL 1998, UME 1997). This is important because soil saturation will lower the infiltration capacity thereby increasing the potential for soil erosion and sedimentation. Minimize steep grades and sharp turns on access roads because these are points of high sedimentation. Grades greater than 15% should be avoided as much as possible. Steeper grades may contribute significant amounts of sediment to the aquatic environment. Also, limiting these types of areas will reduce the amount of maintenance required and may reduce erosion potential. Roads that follow topographic contour lines will lessen the grades and sharp turns therefore protecting the road from erosion during wet periods of the year such as spring and fall (Brandrup 2002, Anon. 1999).

Roads should not be located near watercourses with the exception of stream crossings. Pre-harvest planning using topographic maps and aerial photographs will help minimize the amount of stream crossings that are required to efficiently harvest an area. When crossing a stream it is best to used a bridge or an arc culvert because the stream bottom and flow are less impacted therefore the stream biota is also less impacted (Ezell 1998). The stream crossing should be built at the narrowest point of the stream and perpendicular to the flow. The crossed area should have a stable bottom with banks dominated by cobble and small boulders to help minimize the potential impacts. The access road approach to the stream crossing should be slightly inclined to limit runoff from the road reaching the stream. When necessary rip-rap can be applied to both banks to provide extra strength (UNL 1998).

Erosion control devices may be employed on access roads to limit the amount of sedimentation that may reach a watecourse. Water bars, filter fabrics, and seeding are common erosion control devices utilized on forest access roads (UME 1997). Water bars are built of stone and/or wood and are used to divert road runoff from ditches into vegetated areas. The sediment laden water is then filtered by the vegetation. Herbaceous vegetation has the greatest capacity for filtering sediment because of the stem complexity on the surface of the forest floor (Summers at al. 1998). This stem complexity slows the flow of the water thereby allowing the suspended sediment to settle out. Filter fabrics are often employed in ditches bordering forest access roads. These fabrics filter the sediment from the water flowing in ditches, often filter fabrics are used in a series of three or more to ensure that the maximum amount of sediment is removed before the runoff may enter a waterway. The least common erosion control device is seeding or revegetating road banks and ditches (Anon. 2000, UME 1997). This method is primarily used in the United States and is similar to hydroseeding. A seed mixture is applied to the road banks and ditches. The seed mixture is usually herbaceous grasses and weeds which are sprayed on the expose soil, the seeds quickly germinate and this stabilizes the road banks and filters road runoff.

2.2 Timber Harvesting Activities

The time of year when harvesting and timber extraction occurs may be a key factor in minimizing the potential impacts caused by forestry operations. Skidding timber during wet periods of year such as spring thaw or fall rains increases the potential for soil erosion, sedimentation, and loss of productive land (Anon. 1999, Anon. 1993). Skidding should be limited to dry periods of the year on dry or frozen soils, this will minimize both erosion and compaction and rutting of the cut area (Anon. 1994). All log landings/decks should be located on high and dry soils to limit erosion and compaction of the soils. These areas should be identified during the pre-harvest planning.

When harvesting within the riparian zone avoid the use of heavy machinery. Compaction and rutting of vegetation and soil bordering the watercourse will reduce bank stability therefore increasing erosion potential during peak flows and floods (Archibald et al. 1997). Using alternate techniques to extract timber will protect the riparian zone and limit the amount of damage done to the terrestrial environment and neighbouring aquatic systems. Alternate extraction techniques include manual harvesting, cable logging, mechanical harvester reaching into buffer, helicopter logging and even horse hauling have been utilized across Canada to limit ground disturbance.

A BMP for timber harvesting activities that is listed within many of the North American manuals is avoid windrowing. Windrowing is process of piling all slash and debris from harvested trees in long narrow piles within the cut block. The decomposition of windrows has the potential to alter the nutrient cycling of the site and increase the acidity of the soil. Aside from the negative impacts windrowing has on mineral soil, it may be beneficial in the short-term because it increases the availability of nutrients to the regenerating vegetation of the site (Barnes et al. 1998). Unfortunately, this increase in nutrients also has the potential to leach into neighbouring streams and ponds therefore increasing NPS pollution to the aquatic environment (Devito et al. 2000, Pomeroy 1998).

Another BMP for harvest activities deals with the harvesting method. Choosing a method that will maintain or enhance the structural diversity will maintain or increase the productivity of the site. Increased structural diversity of a stand creates numerous habitat spaces for many different organisms increasing the species richness of the area. The edge habitat along cut blocks and riparian zones have the highest degree of structural diversity because within a short horizontal transect there is a vertical change from an open cut block to mature trees (McCleary and Mowat 2002, Naiman et al. 1993). This creates habitat for interior species as well as species better adapted to open areas within a short distance. Areas with increased diversity are better able to withstand and survive catastrophic events such as wind, fire or insect outbreak because there is a greater diversity of vegetation to regenerate the site.

2.3 Revegetation

Planting trees after a harvesting event is considered a BMP because the goal is not only to renew the cut trees but also benefit the remaining woody and herbaceous vegetation that contributes to a functioning forest (Chunko and Wolf 2001). Benefits include increased shade, soil stability and wind stability. Reforestation can occur naturally or artificially by hand or mechanical planters. Mechanical planters are much quicker than hand planting but are more destructive to the land because a tilling process is used to expose the mineral soil and plant the tree. On slopes greater than 21% hand planting should be used while machine planting can be employed on slopes 5 – 21% if the machine follows the natural contours of the land. Avoid mechanical planting up or down slopes greater than 5% because rutting by machinery may facilitate runoff (Anon. 1999).

Revegetation is beneficial because it will increase soil stability of the cut block due to increase root structure, increase both plant and structural diversity therefore promoting biodiversity and protecting watercourse by filtering sediment-laden runoff. Revegetation will also provide wildlife with habitat and food potentially increasing species diversity (MacKinnon 1994). If planting is done correctly, regeneration of the site will replicate forest succession allowing a host of different flora and fauna to utilize the area at different periods along the succession. A key issue while revegetating is never use non-native or exotic species because they may out-compete the native species and alter the local landscape and food webs. This may be extremely detrimental in areas depended on by endangered or threatened species of flora or fauna.

2.4 Forest Improvement and Protection

The BMP for forest improvement and protection includes pre-commercial thinning operations, insecticide application and prescribed burning. Each of these assure the long-term viability of the forest and creates commercially valuable timber without major perturbations to the environment. Prescribed burning is not often utilized in this province even though forest fires are an important component of some forest types of central Newfoundland and Labrador (Damman 1964). In this province, like the majority of Canada, pre-commercial thinning and pest control are the most utilized methods for forest improvement and protection.

Mortality within a forest stand is greatest at the seedling stage and is caused by competition for available light, water and nutrients (Barnes et al. 1998). Pre-commercial thinning is carried out to reduce stand density thereby limiting stand competition and producing larger trees within a shorter time frame (Chunko and Wolf 2001). The thinned trees remain in the stand to add nutrients to the site during decomposition and also contribute to the duff layer of the forest floor. Recent studies in Newfoundland have shown that thinning balsam fir stands lead to significant root and butt rott (English and Warren 1999). It is more beneficial to pre-commercially thin white and black spruce stands.

Insecticide application is another heavily used method for forest improvement and protection. A variety of different insects attack commercial forest across Canada and around the world. A large outbreak can render a stand commercially worthless. To protect against these drastic losses to insect outbreak many insecticides have been developed to attack the culprit insects while minimizing any potential impacts on other insects, birds, mammals and the neighbouring aquatic systems. In Newfoundland and Labrador the Hemlock Looper and the Balsam Fir Sawfly can have extreme impacts on the softwood forest and it is these two insects that are the target of the insect control program. In 1970, prior to insecticide programs the spruce budworm destroyed 50 million m^3 of black spruce and balsam fir, this is equivalent to approximately 25-year wood supply for the forest industry in Newfoundland (DFRA 2002).

2.5 Riparian Buffer Zones

Riparian buffers are narrow strips of land bordering aquatic systems and have direct interactions with both the aquatic environment and the terrestrial environment. These areas are the most utilized best management practice to protect against the potentially adverse effects of forest harvesting. Riparian buffers help protect against excessive siltation in streams, increases in water temperature, losses of woody debris inputs, loss of bank stability, changes to the hydrologic cycle, changes to nutrient cycling, and losses of wildlife habitat (O'Laughlin and Belt, 1993, Anon 1995, White and Krause 1993, Moore 1983).

A common trend in all BMP manuals from Canada, the U.S., and Europe is that riparian buffers remain adjacent to all water bodies with limited or no harvesting to occur within them. The width of the buffer varies between areas from a minimum of 3m to a maximum of 100m. The majority of riparian buffers are 15 – 30m wide with some selective harvesting allowed within. A review of the role of buffers is provided below.

3.0 Riparian Buffer Zones

3.1 Functions of Riparian Buffers

There are many ecological functions of riparian zones stated within the literature and these include maintaining physical structure of streams, bank and channel stability, stream shading, sediment interception, wildlife corridors, cavity trees and snags, and wildlife foraging areas (Koning 1999, Reid and Hilton 1998). Undisturbed riparian buffers adjacent to cut blocks help maintain water quality, aquatic habitat, support distinct vegetation, and are areas of high quality terrestrial habitat for wildlife (Whitaker and Montivecchi 1999). These functions incorporate both the aquatic and terrestrial environments and can be divided into four broad categories, 1) filters, 2) shelters, 3) stabilizers, and 4) detritus suppliers. The preventative functions of each category are discussed below.

3.2 Filters

Forest harvesting operations have the potential to increase the sediment and nutrient inputs to a stream thereby lowering the water quality. Riparian buffers minimize this disturbance through a filtering action. Increased sediment loading into a watercourse can occur from the construction and maintenance of access roads, skid trails, log landings, and also from cut blocks. The majority of sedimentation that occurs within a harvested watershed is directly related to the amount of access roads (Elliot et al. 1999, Clarke et al. 1997). Surface erosion and mass failure are the two processes that sediment leaves the road or cut block and enters neighboring watercourses. Skid trails also have the potential to increase sedimentation because heavy equipment used to extract logs can expose soil and cause compaction and rutting of the ground which aids the movement of sediment-laden runoff from the cut block (Archibald et al. 1997). Kreutzweiser and Capell (2000) found significant increases in fine sediments after significant ground damage caused by forest harvesting, up to 1900 times the pre-harvest average. Log landings contribute to sedimentation because similar to the access roads the log landings are finished with fine sediment and compacted. This fine sediment is removed from the surface of the log landing during rainfalls, snowmelt, and by mass wasting. Sedimentation can also occur from the cut block. Once trees are harvested and vegetation is disrupted the soil losses its stability due to the loss of roots. The loosened soil in the cut block then has the potential to be washed into watercourses by rain, snowmelt and by the mass failure on areas with increased slope. Snow accumulation is greater on the cut block than in neighboring riparian zones because there is no snow interception by trees therefore there is greater potential for runoff from the cut block (Meng et al. 1995).

