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STRUCTURAL AND FUNCTIONAL ROLES OF RIPARIAN MANAGEMENT AREAS IN MAINTAINING STREAM VALUES IN THE ACADIAN FOREST

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by

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PRESIDENT'S NOTE

The Acadian Forest Region (AFR) of eastern Canada and the northeastern United States is a transitional zone between coniferous forests to the north and deciduous forests to the south. As in other regions, streams and riparian forests in the AFR provide habitats for a diverse range of aquatic and terrestrial organisms, and have other important roles in ecosystem processes such as nutrient cycling and water filtration. Experience and research show that care to protect streams is warranted during harvest operations.

Riparian Management Areas (RMAs) are often used to control the amount and type of harvest and residual forest cover in zones adjacent to streams. This report reviews the current literature on use of RMAs in the AFR with the following objectives: a) determine how the biophysical properties of the riparian communities of the AFR respond to forest management practices; b) assess how these responses compare with those in the rest of North America, c) identify information gaps; and d) suggest future research needs. The report was prepared for NCASI by Dr. Azim Mallik at Lakehead University.

This report supports the view that RMAs help maintain important functions of aquatic and terrestrial ecosystems in the AFR: e.g., by moderating stream temperature changes associated with timber harvest; by maintaining a source of organic inputs to watercourses; and by providing refugia for plants and animals affected by timber harvesting. None of the literature reviewed by Dr. Mallik highlighted particular differences between the AFR and the rest of North America with respect to the general functions and effectiveness of RMAs.

RMA guidelines vary across the AFR, and are province- or state-specific. The level of stream protection that can be achieved with any RMA design is difficult to predict because factors other than RMA design and function can affect stream characteristics (e.g., groundwater intrusion affecting stream temperature; sediment from roads affecting turbidity). RMAs are most appropriately used as part of a suite of management practices designed to minimize negative effects of harvest operations. Some private forest owners in the AFR are supplementing the applicable RMA guidelines with additional protective measures.

Priority topics for future research suggested by Dr. Mallik include a) effectiveness of RMAs in conserving terrestrial habitats, plant communities, and biodiversity in the AFR; b) studies of harvesting effects on headwater streams with and without RMAs; c) ecological effects of partial harvests (e.g., thinning, variable retention) and management options for logging slash within RMAs;

d) long-term studies of RMA functions and response to both natural and human disturbance;
e) feasibility and effectiveness of managing RMAs as late-successional reserves; and f) ecological studies to determine whether riparian areas in the AFR have unique functions or characteristics that require particular consideration in forest management.

Ronald A. Yeske

August 2006

MOT DU PRÉSIDENT

La région forestière acadienne (RFA) de l'est du Canada et du nord est des États-Unis constitue une zone de transition entre les forêts de conifères du Nord et les forêts de feuillus du Sud. Comme dans les autres régions, les forêts riveraines et les cours d'eau de la RFA fournissent des habitats pour une variété d'organismes aquatiques et terrestres. Ils ont également d'autres rôles importants dans les processus des écosystèmes tels que le cycle des nutriments et la filtration de l'eau. L'expérience et la recherche démontrent que la protection des cours d'eau est nécessaire lors des opérations de récolte.

Les zones d'aménagement des rives (ZAR) sont souvent utilisées pour contrôler la quantité et le type de récolte du bois ainsi que le couvert de forêt résiduelle adjacente aux cours d'eau. Ce rapport fait la synthèse de la littérature actuelle portant sur l'utilisation des ZAR dans la RFA. Cette synthèse vise les objectifs suivants : a) déterminer comment les propriétés biophysiques des communautés riveraines de la RFA répondent aux bonnes pratiques forestières; b) évaluer comment ces réponses se comparent avec celles du reste de l'Amérique du Nord; c) identifier les lacunes en matière d'information et d) identifier les futurs besoins de recherche. Dr.Azim Mallik, de l'Université Lakehead, a préparé ce rapport pour NCASI.

Le rapport appuie l'idée que les ZAR contribuent au maintien des fonctions importantes des écosystèmes aquatiques et terrestres dans la RFA, par exemple, en modérant les changements de température d'un cours d'eau qui surviennent lors de la récolte du bois, en maintenant une source d'intrants de matières organiques vers les cours d'eau et en fournissant un refuge pour les plantes et les animaux affectés par les activités de récolte du bois. Aucune littérature examinée par le Dr. Mallik ne faisait ressortir des différences particulières entre la RFA et le reste de l'Amérique du Nord en ce qui concerne les fonctions générales et l'efficacité des ZAR.

Les lignes directrices des ZAR varient à travers la RFA et sont spécifiques à chaque province ou état. Le niveau de protection des cours d'eau qui peut être atteint dans la conception de n'importe quelle ZAR est difficile à prédire car il existe des facteurs autres que la conception et les fonctions des ZAR qui peuvent affecter les caractéristiques d'un cours d'eau (par exemple l'intrusion d'eau souterraine affectant la température du cours d'eau, les sédiments s'écoulant des chemins affectant la turbidité). Les ZAR font habituellement partie d'une suite de pratiques de gestion conçues pour minimiser les effets négatifs des opérations de récolte. Certains propriétaires de forêts privées dans la RFA complètent les lignes directrices applicables dans les ZAR avec des mesures protectrices additionnelles.

Parmi les futurs sujets de recherche jugés prioritaires et suggérés par le Dr. Mallik, mentionnons a) l'efficacité des ZAR pour conserver les habitats terrestres, les communautés de plantes et la biodiversité dans la RFA; b) la réalisation d'études traitant des effets de la récolte sur les cours d'eau de tête, avec et sans ZAR; c) les effets écologiques des récoltes partielles (par exemple, l'éclaircie, la rétention variable) et les options de gestion des rémanents de coupe à l'intérieur des ZAR; d) la réalisation d'études à long terme sur les fonctions des ZAR et la réponse aux perturbations naturelle et humaine; e) la faisabilité et l'efficacité associées à la gestion des ZAR en tant que réserves de fin de succession et f) la réalisation d'études écologiques pour déterminer si les zones riveraines de la RFA possèdent des fonctions ou caractéristiques uniques qui nécessitent des considérations particulières en ce qui concerne l'aménagement forestier.

Ronald A. Yeske

Août 2006

STRUCTURAL AND FUNCTIONAL ROLES OF RIPARIAN MANAGEMENT AREAS IN MAINTAINING STREAM VALUES IN THE ACADIAN FOREST

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ABSTRACT

Dynamic geomorphic and hydrological processes maintain the ecosystem functions of both the aquatic and terrestrial components of the riparian areas of forested streams. These ecosystem functions include the moderation of stream temperature and light