Excess sedimentation can render streams and ponds unsuitable for drinking water because of increased turbidity. The increase of suspended solids within a water column will create murky or dirty water which is unsuitable for human consumption. Increased turbidity can also impact fish populations by lowering the success rates of capturing prey due to reduced visibility (Berkman and Rabeni 1987). High rates of suspended solids in the watercourse can irritate fish gills leading to increased stress, infection, disease and may potential lead to death. Sedimentation can destroy important fish habitat by filling pools and it can also reduce or destroy breeding or spawning grounds (Newcombe and MacDonald 1991). Salmonids required gravelly substrate to create spawning beds (redds) and in streams with excessive sedimentation the interstitial spaces required for spawning are filled thereby destroying the redd. When sediment covers existing redds then the salmonids egg or recently emerged alevin can perish due to loss of oxygen (Lisle 1989). Macroinvertebrate populations are also hindered by increases in sedimentation that may be caused by forestry operations because similar to fish it destroyed substrate habitat and covers detritus on the stream bottom which is an important macroinvertebrate food source (Garmon and Moring 1993). Increased sedimentation also can help increase water temperatures. Suspended sediment particles can absorb sunlight therefore raising the temperature of the water and lowering the amount of available dissolved oxygen (DO).

Increased nutrient concentrations within watercourses can occur immediately after a harvest event. An increase in nutrients is caused by the loss of uptake by trees, an increase in decomposing slash on the forest floor, excess surface runoff, and increased soil leaching (Moore 1983). The increase of nutrients within a watercourse varies depending on the soil characteristics of the neighboring cut site including soil type, texture, parent material, and biogeochemical cycling rates (Fulton and West 2001, Carignan and Steedman 2000). Nitrogen and phosphorus are potentially the most damaging nutrients to enter the watercourse because they are often biologically limited within an aquatic system (Rosen et al. 1995, Jewett et al. 1995). When in excess, nitrogen and phosphorus may facilitate increased algal growth referred to as an algal bloom. Algal blooms are detrimental to the aquatic system because they can reduce water clarity, thereby reducing photosynthesis, and blooms may produce anoxic conditions during the mass death and decomposition of the algal population (Horne and Goldman 1994).

Riparian buffers also help maintain normal streamflow. After a harvesting event streamflow tends to increase because of the loss of evapotranspiration (Twery and Hornbeck 2001). This loss of evapotranspiration causes an increase in the amount of water within soils and this leads to a “watering-up” of neighboring watercourses. Many studies have shown significant increases in water yield and peak flow following clear-cuts and this is directly related to the loss of trees and its impact on the hydrological cycle (Jones and Grant 1996, Lynch et al. 1972, Douglass and Swank 1972, Dunford and Fletcher 1947). Larger watersheds are less susceptible to increased water levels than smaller watersheds.

Riparian buffers help minimize the potential inputs of sediment, nutrients, and excess water by a filtering action. The structural complexity of roots and herbaceous stems in addition to the absorption capability of the duff layer limits excess sedimentation to the aquatic system (Barden 2001). Surface runoff will slow down when it comes in contact with herbaceous shrubs, mature trees and the duff layer on the forest floor. As the flow slows large amounts of sediment are deposited within the riparian buffer before it reaches the watercourse. Water movement through the soil is filtered by the existing soil and also by the roots of riparian vegetation. Nutrients are often removed via the absorption by riparian plants as runoff moves through the soil column prior to entering watercourse. Also, excess water from the cut block is reduced as it flows through the riparian buffer. The litter layer and moss cover of the forest floor has high moisture capacities therefore it is able to absorb large quantities of water (France 1997). The riparian buffer also maintains evapotranspiration of the hydrological cycle therefore some of the water is return to the atmosphere before it can reach a watercourse.

3.3 Shelters

Riparian buffers help shelter the aquatic environment through shading by the canopy cover while also providing shelter to terrestrial organisms. In the aquatic environment, loss of canopy cover can lead to increases in water temperature via two mechanisms, 1) increase solar radiation to water surface and 2) warmed groundwater through increased solar on exposed forest floor (Mellina et al. 2002, Garman and Moring 1991). First, as the canopy is removed there is an increase in the amount of sunlight that is able to reach the surface of the watercourse. This causes a direct increase in water temperature. Secondly, warmed groundwater entering a stream will increase its thermal regime. This occurs indirectly when increased solar radiation is able to reach the forest floor after a harvest event thereby warming the soil. As runoff and rainwater percolates down through the soil it warms therefore warmed groundwater may enter a watercourse. Increasing solar radiation and water temperature may be beneficial because it may increase the primary production of the stream (Berg 1995) but it may also be detrimental due to increasing stress on fish and macroinvertebrates. Studies have proven that temperatures rise to levels stressful to fish and macroinvertebrate populations after harvesting events (Brown et al. 1997, Newbold et al. 1980, Clarke et al. 1997). Increased stress is related to the reduction in dissolved oxygen within the water column as the temperature increases. Also, increased temperature may reduce the hatching success of freshwater fishes (Scruton et al. 2000). Many species will only hatch during a particular temperature range and if this occurs early do to increase solar radiation then the juvenile has a limited chance of survival. Also, the microclimate of the riparian zone is sheltered by the overhanging canopy. Changes to the temperature, solar radiation and humidity within the riparian area may impact ecosystem processes such as succession, biogeochemical cycling, decomposition of duff layer, and stand productivity (Brosofske et al. 1997).

In the terrestrial environment, riparian buffers act as protective shelters and corridors for wildlife. Most terrestrial organisms do not utilize cut areas because of the limited shelter from predators (Rodewald and Brittingham 2001). The greatest diversity of wildlife is within the core habitat of old growth forest. Outside interior forest there is a decline in species diversity (Stocek 1994). As forests are removed wildlife tend to seek out areas with forest cover. Also, there is limited movement across cut blocks to other forested areas therefore the wildlife populations may become disjoint from other populations (Meffe et al. 1997). This may decrease the survival success of the population because of limited genetic diversity caused by inbreeding. Also, during the winter months there is a greater accumulation of snow on cut blocks than within uncut riparian buffers therefore wildlife may be unable to move through the deep snow (Meng et al. 1995). When this occurs, terrestrial organisms may use the riparian buffers as travel corridors. Forest harvesting operations leads to decreased wildlife habitat and migration.

Riparian buffers help minimize each of these impacts by acting as a shelter. This includes providing shade to the stream and forest floor to minimize temperature changes to the aquatic environment and by providing protective shelter and dispersal corridors to wildlife. The retention of canopy cover within the riparian buffer may limit changes to the thermal regime of neighbouring watercourses. South-facing slopes may require a greater buffer because of higher incident solar radiation (Megahan et al. 1995). Terrestrially, wildlife tend to seek refuge in riparian buffers because they provide cover and migration paths. Potentially, there may be an increase in species diversity because of increased structural diversity created at the edge of the buffer. A study from Labrador showed that there was an increase in avifauna species in areas impacted by 30% forest removal because there was enough old-growth forest and canopy openings to support both interior birds and birds depended on early successional forest conditions (Simon et al. 2000). Unfortunately, other than avifauna, little work has been conducted in the boreal forest to quantify the use of buffers as habitat and corridors for terrestrial organisms.

3.4 Stabilizers

Soil stability is dependent on the root structure of all types of vegetation, particularly mature trees. After a harvest event remaining roots from cut trees decay within the thereby soil lowering soil stability potentially leading to mass movement of soil and/or erosion of stream banks during peak flows (Barden 2001, White and Krause 1993). Mass soil movements are more frequent as the slope of the stream bank increases. These types of soil movements result in a one-time large input in sediment into adjacent watercourses and can quickly destroy aquatic habitat by filling pools and covering spawning beds. Loss of bank stability after the removal of trees may also lead to erosion of the stream banks during peak flows and floods. Similar to mass movement, bank erosion is often severe and causes a large one-time input of sediment. There is also the destruction of key fish habitat associated with stream bank erosion such as undercut banks.

Riparian buffers also help stand stability against wind. Often there is an increase in windthrow at the edge of the riparian buffer. These fallen trees often blow into the buffer and have the potential to down other trees. The riparian buffer is considered to have two zones, the core which is adjacent to the stream edge and the outer area which includes the buffer edge. The interior core does the majority of protection, acting as filters and shelters to watercourses. The outer zone of the riparian buffer has more structural diversity because of the edge therefore it is related with the protection of wildlife and wildlife habitat. The outer zone acts as wind protection to the interior core (Anon 1995). Areas heavily influenced by wind may increase the width of the buffer to protect the interior zone and the watercourse.

3.5 Detritus Suppliers

Forest harvesting removes the source of litter on the forest floor along with fine and coarse woody debris within watercourses. On the forest floor detritus from overhanging vegetation is extremely important because it contributes to the duff layer. The duff layer acts to retard the movement of sediment-laden water therefore it aids in the filtering action of riparian buffers. Also, as the duff layer decomposes nutrients get returned to the biogeochemical cycling of the site and are available to be absorb by plants again. In addition to this, the duff layer has a high moisture capacity therefore after a harvest event it is able to store the excess water not lost to evapotranspiration (France 1997). This limits the "watering-up" effect on neighboring watercourses. When trees are harvested the duff layer slowing decomposes without any new inputs then these benefits are lost (Tims 1994). Also, the removal of trees by heavy machinery can destroy the duff layer and soil through compaction and rutting.

Organic matter budget for small streams are dominated by inputs of terrestrial material (Bilby and Bisson 1992) therefore these systems are depended on allochthonous production rather than autochthonous (primary production). Allochthonous debris in stream is usually in the form of particulate organic matter, both fine (<1mm) and course (>1mm). Once trees are harvested there is a significant reduction in the amount of debris which enter a watercourse which may potentially lead to a reduction in productivity of the system. The retention of riparian buffers ensures debris inputs for allochthonous production within watercourses. The riparian zone is the source of the majority of debris that enters a watercourse, and the debris enters primarily via windthrow or snowloading. Large woody debris (LWD) is also important to the aquatic environment because of its potential to create habitat. LWD helps form and maintain habitat units such as pools through the scouring action of the stream bottom (Flebbe and Dolloff 1995). In Newfoundland and Labrador, LWD is determined to be anything larger than 8cms in diameter (Decker at al. 2000). LWD of this size is large enough remain stable under normal flow conditions within small NL streams.

4.0 Provincial Guidelines/Legislation

4.1 Newfoundland and Labrador

Currently in Newfoundland and Labrador there is a 20m riparian buffer requirement on all watercourses that are represented on a 1:50,000 topographic map (Goose et al. 1998). A 20m buffer is also require adjacent to any water body greater than 1m wide not visible on a 1:50,000 topographic map (Scruton et al. 1997). The buffer must be treed and it is measured from the high water mark of the watercourse. The riparian buffer strip is used for both the protection of water quality and as habitat for wildlife. Buffer width can be greater than 20m if the bank slope is greater than 30% or if the forestry application changes. When the slope is greater than 30% the buffer width must be 20m plus 1.5 times the slope (%) (Table 2) (Scruton et al. 1997). Different forestry applications refer to land uses other than harvesting. This includes the use of an area for fuel or pesticide storage, logging camps and maintenance buildings, and areas treated with insecticide. These areas may require up to a 400m buffer bordering watercourses (Table 3). In Newfoundland and Labrador harvesting within the 20m riparian buffer is not permitted although most other provinces and territories across Canada do permit some level of selective cutting within their buffers.

Table 2. Recommended minimum buffer strips to protect fish habitat during forest cutting activities. Buffer strip width is equal to 20m plus 1.5 times the slope in percent where the slope exceeds 30% (reproduced from Scruton et al. 1997).

Slope (%)	Slope (°)	Width (m) of Buffer
0	0	20
15	8	20
30	17	65
45	24	88
60	31	110

Table 3. A summary of recommended minimum riparian buffer strips for various forestry-related activities (reproduced from Scruton et al. 1997).

Activity	Recommended Buffer Width (m)
Fuelling/Servicing	30 m
Fuel Storage	100 m
Landings	20 m (+1.5 x % slope where > 30%)
Skid Trails	20 m (+1.5 x % slope where > 30%)
Roads	20 m (+1.5 x % slope where > 30%)
Barrow Pits	100 m
Drainage	30 m
Pesticide Storage, Mixing	100 m (temporary storage)
Herbicide Application	44+ m
Insecticide Application	400m from freshwater, 1.6 km from coastal areas
Silviculture	20 m (+1.5 x % slope where > 30%)
Camps/Maintenance Buildings	100 m
Primary Processing Facility	100 m
Slash Placement	30 m
Controlled Burns	20 m (+1.5 x % slope where > 30%)

4.2 Nova Scotia

In April 2000, Nova Scotia's Forest Sustainability Regulations became law and state that all users of the forest that require greater than 5,000 cubic meters of timber annually must have a silviculture program in place or contribute to the Sustainable Forest Fund (Anon. 2002a). Forest management practices within Nova Scotia attempt to maintain, protect and enhance biodiversity and other forest values including environmental, economic and social needs. The provincial Department of Natural Resources ensures that the forest harvest rate does not exceed timber growth. The annual sustainable harvest for Nova Scotia is 3.8 million cubic meters of softwood and 1.5 million cubic meters of hardwood and clear-cutting is the most used method of harvesting (DNR 1997). The major exports from Nova Scotia's forest industry is pulpwood and saw logs and the value of exports is a major component of the harvesting levels set by the provincial government. Much of the land in Nova Scotia is privately owned (69%) and more than 60% of all timber harvested in 1998 was from these privately owned blocks (Nova Forest Alliance 2002). Due to the large amount of privately owned land it is important for the Department of Natural Resources to have a good working relationship with landowners to ensure departmental regulations and guidelines regarding riparian zone management are understood and followed.

Riparian buffers in Nova Scotia are referred to as Special Management Zones (SMZ). Similar to Newfoundland and Labrador, a 20m riparian buffer is required on all water-bodies present on a 1:50,000 topographic map including streams/rivers greater than 50cms wide, all lakes and ponds, marshes with permanent water openings, and all salt water bodies (NSNR 1997). Streams less than 50cms wide can be harvested to the stream bank providing there is a 5m no-machine zone from stream, minimal disturbance to the small trees and shrubs bordering the stream, and no sediment can enter the waterway. SMZ width may be greater than 20m if the buffer slope exceeds 20%. When this occurs the operator must add 1m to the SMZ width for every 2% increase in slope beyond 20%. This continues up to 60m which is the maximum SMZ width (Duke 1997).

An interesting component of Nova Scotia's forest management plan is the retention of forest clumps within the cut block to help maintain wildlife connectivity and productivity by aiding dispersal. Clumps are also important to the regeneration of the cut block because the mature trees within the clumps are the seed potential for the surrounding areas (Anon. 1999a). Within each clumps at least 30 trees must remain and there should one clump per each hectares of harvested area. One clump is to be no further than 20m from the edge of the SMZ and beyond this each clump should be no more than 200m apart to ensure dispersal of all forest organisms. All standing dead trees, or snags, are to be left standing for habitat purposes and harvesting is not permitted within clumps. Clumps are not required on cut blocks less than 3 hectares. The retention of forest clumps within the cut block is unique to Nova Scotia's forest management plan.

Selective harvesting within the SMZ is permitted in Nova Scotia but there are a number of guidelines that must be followed. The operator should cut no more than 40% of the merchantable timber, leaving at least $20m^2$ per hectare of the basal area within the SMZ. The operator must also ensure that no canopy opening greater than 15m across are created by the selective harvest within the SMZ. No machinery is allowed within 7m of the watercourse and disturbance to small trees and shrubs has to be minimal (DNR 1997, Duke 1997). Both of these items are to protect the soil and bank stability from erosion related to compaction and rutting by heavy equipment. All snags within the SMZ are not to be harvested because of their importance as habitat, often as cavity trees, for insects, birds and small mammals. At least 1/3 of Nova Scotia's animals use snags for habitat purposes (Nova Forest Alliance 2002). The final parameter is not to allow sediments from forestry operations within the SMZ to enter neighbouring watercourses. This is a common guideline for all provinces and territories across Canada.

4.3 Prince Edward Island

The small province of PEI is covered by 0.29 million hectares of forest which is approximately 51% of the total land area of the province. Of this forest, only 18,900 hectares is controlled by the province and it is in the form of provincial parks. Similar to Nova Scotia, 92% of land in PEI is privately owned. The high percentage of private landownership relates to the high number of farms operated within the province (MacKinnon 1994). There are even portions of softwoods, mixed woods and hardwoods across the province yet the major export from the forest industry is softwood lumber (Anon. 2002a). The annual allowable cut for PEI is 0.5 million cubic meters.

Riparian buffers are referred to as Forested Riparian Zones (FRZ) and are required on all watercourses and wetlands. Watercourses refer to all streams, estuaries, and intermittent streams and springs that have a definable sediment bed and banks that are connected to larger permanent streams, or have a 72-hour continuous flow between July 1 and October 31 of any year (DAF Undated). FRZ are not required along the ocean coastline of the province or around any ponds that lack access to the ocean. The width of the FRZ is either 20m or 30m depending on the bank slope adjacent to the watercourse. A 20m FRZ is required when the slope is less than, or equal to, 9% while a 30m FRZ is required when the bank slope exceeds 9% (DAF undated). Clear-cutting is the method of harvest although no exposure of soil permitted in the cut block with the exception of mechanical tree planting procedures. Heavy equipment is not permitted within 10m of a watercourse with the exception of access road construction and maintenance. Access roads from forestry operations are not permitted to have ditches or road run-outs within 15m of watercourse to limit the amount of sedimentation which may occur. Also the FRZ is not to be converted to any other land use such as grazing areas or farmland.

Selective harvesting is permitted within FRZ provided that guidelines are followed to protect the integrity of the buffer and the neighbouring aquatic environment. First, 1/3 of the live trees may be removed from the FRZ in a 10-year period from two different sizes classes. The size classes are trees 10-30cms at the base and trees greater than 30cms at the base (DAF Undated). The measurement is made approximately 20cms above the ground. Harvesting from 2 different size classes helps produce an uneven-aged stand which is structurally diverse therefore it can support greater species diversity. Anything less than 10cms at the base must remain undisturbed during the harvest event. Within the FRZ a selective patch cut up to 0.2 hectare is approved as long as 0.1 hectare remains uncut between each patch. This creates a patchy habitat within the FRZ and has the potential to increase the diversity of the terrestrial organisms because it increases the amount of edge habitat. Edge habitat is beneficial because there is a diversity of habitat and food but unfortunately it can also be an ecological trap for many species because it is an area frequented by predators (Stevens et al. 1995).

4.4 New Brunswick

The province of New Brunswick is covered by approximately 6.1 million hectares of forest land. The majority of the province's forest is softwood (47%) while mixed wood and hardwood are proportionally similar, 29% and 24%, respectively (Anon 2002a). The annual allowable cut for New Brunswick is 11.0 million cubic meters. Compared to Nova Scotia and PEI there is considerably more public land in New Brunswick, publicly owned land covers 48% while privately owned land covers 51% of the province (Anon Undated b). The majority of export from New Brunswick is softwood products in the lumber, pulp and paper.

Riparian buffers are referred to as Watercourse Buffer Zones (WBZ) and are measured from the area of stream bank with stable vegetation at least 2m in height. WBZ width is depended on the size of the area drained by the watercourse. A 30m WBZ is required along all watercourses draining more than 600 hectares while a 15m WBZ may be approved for watercourses draining less than 600 hectares. Any natural watercourse that is less than 0.5m only requires a 3m WBZ provided that there is minimal bank disturbance during the harvesting (DNRE 1999, MacLauchlan 1994). The width of the WBZ may be a great as 100m depending on site-specific conditions such as slope, erosion potential, windthrow potential and habitat potential. A bank slope less than 24% requires a 30m WBZ while a slope greater than 25% receives a 60m WBZ. Any area dominated by shallow rooted trees such as balsam fir or black spruce require a 60m WBZ. Areas with high erosion potential also get a 60m WBZ, these are areas dominated by fine silts, clays and sands that are easily transported by wind and water. Streams considered critical habitat for fish (i.e. spawning grounds or rearing habitat for young) are bordered with a 60m WBZ. For the protection of waterfowl the WBZ is either 60m or 100m. A 60m WBZ is required along wetlands that obtain a Golet score of 70 – 84 while a 100m WBZ borders wetlands with a Golet score greater than 85 (DNRE 1999). The Golet score is Environment Canada's on-site ranking procedure for the classification of wetlands as waterfowl habitat.

A watercourse buffer zone may also double as wildlife travel corridors in many areas of the province. WBZ bordering streams, bogs, and ponds that provide a travel corridor are 50m wide. WBZ travel corridors along rivers and lakes (larger systems) are 100m wide. Within these WBZ travel corridors retention of 18m^2/ha basal area, a tree height greater than 10m, and canopy cover must be greater than 50% (Woodley and Forbes 1997). These parameters are in place to accommodate the majority of the organisms that utilize the corridor.

Within the WBZ, 30% of the basal area can be removed by selective harvesting in any 10-year period (DNRE 1999). This creates an uneven-aged stand which is more structurally diverse therefore has the potential to support a greater range of plants and animals. Canopy opening must not exceed 10m and the operator must retain at least 50% of the pre-harvest canopy cover. The height of remaining trees within the WBZ must be at least 10m. Also, no more than 30% of snags within the WBZ can be harvested because snags are important habitat for a variety of insects, birds and small mammals (Woodley and Forbes 1997, Anon Undated a). Heavy equipment in not allowed in the WBZ and timber cut inside the WBZ must be removed using an alternant method such as cable logging. As seen in other guidelines for harvesting within the riparian buffer zone, no sediment should be exposed within 30m of the watercourse bank.

In New Brunswick, the recently legislated Watershed Protected Area Designation Order was created to protect 30 municipal watersheds beyond the 30m WBZ. This new order consists of 3 distinct zones, Protected Area A refers to the watercourse, Protected Area B is a 75m setback zone bordering the watercourse, and Protected Area C encompasses the remainder of the watershed drainage area not included in the 75m setback zone (Anon. Undated c). Some forest harvesting is permitted within the Protected Areas B and C but the operators must adhere to certain restrictions. In the southern portion of the province selective cutting is approved between 30m and 75m (setback zone) by both mechanical and non-mechanical methods. In northern New Brunswick selective harvesting is permitted between 15m and 75m of the setback zone. No more than 30% of the timber can be removed once every 5 years. Harvesting in the southern region is permitted from January 1 to March 31 while in the north harvesting is permitted from November 1 to March 31. All harvesting must take place 1km upstream of the water supply intake.

Outside the setback zone, in Protected Area C, there are also limitations regarding forest harvesting. Again, no harvesting is allowed within 1km of water supply intake. Clear-cutting is permitted but blocks can be no larger than 25 hectares and between each clear-cut a 100m wide buffer strip must be retained (Anon. Undated c). This buffer strip can be selectively harvested but it cannot be clear-cut for at least 10 years after the initial harvest or when natural regeneration on the adjacent cut block is 2m high. Suspended sediments from any forest harvesting operation should not exceed 25mg/L above background levels. Also, bulldozing activities are not to expose more than 5% of the land area including roads and log landing areas and all access roads are to be built following best management practices.

4.5 Quebec

The province of Quebec is covered by vast forest. Approximately 84.0 million hectares of land is covered by forest. Representative of Canada, the majority of the land in Quebec is publicly owned (89%) therefore it is much easier to design and enforce a province-wide forest management plan. The forest composition is largely softwoods (58%), followed by mixed wood (23%) and hardwood (19%) (Anon. 2002a). With this high percentage of softwood the major exports out of Quebec are pulp and paper products and softwood lumber. The annual allowable cut for the province is 58.0 million cubic meters. The maximum size of the cut blocks varies between regions. The maximum size of cut blocks for the southern, central and northern regions of Quebec are 50 hectares, 100 hectares, and 150 hectares, respectively (MRN 2002). A recent provincial mandate stated that the province plans to increase the number of protected areas from 2.8% to 8%

of the land area by 2005. These protected areas include parks, reserve, recreational areas and riparian buffers.

Clear-cutting is the primarily method of harvest but within cut blocks the operator must preserve stands with tree height less than 7m for a minimal 30% of the cut block. This ensures regeneration of the cut block due to the seed potential from the remaining young stands. This reduces the maximum size of each clear-cut significantly, retention of small stands in the southern, central and northern regions of Quebec are 15 hectares, 30 hectares, and 45 hectares. Another management technique of the provincial government is to pre-commercially thin 33% of the forested land prior to harvest (MRN 2002). This is done to increase the productivity of the stand by reducing competition for light, water, nutrients and space. After a harvest event 80% of the cut block regenerates naturally while the remaining 20% of the cut area is manually reforested.

Harvesting within the riparian buffer is permitted in the province of Quebec and again there are guidelines the operator must follow to maintain the ecological functioning of the buffer zone. Selective harvesting is the method used for cutting within 20m buffers and during the harvest approximately 30% of the merchantable timber is removed (MRN 2002, Hamilton 2003). Heavy machinery is not permitted within the buffer therefore the selected logs are manually cut and felled perpendicular to the watercourse. This allows for easy extraction of the harvested logs with winching cable. Not allowing machinery within the buffer will limit the potential for erosion and slumping of the stream bank because there is no compaction and rutting of the soil. Minimizing soil damage is a major component of Quebec's forest management strategy plan.

4.6 Ontario

Like Quebec, Ontario has vast areas of forested land (58.0 million hectares) and a significant portion of the provincial economy comes from the forest industry. Major exports from the forest industry include pulp, paper products, softwood lumber and waferboard. The composition of Ontario's forest is 50% softwood, 27% mixed wood, and 23% hardwoods. The softwood forests are primarily in the northern portion of the province. The annual allowable cut for the province is 0.4 million hectare (Anon 2002a). The majority of the land (88%) is publicly owned therefore province-wide regulations and guidelines are used to manage forestry operations.

Three different harvesting methods are used in the province of Ontario, clear-cutting, shelterwood and selection cutting. Clear-cutting is the complete removal of forest within a particular area, the size of the cut block varies but most are less than 260 hectares. The clear-cut boundaries follow the natural contours of the land to limit extreme slope differences between the cut block and remaining forest. This will reduce erosion potential from the cut area (OMNR 1995). Clear-cutting is most often used in softwood forests. Shelterwood harvesting removes the mature trees from an area in a series of 2 or more cuts and is usually employed in mixed and hardwood forests. This creates an even-aged stand because all the mature trees are removed in a short period of time, perhaps within a couple of years. Selection cutting is the removal of individual trees of small groups of trees from all ages and diameter classes represented in the stand in a single harvest episode (Chunko 1998). This creates an uneven-aged stand because a mixture of mature trees, immature trees, and saplings remain undisturbed within the site.

Riparian buffers in the province of Ontario are referred to as Areas of Concern (AOC). The retention of an AOC adjacent to a watercourse is based on the presence or absence of fish or fish habitat within the system. If a stream does not support a fish population then timber can be harvested directly to the stream bank. The width of the AOC is primarily a factor of slope, ranging from 30m to 90m. Slope ranges are 0-15%, 16-30%, 31-45%, and 46-60% and required AOC of 30m, 50m, 70m and 90m, respectively (OMNR 1995, OMNR 1994). AOC width may also be increased to prevent windfalls but only in areas with high windfall potential, such as areas dominated by shallow rooted trees. These requirements usually concern the softwood forests of northern Ontario. The hardwood forests in the southern region are usually harvested using shelterwood or selection cut which is less invasive.

Ontario does allow harvesting within the AOC. A maximum of 50% of all timber within the AOC can be removed by harvesting. The method of harvesting varies in Ontario, selective cutting, selection patch cutting and strip cutting can be used to remove merchantable timber from the AOC (Archibald et al. 1997). Strip cutting is unique to Ontario, the operator travels along a strip within the AOC cutting and removing timber from both sides of the strip. All strip cut must be parallel to the watercourse and follow the natural contour of the land. Strips are often placed along a path that will maximum the amount of timber extract with minimal movement of the harvester (OMNR 1995). No matter which harvesting technique is utilized the operator must leaving a portion of snags, small trees and mature trees within the AOC for habitat diversity and regeneration purposes.

4.7 Manitoba

Manitoba is dominated by softwood (59%) while mixed wood (21%) and hardwood (20%) are present in equal portions. Forested land covers 26.3 million hectares which is approximately 48% of province's total land area (Anon 2002a). Ninety-four percent of the land is publicly owned and controlled by the provincial government and the annual allowable cut for the province is 9.7 million cubic meters. With almost 60% softwood, Manitoba's major export consists of pulp and paper products and softwood lumber (Anon 2002a). The exports are almost exclusively sent to the United States.

Buffer zones within Manitoba are a minimum of 100m adjacent to all watercourse classifications (Wedeles and Williams 1995). A Class 1 stream drains an area greater than 50km^2 and contains populations of commercial or sport fish species. A Class 2 stream drains an area less than 50km^2 and lack commercial or sport fish population. Lakes are classified as either productive lakes or small lakes/ponds. Productive lakes are permanently filled having important fish bearing habitat and only the surface is usually frozen during the winter months. Small lakes/ponds may be permanent but are often spring or runoff fed (MNR 1996a). These systems generally completely fish in the winter producing large winterkills of fish, it is reason that these systems have very limited fish concerns. The final classification refers to wetlands and these systems are considered extremely important because they are breeding and rearing habitat for waterfowl, wildlife and aquatic species. A buffer on any of these classifications may be less than 100m if it is approved a provincially funded Integrated Resource Management Team (IRMT) after a site evaluation. Buffer width can be 200m if harvesting if conducted in areas regarded as special habitat for endangered species, recreational areas for society, waterfowl and raptor nesting site, or area containing natural springs or seeps (Peacock 1996).

As in other areas of Canada, selective harvesting is the approved method for harvesting within buffer zones in Manitoba. The selective harvest can be an individual tree removal or a small group cut (MNR 1996a, MNR 1996b). Heavy machinery is not permitted within 15m of a watercourse's high water mark. The high water mark is considered the point where there is a change from water-based vegetation to ground-based vegetation. Harvesting within the buffer zone is restricted to periods of the year when the ground is frozen or well drained (Peacock 1996). This is to protect against compaction and rutting by heavy equipment, increased erosion potential and the destruction of productive land. The province of Manitoba also specifies that only natural inputs of debris should enter the watercourse and no trees/slash can remain on the forest floor within 15m of the high water mark. Any slash within 15m of the high water mark has the potential to enter the watercourse via surface runoff or flooding (MNR 1996a). Similar to all other forest management plans across Canada, no sediment from forestry operations is to enter any watercourse.

4.8 Saskatchewan

The province of Saskatchewan is very similar to its easterly neighbour Manitoba. The amount of forested land in Saskatchewan is 28.8 million hectares, which is approximately 50% of the total land area. Of the total land area within the province, 97% of it is publicly owned and management by the provincial government. The forest composition of Saskatchewan is 39% softwood, 25% mixed wood, and 36% hardwood. Saskatchewan has the lowest provincial percentage of softwood in Canada (Anon 2002a). Even though softwood is less abundant in this province the majority of export from the forest industry is pulp, paper, paperboard and softwood lumber. The annual allowable cut for Saskatchewan is 7.6 million cubic meters. In 1999 the Saskatchewan government announced plans to double the forest industry within the province (SIR 2002).

Riparian width in Saskatchewan can be 15m, 30m, or 90m depending on watercourse classification. Saskatchewan's classification system is opposite to Manitoba's classification of aquatic environments. Class I streams are 3rd order or less and drain an area less than 50km^2. Class II streams are greater than 3rd stream and the drainage area is greater than 50km^2. Lakes are the third classification within Saskatchewan system (Barten 2001). Class I streams require 15m riparian buffers and by definition this stream class lacks populations of commercial or sport fish. Class II streams and Lakes lacking commercial or sport fish require only 30m riparian buffers while the same classifications containing commercial or sport fish populations require

90m riparian buffers. If a system is completely devoid of fish no riparian buffer is required bordering the stream or lake.

Selective harvesting is approved within riparian buffers for the province of Saskatchewan. Harvesting is limited to periods of the year when the ground is frozen or well drained and dry. The exposure of soil within the riparian buffer is prohibited therefore limiting the harvesting times will minimize the amount of compaction and rutting of the soil by heavy machinery used to cut and extract timber from the buffer (Van Rees and Jackson 2002, Thorpe and Godwin 1999). Similar to Manitoba, slash and debris is not to enter the watercourse therefore any slash/debris remaining in the riparian buffer after the selective harvest has to be removed. The final condition for harvesting within riparian buffers is no sediment is to enter neighbouring waterways.

4.9 Alberta

The forests of Alberta covers 38.2 million hectares of land which is approximately 59% of Alberta total land area. The majority of the land (89%) is provincially controlled while the federal government and private landowners control significantly less, 9% and 4%, respectively. Over half of the exports from Alberta's forest industry is wood pulp while other exports include softwood lumber, and waferboard. Newsprint is only 4% of the province's exports. The composition of the forest areas are 44% softwoods, 23% mixed woods and 33% hardwoods (Anon 2002a). The annual allowable cut permitted by the provincial government is 24.3 million cubic meters.

The width of Alberta's buffer zones depends on the type of the system and buffer widths range from 30m to 100m. A 100m buffer is required on all lakes and ponds while a 30m or 60m buffer is required along streams. A 60m buffer must border a large permanent stream that has a stream valley greater 400m across. The stream valley refers to the entire stream area under the same contour level (Anon 1994, Anon 2002). This classification is used to protect the riparian environment against flooding. Small permanent and intermittent streams require 30m buffers. Small permanent streams have stream valleys less than 400m across while intermittent streams have definable channels but only contain water during wet periods of the year (Anon 1994).

Harvesting within the riparian zone is approved for the province of Alberta. The harvesting technique within the buffer is selective harvesting, both single tree and group removal are permitted (Kneeshaw et al. 1999). Machinery is not permitted within 20m of the watercourse's high water mark, one exception to this is intermittent streams. Similar to Saskatchewan and Manitoba, machinery is permitted within 20m of the high water mark of intermittent streams on frozen or dry soils. Wood harvested within the buffer of larger systems is winched out to limit the impact to the forest floor (Anon 1994). Cutting and winching must be done to minimize damage to the residual stand. No slash or debris should enter the watercourse while harvesting within Alberta's riparian buffers. Only natural inputs of slash and debris from windthrow or snowloading should enter the aquatic environment (Kneeshaw et al. 1999). A final restriction is no excess sediment from the forestry operation should enter the watercourse.

4.10 British Columbia

British Columbia's forest industry is worth more than any other province in Canada with the value of exports worth $16.0 billion each year. The major exports include softwood lumber, wood pulp, and paper and most of these products are exported to the United States, Japan, and the European Union. Over 100,000 people are directly employed by British Columbia's forest industry. Forests cover 60.6 million hectares of British Columbia and the forest composition is primarily softwoods (89%). Mixed wood and hardwood comprise only 8% and 3%, respectively (Anon 2002a). The majority of the forest area (95%) is provincially owned and governed therefore legislation regarding the forest industry is set by the provincial government. The annual allowable cut permitted in British Columbia is 70.6 million cubic meters.

Riparian management in British Columbia is more complex than any other province in Canada. Buffers are referred to Riparian Management Areas (RMA) and the objectives of RMA are to minimize or prevent impacts from forestry operations on the following (Anon 1995, Pendergast 2002, Stevens et al. 1995):

1) Stream bank stability.
2) Ecosystem functioning such as hydrological cycling, nutrient cycling and food web dynamics.
3) Water quality.
4) Structural and biological diversity.
5) Productivity of both aquatic and terrestrial environments.
6) Sustainability of wildlife through travel corridors and habitat.

These six features are common to all riparian buffers (O'Laughlin and Belt 1993). The width of the RMA ranges from 10m to 100m and borders all aquatic systems including wetlands, streams and lakes. RMA width is determined by watercourse size, presence of fish, and the biogeoclimatic zones. Biogeoclimatic zones are those areas dominated by Ponderosa Pine, Bunch Grass, Douglas Fir and Coastal Western Hemlock (Anon 1995). These areas usually receive a narrower RMA than areas not dominated by these vegetation types.

Riparian Management Areas consists of two zones, the reserve zone and the management zone (Anon 1995, McCleary and Mowat 2002). The reserve zone is the inner zone of the RMA and no forest harvesting is permitted. The management zone is the outer zone and selective harvesting is permitted. Some watercourse classifications are bordered by a management zone only while other RMA consist of both a reserve zone and a management zone. RMA consisting of both reserve and management zones help reduce windthrow to the reserve zone, retain important wildlife habitat (i.e. snags), and retain natural ecosystem functioning such as hydrological and biogeochemical cycling.

RMA width bordering streams range from 20m to 100m depending on stream classification. Streams are classified by channel width and range from the largest S1 streams to the smallest S6 streams (Table 4). All streams have a management zone where selective harvesting is allowed while the RMA bordering larger systems (S1-S3) have both a reserve zone and a management zone. A special classification, S1 large rivers is applied to systems with channel widths greater than 100m. This system requires the largest management zone of 100m although lacks a reserve zone. S1 large rivers require the largest RMA at 100m while the smallest system, S6, requires the smallest RMA of 20m. By definition, S1 to S4 streams support fish populations and therefore require a larger RMA than S5 and S6 streams. If a stream is in a community watershed than the RMA must be wider than streams not within a community watershed.

Table 4. British Columbia's stream classification system with corresponding Riparian Management Area (RMA) widths (extracted from Anon 1995).

Riparian class	Average channel width (m)	Reserve zone width (m)	Management zone width (m)	Total RMA width (m)
S1 large rivers	≥100	0	100	100
S1 (except large rivers)	>20	50	20	70
S2	>5≤20	30	20	50
S3	1.5≤5	20	20	40
S4	<1.5	0	30	30
S5	>3	0	30	30
S6	≤3	0	20	20

Fish stream or community watershed (shaded: S1–S4)

Not fish stream and not in community watershed (unshaded: S5–S6)

Lake classification is also depended on the size of the system, similar to stream classification. L1 lakes are the largest (>5 ha) while L4 lakes are the smallest (<1 ha) (Table 5). L2 and L4 lakes are in those biogeoclimatic zones dominated by Ponderosa Pine, Bunch Grass, Douglas Firs or Coastal Western Hemlock. RMA width for lakes ranges from 10m on the largest L1 classification to 30m on L2, L3, and L4 lakes. Reserve zones of 10m are required on the two larger systems, L1 and L2. A special classification on L1 lakes is lakes larger than 1000 hectares require a 10m management zone rather than a 10m reserve zone, the reason being larger systems are better able to absorb non-point source pollution potentially caused from forest harvesting activities (Garman and Moring 1991).

Table 5. British Columbia's lake classification system with corresponding Riparian Management Area (RMA) widths (extracted from Anon 1995).

Riparian class	Reserve zone width (m)	Management zone width (m)	Total RMA width (m)
L1*	10	0	10
L2	10	20	30
L3	0	30	30
L4	0	30	30

L1 Lakes < 1000 ha in area, have a 10-m reserve zone and a lakeshore management zone established by the district manager. L1 lakes > 1000 ha in area only have a lakeshore management zone.

Wetlands also receive protection from forestry operations by the retention of Riparian Management Areas. Again, the width of the RMA for wetlands is depended on the size of the system. Wetland classification ranges from W1 being the largest (> 5ha) to W5. W4 is the smallest system at 0.25-1.0 hectares while W5 is a combination of 2 or more neighbouring wetlands with a combined size greater than 5 hectares (Table). W2 and W4 wetlands are within the same biogeoclimatic zones listed for L2 and L4 lakes. RMA width ranges from 30m on the smaller wetlands (W2, W3, W4) to 50m on the larger wetlands (W1, W5). Wetlands classifications W1, W2, and W5 require both a reserve zone and a management while W3 and W4 require only a management zone. The retention of a reserve zone is for added protection to the larger wetlands. No RMA is required on upland areas dominated by bog or muskeg if the area is larger than 1000 hectares (Table 6).

Harvesting within the RMA is approved for British Columbia but the harvesting is restricted to the outer management zone. Forestry activities are prohibited within the inner reserve zone. Selective harvesting is the approved method for timber removal and the maximum retention rates varies between size and type of the aquatic system. Within the management zones of all lakes and wetlands 25% retention is required. On larger streams (S1 – S3) 50% retention is required within the management while only 25% retention is required on S4 and S5 streams. The smallest stream, S6, requires only 5% retention of timber within the management zone (Anon 1995).

Table 6. British Columbia's wetland classification system with corresponding Riparian Management Area (RMA) widths (extracted from Anon 1995).

Riparian class	Reserve zone width (m)	Management zone width (m)	Total RMA width (m)
W1*	10	40	50
W2	10	20	30
W3	0	30	30
W4	0	30	30
W5*	10	40	50

* No riparian reserve or riparian management zone is required for upland terrain within a bog dominated or muskeg dominated wetland larger than 1000 ha in boreal, sub-boreal, or hypermaritime climates. However, where a reserve or management zone is established by the district manager, the RMA should reflect the landscape level management strategy as outlined in the *Biodiversity Guidebook*.

When harvesting within the RMA machinery is not permitted within the reserve zone and limited use within the management zone. Limited machinery use within this zone will reduce the potential for soil disruption, exposure and erosion. Also, foresters in British Columbia attempt to retain all non-merchantable conifers, understory deciduous trees, shrubs and herbaceous vegetation within 10m of stream reserve zones and 20m of wetland/lake reserve zones. This is done to promote structural diversity with the intentions to increase species richness and biodiversity of the impacted area (Pendergast 2002, Stevens et al. 1995)

4.11 Yukon Territory

Approximately 27.5 million hectares of forest land covers the Yukon territory which is just over half of its total land area. Although the land is 100% federally owned the territorial government has a department of forestry which deals with harvesting permits, fire suppression, and forest renewal. The annual allowable cut for the Yukon Territory is 352 200 cubic meters. All of the exports from Yukon's forest industry go to the United States and the majority (94%) is softwood lumber. Forest composition is 79% softwood, 19% mixed wood and 2% hardwood forests (Anon 2002a).

A recent territorial document stated that legislation regarding riparian buffers was soon to be implemented. These buffers are referred to as Special Management Areas and the width would vary between 30m and 90m. A 30m Special Management Area will be required around all watercourses and would also act as a wildlife corridor. Ninety meters may be required for the protection of sensitive areas or community water supplies (Anon 2001). Timber removal within these Special Management Areas will be permitted by selective harvesting. The amount removal within the Special Management Area is yet to be determined.

4.12 Northwest Territories

Northwest Territories has a large land area (329.3 million hectares) yet only 18% of it is covered by forest land. Like the Yukon Territory the federal government owns 100% of the land. There is a forestry department within the territorial government and it controls the same items as the Yukon territorial government. The annual allowable cut is 236 500 cubic meters. The forest composition is 33% softwoods, 58% mixed wood and 9% hardwood forests (Anon 2002a). All of the territory's exports from the forest industry is shipped to the United States in the form of softwood lumber. Unfortunately, there is a lack of information available on the forest industry activities and riparian management for the Northwest Territories.

4.13 Nunavut

The forest industry within Nunavut is worth less than $100 000 and only a small portion of the total land area is covered with forests (Anon 2002a). The only export from the forest industry is softwood lumber and all of it is exported to the United States. Unfortunately, there was no information available on the forestry operations or riparian management within the territory.

5.0 Managed Buffers Across Canada

Canada's forest industry is managed by provincial and territorial governments therefore many different rules and regulations regarding managed buffers exist. Although there are many differences there are similarities for working within buffers. To properly design a successful management plan for riparian buffers in Newfoundland and Labrador it is important to understand the ideas from other areas. The common trends for managed buffers are discussed below.

Currently in Newfoundland and Labrador forest harvesters are not permitted to cut within the 20m riparian buffer although the majority of Canada allows management of the riparian zone. A major component for harvesting within riparian buffers seems to be the type of harvest permitted. With the exception of Ontario, all timber removed within the buffer is done so by selective harvesting. Selective cutting is also know as diameter-limit cutting or high grading because a percentage of the most merchantable trees are removed from an area during the harvest event (Chunko 1998). Ontario does allow strip cutting within their Areas of Concern providing the strip is parallel to the watercourse and follows the natural contour of the land. During the selective harvest there is a limited removal of living, merchantable trees. This removal rate varies across Canada, ranging from 30% to 50% of the riparian zone. Provinces in eastern Canada tend to permit 30%, or 1/3, removal of living trees within the buffer as long as soils, canopy, snags, and other important habitat features are maintained.

Many areas limit the canopy opening size produced during the selective harvest within the riparian zone. This restriction on canopy opening is most prominent within the eastern provinces of Canada. The maximum opening is 10m in New Brunswick and Prince Edward Island, and 15m in Nova Scotia. These openings may be considered to large for Newfoundland and Labrador because a 10m opening within a 20m buffer is considerably large. Also, creating a large canopy opening has the potential to increase windfalls through increased exposure and raise water temperature via increased sunlight. Newfoundland and Labrador forests are dominated by balsam fir and black spruce, these trees have small sails therefore a selective harvest rate of 30% should not create a single canopy opening greater than 5m across.

Stated in a majority of the forestry mandates regarding managed buffers is limited use of heavy equipment within the riparian zone. Most provinces prohibit the use of machinery within 20m of the watercourse especially if the watercourse is classified as fish-bearing or is a component of a community watershed. Ontario does allow equipment within their Area of Concern during strip cutting procedures. Quebec has allowed heavy equipment within their riparian zones by cutting narrow strips parallel to watercourse for machine travel or 10m into the buffer on brushmats during some recent trial cuts. Most other eastern provinces harvest the buffer by manual felling and reaching into buffer with machinery to remove timber. In Manitoba, Saskatchewan, and Alberta harvesting within the riparian zone is restricted to dry or frozen soils. Harvesting on dry or frozen soils will reduce the erosion potential thereby protecting neighbouring aquatic environments. Wet periods such as spring and fall have the highest erosion potential because often the soil is saturated and is easily transported by rain or snow melt.

When heavy equipment is prohibited within the riparian zone operators must use other methods for removing the merchantable timber. The most used method is manually felling and then cable winching the logs out. When winching it is important that there is minimal damage done to the residual stand, this is common among all provincial and territorial forestry mandates. Residual trees may be damaged when the harvest stem is felled against thereby removing limps and bark or during the cable winching as the cable and harvested stem rub and grind against standing trees. Any stems that have been damaged are weaken and more susceptible to rot, wind, and disease. Another component of most forestry plans is to limit slash and debris that may enter neighbouring watercourses. Manitoba and Saskatchewan's forestry objectives prohibit slash or debris within 15m of the high water mark of the watercourse, this reduces the chance of it entering the watercourse via runoff or flooding. Excess slash and debris within streams may create barriers to fish passage thereby reducing productivity of upstream areas. Slash and debris on the forest floor has the potential to alter local nutrient cycling through decomposition and may also increase the acidity of the soil. Both of these may alter the plant composition of the site potentially changing local food web dynamics and productivity.

A major consideration for all forestry operations is sedimentation. As stated earlier excess sediment is a non-point source pollutant and is often related to access roads, skid trails, log landings, and cut blocks. Due to the negative impacts of sedimentation to aquatic environments all provincial and territorial forestry plans that allow harvesting within the riparian zone state that no excess sediment should enter neighbouring waterways. Many forestry plans also prohibit the exposure of soil within 20m of the waterways. Limiting the use of heavy equipment will reduce the erosion potential from harvested areas.

A final consideration for managed buffers is wildlife. Many species of wildlife, such as small mammals, large mammals, and birds utilize riparian buffers as protective and productive shelter therefore it is important to maintain these areas. Many forestry plans across Canada attempt to promote stability and biological diversity by maintaining or enhancing structural diversity within the stand. Foresters do this by leaving a variety of undisturbed shrubs, small trees, mature trees and snags for habitat purposes. Some areas, such as New Brunswick and Manitoba, increase their buffer width if an area is considered to have special habitat features or the area is used as a travel corridor by wildlife. Unfortunately, it is difficult to quantify the value of an area to present wildlife population. Nova Scotia's management plan retains forest clumps within the cut block to facilitate wildlife travel is perhaps the most comprehensive plan to maintain current wildlife populations.

6.0 Managed Buffers for Newfoundland & Labrador/Conclusion

Prior to any harvesting trials within riparian buffers in Newfoundland and Labrador an operations plan that is consistent with other provinces across Canada and conservative to help maintain the integrity of the riparian area. A recent trial in the Caribou Lakes watershed near Corner Brook removed 2/3 of the timber from the outer 8m of the buffer by reaching into the buffer with a harvester. The harvester did not enter the buffer therefore there was limited impact to the forest floor. Perhaps a better harvesting method is to remove 1/3 the timber from the entire riparian zone. This can be accomplished by manual felling of timber and then winching it out of the riparian buffer or by inserting the harvester within the buffer on brush mats so that it can treat the entire area. Manual felling and winching is less invasive because there is limit disturbance to the forest floor although it is more labour intensive. Canopy openings should also be minimized during harvesting. Some areas allow canopy openings up to 15m across, this would be significantly large in Newfoundland and Labrador buffers which are only 20m wide. Canopy openings less than 5m across will help maintain the shading function of the riparian buffer and also maintain habitat requirements for many terrestrial animals.

While harvesting within the riparian zone it is important to remember key wildlife issues. First, do not remove any snags from the riparian area. Snags are important habitat areas for insects, birds and small mammals and leaving these within the buffer will help maintain current wildlife populations within the area. Operators should leave a portion of herbaceous vegetation, shrubs, small trees, mature trees and snags to maintain habitat niches. A percentage of all vegetation types within the buffer will maintain the diversity of habitat therefore promote species diversity. Often riparian buffers are used as movement corridors for wildlife and the width of the buffer may be increased to facilitate wildlife dispersal. Newfoundland and Labrador may consider increasing buffer widths to 50m in areas frequented by terrestrial species such as moose and caribou. Quantifying habitat use by terrestrial animals in riparian zones is an area where further research is needed. There has been some work conducted on birds and small mammals but the amount a buffer is used as habitat and travel corridors is difficult to quantify. Research may be required on the minimum buffer width that is needed to maintain wildlife populations within the harvested area. Simon et al. (2000) found that there was a greater diversity of birds inhabiting areas that were selectively harvested rather than the open areas and forest areas. Within these selectively harvested areas both forest birds and open-areas birds were present. The same may occur for selectively harvested riparian zones.

Site-specific conditions should also be factored into the harvesting plan when referring to riparian buffers. Newfoundland and Labrador already have increased buffer width for areas with bank slope greater than 30°. Restricting timber removal within these areas may decrease the potential impacts of forestry operations to both the aquatic and the terrestrial environments. Newfoundland and Labrador is dominated by shallow-rooted black spruce and balsam fir trees which have high windthrow potential. Limiting harvesting within buffers where windthrow potential is the highest, such as hilltops and areas with loose soils may reduce the risk of blown down buffers. Areas with increased windfall potential may require larger buffers with no harvesting allowed within them. A before-after-control-impact (BACI) experiment on the amount of windfalls in fixed 20m riparian buffer compared the amount of windfalls in a selectively harvested 20m riparian buffer with a 1/3 timber removal rate could easy be performed in selected areas. Also, it would be beneficial to create a windfall potential classification system similar to slope classification to help protect areas with increased potential for blow downs. This is area where further research is needed.

Another site-specific condition that may be considered during a managed buffer harvesting plan would be erosion potential. Areas dominated by easily eroded materials such as sands, silts and clays may also required wider buffers with limited activity within them. Restricting harvesting within these areas will limit the potential environmental impacts caused by forest harvesting. Better use of soil survey maps may help limit erosion potential. Other than slope, these other two site-specific conditions need to be addressed for Newfoundland and Labrador.

Another question which needs to be addressed is the importance of smaller headwater streams as compared to larger systems. Are larger systems better able to absorb the impacts of forestry operations? There is a shift in thinking that more riparian protection is required around smaller headwater streams because these systems impact the downstream environment and are important breeding and rearing habitat for many fish species. Again, how much protection is required upstream to limit disturbances to the entire watershed? A long-term, large-scale watershed study on the potential impacts of forest harvesting should be considered for Newfoundland and Labrador.

Before managed buffers are applied to the entire province it is important to conduct further research that may fill in the existing data gaps mentioned. Although other areas allow harvesting within the riparian zone there is little scientific literature available on increased impacts on the terrestrial and aquatic environments. Fisheries and Oceans Canada have conducted work on the effectiveness of riparian buffers at protecting the aquatic environment from many areas within the island portion of the province (Decker et al. 2002, Clarke et al. 1997). Because the baseline data on 20m riparian buffers does exist for some watersheds it would be beneficial to have a BACI study on managed buffers within these areas.

In conclusion, Newfoundland and Labrador’s forest management practices are consistent with other provinces in regards to the retention of riparian buffers. All other areas utilize a riparian system which is used to protect both the aquatic and terrestrial environments from the adverse impacts caused by forestry operations. Although similar there is one major difference, Newfoundland and Labrador does not allow harvesting within the legislated riparian buffer where as other areas do allow harvesting. The approved harvesting method is often selective cutting at a rate ranging from 30% to 50%, depending on the provincial guidelines. Implementing managed buffers within Newfoundland and Labrador is possible but will require some regional specific studies to obtain an optimal design which can maximize timber removal with limited impacts on the environment.

7.0 References

Anderson, S. and R. Masters. 2002. Riparian Forest Buffers. Water Quality Series, OSU Extension Facts F-5034, Division of Agricultural Sciences and Natural Resources, Oklahoma State University. 6pp. http://agweb.okstate.edu/pearl/wqs/f-5034.pdf.

Anon. 2002. Policy and procedures document for submitting the geophysical field report form. Alberta Sustainable Resource Development, Calgary, Alberta. 30p.

Anon. 2002a. The State of Canada's Forestry; Sustainable Forest; Reflections of a Decade. Natural Resources Canada. 35p. http://www.nrcan.gc.ca/cfs-scf/national/what-quoi/sof/sof02/index_e.html.

Anon. 2001. Peel Plateau River: Summary Issues and Government Response. Government of Yukon, Whitehorse. 6p.

Anon. 2000. Texas Forestry Best Management Practices. Texas Forestry Association, Lufkin. viii+111p.

Anon. 1999. Georgia's best management practices for forestry. Georgia Forestry Commission. 68p.

Anon. 1999a. Forest/Wildlife Guidelines and Standards for Nova Scotia: Draft Report. Department of Natural Resources, Nova Scotia. 14p.

Anon. 1995. Riparian Management Area Guidebook. British Columbia's Ministry of Forests Library, Victoria. 68p.

Anon. 1994. Alberta timber harvest planning and operating ground rules. Alberta Environmental Protection. Pub. No.: Ref. 71, Edmonton, Alberta. 57p.

Anon. 1993. Guide to forestry best management practices. Tennessee Department of Agriculture – Forestry Division, Ellington. 41p.

Anon. Undated a. Forest management guidelines to protect native biodiversity in the Fundy Model Forest. Greater Fundy Ecosystem Research Project, UNB Faculty of Forestry and Environmental Management. 2p.

Anon. Undated b. Forest Management Practices: Sustainable Forest Principles for J. D. Irving, Limited's Forest Landbase. http://www.jdirving.com/fmpssite/index.htm.

Anon. Undated c. Understanding the Law: A guide to New Brunswick's Watershed Protected Area Designation Order. Department of the Environment and Local Governments, New Brunswick. iii + 17p.

Archibald, D. J., W. B. Wiltshire, D. M. Morris and B. D. Batchelor. 1997. Forest Management Guidelines for the Protection of the Physical Environment. Ontario Ministry of Natural Resources, MNR # 51032. iv+42p.

Arthur, M. A., G. B. Coltharp and D. L. Brown. 1998. Effects of best management practices on forest streamwater quality in eastern Kentucky. Journal of the American Water Resources Association, **34**: 481 – 495.

Barden, C. J. 2001. Establishing riparian buffers. Forestry Report MF-2489. Kansas State University. 4pp.

Barten, P. K. 2001. Riparian Area Management Principals and Practices: Workshop Summary Report. Saskatchewan Environment and Resource Management. Forest Ecosystem Branch, Prince Albert. 48p.

Barnes, B. V., D. R. Zak, S. R. Denton and S. H. Spurr. 1998. Forest Ecology (4th ed.). John Wiley & Sons, Inc., New York. 774p.

Belt, G. H., J. O'Laughlin and T. Merrill. 1992. Design of Forest Riparian Buffer Strips for the Protection of Water Quality: Analysis of Scientific Literature. Idaho Forest, Wildlife and Range Policy Analysis Group, Report No.8. iv+40p. www.uidaho.edu/cfwr/pag/pagr8.html.

Berg, D. R. 1995. Riparian silvicultural system design and assessment in the Pacific Northwest Cascade Mountains, USA. Ecological Applications, **5**: 87-96.

Berkman, H. E. and C. F. Rabeni. 1987. Effect of siltation on stream fish communities. Environmental Biology of Fishes, **18**: 285 – 294.

Berube, P. and F. Levesque. 1998. Effects of forest clear-cutting on numbers and size of brook trout, *Salvelinus fontinalis* (Mitchell), in lakes in the Mastigouche Wildlife Reserve, Quebec, Canada. Fisheries Management and Ecology, **5**: 123 – 137.

Bilby, R. E. and P. A. Bisson. 1992. Allochthonous versus autochthonous organic matter contribution to the trophic support of fish populations in clear-cut and old-growth forested streams. Can. J. Fish. Aquat. Sci. **49**: 540 – 551.

Brandrup, M. (ed.). 2002. Forestry Best Management Practices. Iowa Department of Natural Resources. 10p. http://www.state.ia.us/forestry/bmps.htm.

Brosofske, K. D., J. Chen, R. J. Naiman and J. F. Franklin. 1997. Harvesting effects on microclimate gradients from small streams to uplands in western Washington. Ecological Applications, **7**: 1188 – 1200.

Brown, A. V., Y. Aguila, K. B. Brown and W. P. Fowler. 1997. Responses of benthic macroinvertebrates in small intermittent streams to silvicultural practices. Hydrobiologia, **347**: 119 – 125.

Carignan, R. and R. J. Steedman. 2000. Impacts of major watershed perturbations on aquatic ecosystems. Canadian Journal of Fisheries and Aquatic Sciences, **57 (Suppl. 2)**: 1 – 4.

Chunko, S. E. and W. E. Wolf. 2001. Best management practices for Pennsylania forests; promoting forest stewardship through education, cooperation and voluntary action. College of Agricultural Sciences, Penn State. 52p.

Chunko, S. E. 1998. Selection vs. Selective Cutting: Do you know the difference? Pennsylvania Forest Stewardship Quarterly, **12**: 1.

Clarke, K. D., D. A. Scruton and J. H. McCarthy. 1998. The effect of logging and road construction on fine sediment accumulation in stream of the Copper Lake watershed, Newfoundland, Canada: initial observations. Pages 353 – 360 *in* M. K. Brewin and D. M. A. Monita, tech. Cords. Forest-fish conference: land management practices affecting aquatic ecosystems. Proc. Forest-Fish Conf., May 1 – 4, 1996, Calgary, Alberta. Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-356.

Clarke, K. D., D. A. Scruton, L. J. Cole, J. H. McCarthy, J. M. Green, I. Bell, and L. J. Moores. 1997. The Copper Lake Buffer Study: Pre-harvest Conditions of the Aquatic Habitat. Can. Tech. Rep. Fish. Aquat. Sci. No. 2181: vii + 66p.

Collins, K. D., G. Gallagher, J. J. Gardiner, E. Hendrick, and D. McAree. 2000. Code of Best Forest Practices. Forest Service, Department of the Marine and Natural Resources, Dublin, Ireland. 200p.

DAF. Undated. The Provincial Forest and Watercourse Buffer Zones. Prince Edward Island Department of Agriculture and Forestry. http://www.gov.pe.va/af/.

DFRA. 2002. Insect and Disease Control. Department of Forest Resources and Agrifoods, Newfoundland and Labrador. http://www.gov.nf.ca/forestry/protection/insect_01.asp.

DNR. 1997. Toward Sustainable Forestry: A Position Paper. Nova Scotia Natural Resources. Working Paper, 1997-01. iii + 42p.

DNRE. 1996. Watercourse Buffer Zone Guidelines for Crown Land Forestry. New Brunswick Natural Resources and Energy. iii+20pp.

Damman, A. W. H. 1964. Some forest types of central Newfoundland and their relationship to environmental factors. Forest Science Monograph No. 8. 62p.

Decker, R. C., D. A. Scruton, J. D. Meade, K. D. Clarke and L. J. Cole. 2002. The Newfoundland Small Stream Buffer Study Phase I: Impacts of Current Forest Harvesting Practices on Stream Habitat and Biota. Can. Tech. Rep. Fish. Aquat. Sci. 2449: ix + 77p.

Devito. K. J., I. F. Creed, R. L. Rothwell and E. E. Prepas. 2000. Landscape controls on phosphorus loading to boreal lakes: implications for the potential impacts of forest harvesting. Can. J. Fish. Aquat. Sci. **57**: 1977 – 1984.

Dolter, S., L. Moores and E. Rolls. 1999. Buffer Zone Working Group Western Newfoundland Model Forest: Workshop Proceedings, June 8, 1999. Western Newfoundland Model Forest Network.

Douglass, J. E. and W. T. Swank. 1972. Streamflow modification through management of Eastern forests. U.S. Government Printing Office: 1972-745-563/5042, Region No. 4. 15pp.

Duke, T. 1997. Wildlife Habitat and Watercourse Protection Regulations. Nova Scotia Natural Resources. Unpublished.

Dunford, E. G. and P. W. Fletcher. 1947. Effect of removal of stream-bank vegetation upon water yield. Transactions, American Geophysical Union, **28**: 105 – 110.

Elliot, W. J., D. E. Hall and S. R. Graves. 1999. Predicting sedimentation from forest roads. Journal of Forestry, **Aug**: 23 – 28.

English, B. and G. Warren. 1999. Butt rot in semi-mature pre-commercially thinned balsam fir: pilot study results. Silviculture Notebook No. 48. Silviculture and Research Section, Newfoundland Forest Service. 16p.

Ezell, A. W. 1998. Educational Programs: Best Management Practices Overview. Mississippi State University Extension Service. http://www.msucares.com/forestry/education/bmp.html.

Flebbe, P. A. and C. A. Dolloff. 1995. Trout use of woody debris and habitat in Appalachian wilderness streams of North Carolina. North American Journal of Fisheries Management, **15**: 579 – 590.

Flynn, K. 1999. The Alabama Watershed Demonstration Project: water quality, nonpoint source pollution, and best management practices – what landowners need to know. Alabama A & M and Auburn Universities. Alabama Cooperative Extension System; ANR-1150.

Flynn, K. 1997. Forest practices and water quality: guidelines for landowners. Alabama A & M and Auburn Universities. Alabama Cooperative Extension System; ANR-1031.

France, R. L. 1997. Potential for soil erosion from decreased litterfall due to riparian clearcutting: Implications for boreal forestry and warm- and cool-water fisheries. Journal of Soil and Water Conservation, **52**: 452 –455.

Fulton, S. and B. West. 2001. AQUA-3: Forestry Impacts on Water Quality. Southern Forest Resource Assessment Draft Report. www.srs.fs.fed.us/sustain.

Garman, G. C. and J. R. Moring. 1993. Diet and annual production of two boreal river fishes following clearcut logging. Environmental Biology of Fishes, **36**: 301 – 311.

Garman, G. C. and J. R. Moring. 1991. Initial effects of deforestation on physical characteristics of a boreal river. Hydrobiologia, **209**: 29 – 37.

Goose, M. M., A. S. Power, D. E. Hyslop and S. L. Pierre. 1998. Guidelines for protection of freshwater fish habitat in Newfoundland and Labrador. Fisheries and Oceans, St. John's, NF. 105pp.

Grosse, D. 1989. Effectiveness of forestry best management practices in protecting fish resources of two national forests in western Washington. U.S. Environmental Protection Agency; Water Division. EPA 910/9-89-008. xiii+39p.

Hall, J. P. 1995. Forest health monitoring in Canada: How healthy is the boreal forest? Water, Air and Soil Pollution, **82**: 77 – 85.

Hamilton, P. 2003. Harvesting in Riparian Zones. Newfoundland and Labrador Buffer Zone Workshop: Proceedings. Compact Disc Format.

Horne, A. J. and C. R. Goldman. 1994. Limnology (2nd ed.). McGraw-Hill, Inc., New York. 576p.

Hosie, R. C. 1990. Native trees of Canada (8th ed.). Fitzhenry & Whiteside Limited, Markham, Ontario. 380p.

Jewett, K., D. Daugharty, H. H. Krause and P. A. Arp. 1995. Watershed responses to clear-cutting: Effects on soil solutions and stream water discharge in central New Brunswick. Canadian Journal of Soil Science, **75**: 475 – 490.

Jones, J. A. and G. E. Grant. 1996. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon. Water Resources Research, **32**: 959 – 974.

Kneeshaw, D. D., A. Leduc, P. Drapeau, S. Gauthier, D. Par?, R. Doucet, R. Carignan, L. Bouthillier, and C. Messier. 1999. Development of integrated ecological standards of sustainable forest management at an operational scale. Sustainable Forest Management Network, Working Paper 1999-21. University of Alberta, Edmonton. ii+28p.

Koning, C. W. (ed.). 1999. Riparian Assessment and Prescription Procedures. Watershed Restoration Technical Circular No. 6. Watershed Restoration Program, Ministry of Environment, Lands and Parks, and Ministry of Forest. vi+79p.

Kreutzweiser, D. P. and S. S. Capell. 2001. Fine sediment deposition in streams after selective forest harvesting without riparian buffers. Canadian Journal of Forest Research, **31**: 2134-3142

Lambert, J. D. and S. J. Hannon. 2000. Short-term effects of timber harvest on abundance, territory characteristics, and pairing success of ovenbirds in riparian buffer strips. The Auk, **117**: 687 – 698.

Lisle, T. E. 1989. Sediment transport and resulting deposition in spawning gravels, North Coastal California. Water Resources Research, **25**: 1303 – 1319.

Lynch, J. A. and E. S. Corbett. 1990. Evaluation of best management practices for controlling nonpoint pollution from silvicultural operations. Water Resources Bulletin, **26**: 41 – 51.

Lynch, J. A., W. E. Sopper and D. B. Partridge. 1972. Changes in streamflow following partial clearcutting on a forested watershed. pp.313 – 320. *In*: Csallany, S. C., T. G. McLaughlin and W. D. Striffler. 1972. Proceedings of a Symposium on "Watersheds in Transition" Held at Fort Collins, Colorado June 19-22, 1972. American Water Resources Association Proceeding Series No.14.

MFC. 2000. Mississippi's Best Management Practices (3rd ed.). Mississippi Forestry Commission, MFC Publication # 107. iii+27p.

MNR. 1996a. Consolidated Buffer Management Guidelines. Manitoba Natural Resources. iii+5pp.

MNR. 1996b. Timber Harvesting Practices for Forestry Operations in Manitoba. Manitoba Natural Resources. ii+9pp.

MRN. 2002. Summary Report on the State of Quebec's Forests: 1995-1999. Ministere des Ressources naturelles, Gouvernement du Quebec. 8pp.

MacKinnon, W. 1994. Silviculture recommended for riparian zones on Prince Edward Island. *In*: Proceedings of the Symposium on Riparian Zone Management.

Canadian Forest Service, Maritimes Region, R&D Report #9. Fredericton, N.B. 127pp.

MacLauchlan, H. W. 1994. Riparian Zone Management: Legislation and Objectives. *In*: Proceedings of the Symposium on Riparian Zone Management. Canadian Forest Service, Maritimes Region, R&D Report #9. Fredericton, N.B. 127pp.

McCleary, K. and G. Mowat. 2002. Using forest structural diversity to inventory habitat diversity of forest-dwelling wildlife in the West Kootenay region of British Columbia. B.C. Journal of Ecosystems and Management, **2**: 1 – 13. http://www.forrex.org/jem/2002/vol2/no2/art1.pdf.

Meffe, G. K. and G. R. Carroll. 1997. Principles of Conservation Biology (2nd ed.). Sinauer Associates, Inc. Publishers, Massachusetts. 729p.

Megehan, W. F., J. G. King and K. A. Seyedbagheri. 1995. Hydrologic and erosional responses of a granitic watershed to helicopter logging and broadcast burning. Forest Science, **41**: 777 – 795.

Mellina, E., R. D. Moore, S. G. Hinch, J. S. Macdonald and G. Pearson. 2002. Stream temperature responses to clearcut logging in British Columbia: the moderating influences of groundwater and headwater lakes. Can. J. Fish. Aquat. Sci. **59**: 1886 – 1900.

Meng, F. R., C. P. A. Bourque, K. Jewett, D. Daugharty and P. A. Arp. 1995. The Nashwaak Experimental Watershed Project: Analysing effects of clearcutting on soil temperature, soil moisture, snowpack, snowmelt and stream flow. Water, Air and Soil Pollution, **82**: 363 – 374.

Moore, G. C. 1983. A report on the feasibility of harvesting timber within buffer zones: A literature review. Umpublished Rept., Dept. of Nat. Resour., Fredericton, NB, Canada.

Naiman, R. J., H. DeCamps and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications, **3**: 209 – 212.

Newbold, J. D., D. C. Erman and K. B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Can. J. Fish. Aquat. Sci. **37**: 1076 – 1085.

Newcombe, C. P. and D. D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management, **11**: 72 – 82.

Nova Forest Alliance. 2002. Contractors and operators best management practices manual. Model Forest Network, Natural Resources, Canada. 64p.

NSNR. 1997. Toward Sustainable Forestry; a position paper. Nova Scotia Department of Natural Resources, Working Paper, 1997-01. iii+42pp.

ODNR. Undated. Best Management Practices for Logging Operations Fact Sheet. Ohio Division of Forestry, A division of the Ohio Department of Natural Resources. 4p. http://www.hcs.ohio-state.edu/ODNR/Forestry.htm.

OMNR. 1995. Forest Operations and Silviculture Manual. Ontario Natural Resources Information Center, Toronto. 64p.

OMNR. 1994. Code of Practice for Timber Management Operations in Riparian Areas. Ontario Ministry of Natural Resources, MNR # 4623. iii+9pp.

O'Laughlin, J. and G. H. Belt. Functional approaches to riparian buffer strip design. Journal of Forestry, **93**: 29-31.

Park, S. W., S. Mostaghimi, R. A. Cooke and P. W. McClellan. 1994. BMP impacts on watershed runoff, sediment, and nutrient yields. Water Resources Bulletin, **30**: 1011 – 1023.

Peacock, H. 1996. Guidelines for Environmentally Responsible Forestry Operations in Manitoba; a practical guide towards sustainable forestry operations. Manitoba Model Forest Inc. iv+54pp.

Pendergast, B. 2002. Wildlife and habitat inventory for a results-based Forest Practices Code. B.C. Journal of Ecosystems and Management, **2**: 1 – 8. http://www.forrex,org/jem/2002/vol2/no2/art6.pdf.

Phillips, M. J., L. W. Swift, Jr. and C. R. Blinn. 2000. Best management practices for riparian areas. *In*: Verry, E.S., J. W. Hornbeck and C. A. Dolloff (eds.). 2000. Riparian management in forests of the continental eastern United States. Lewis Publishers, Florida. 402p.

Pomeroy, J. 1998. State of the Greater Fundy Ecosystem Case Study: Hayward Brook Watershed Study; Stream Hydrochemistry. Faculty of Forestry, University of New Brunswick. 6p. http://www.unbf.ca/forestry/centers/cwru/soe/hydro.htm.

Reid, L. M. and S. Hilton. 1998. Buffering the buffer. pp71 – 80. *In*: Ziemer, R. R., technical coordinator. 1998. Proceedings of the conference on coastal watersheds: the Caspar Creek Story; 6 May 1998; Ukiah, CA. Gen. Tech. Rep. PSW-GTR-168. Albany, CA: Pacific Southwest Station, Forest Service, U.S. Department of Agriculture; 149p.

Rodewald, A. D. and M. C. Brittingham. 2001 Incorporating wildlife needs into best management plans. Ohio State University Extension Fact Sheet W-1-2001. http://www.ag.ohio-state.edu/~ohioline/w-fact/0001.html.

Ros?n, K., J. Aronson and J. M. Eriksson. 1996. Effects of clear-cutting on streamwater quality in forest catchments in central Sweden. Forest Ecology and Management, **83**: 237 –244.

SIR. 2002. Forestry Status Report; Growing Opportunities – Today and Tomorrow. A Status Report on Saskatchewan's Forestry Initiatives. Saskatchewan Industry and Resources. 4p.

Scruton, D. A., S. C. Riley, B. A. Bennett, F. T. Bowdring and K. D. Clarke. 2000. A review of habitat suitability criteria applicable to four salmonids species of Newfoundland, Canada. Can. Manu. Rep. Fish. Aquat. Sci. No. 2548: vi + 56p + appendices.

Scruton, D. A., D. R. Sooley, L. Moores, M. A. Barnes, R. A. Buchanan and R. N. McCubbin. 1997. Forestry guidelines for the protection of fish habitat in Newfoundland and Labrador. Fisheries and Oceans, St. John's, NF. 63pp.

Simon, N. P. P., F. E. Schwab and A. W. Diamond. 2000. Patterns of breeding bird abundance in relation to logging in western Labrador. Canadian Journal of Forest Research, **30**: 257 – 263.

Stevens, V., F. Backhouse, and A. Eriksson. 1995. Riparian management in British Columbia: an important step towards maintaining biodiversity. Res. Br., B.C. Min. For. Hab. Protect. Br., B.C. Min. Environ., Lands and Parks, Victoria, B.C. Work. Pap. 13/1995.

Stocek, R. 1994. The importance of riparian zones as wildlife habitat. *In*: Proceedings of the Symposium on Riparian Zone Management. Canadian Forest Service, Maritimes Region, R&D Report #9. Fredericton, N.B. 127pp.

Summers, R. P., E. Storey and E. S. Burroughs. 1998. Nonpoint source management plan: silvicultural activities. NPS Task Force, Division of Forestry, Fire, and State Lands, Utah. v+124p

Thorpe, J. and B. Godwin. 1999. Threats to Biodiversity in Saskatchewan. Plant Ecology Section, Environment Branch. Saskatchewan Research Council, Saskatoon. SRC Publication No. 11158-1CPP. iv + 69p.

Tims, J. 1994. The role of the riparian zone as it affects water quality. *In*: Proceedings of the Symposium on Riparian Zone Management. Canadian Forest Service, Maritimes Region, R&D Report #9. Fredericton, N.B. 127pp.

Twery, M. J. and J. W. Hornbeck. 2001. Incorporating water goals into forest management decisions at a local level. Forest Ecology and Management, **143**: 87 – 93.

UME. 1997. Best Management Practices (BMPs). University of Maine. http://www.ume.maine.edu/~woodlot/bmp.htm.

UNL. 1998. Forestry best management practices for Nebraska; a reference guide for loggers, landowners and managers. Nebraska Forest Service and University of Nebraska Cooperative Extension Work. 16p. http://www.ianr.unl.edu/pubs/forestry/nfs/nfs-1.htm.

Van Rees, K. and D. Jackson. 2002. Impacts of harvesting riparian areas on soil properties. Final report submitted to Prince Albert Model Forest Association prepared by Department of Soil Science, University of Saskatchewan. 33pp.

von Mirbach, M. 1999. Criteria and Indicators of Sustainable Forest Management; a practical guide to using local level indicators in Newfoundland and Labrador. Western Newfoundland Model Forest Inc. iii+38pp.

Wang, L., J. Lyons and P. Kanehl. 2002. Effects of watershed best management practices on habitat and fish in Wisconsin streams. Journal of the American Water Resources Association, **38**: 663 – 680.

Wedeles, C. and J. Williams. 1995. A framework for ecosystem based management in the Manitoba Model Forest. ESSA Technologies Ltd., Ontario. 65p.

Whitaker, D. M. and W. A. Montevecchi. 1999. Breeding bird assemblages inhabiting riparian buffer strips in Newfoundland, Canada. Journal of Wildlife Management, **63**: 167 – 179.

White, J. B. and H. H. Krause. 1993. The impact of forest management practices on water quality and the establishment and management of protective buffer zones; a review of literature. Department of Forest Resources, University of New Brunswick, Fredericton, N.B. v+47pp.

Woodley, S. and G. Forbes (eds.). 1997. Forest Management Guidelines to Protect Native Biodiversity in the Fundy Model Forest. Greater Fundy Ecosystem Research Group, Fundy Model Forest Network. vii+35pp.

Young, E. 1994. Newfoundland Timber Harvesting: Logging Systems in Use Today. FPD Internal Report #12. Newfoundland Forest Service, Forest Products and Development Division. 9p.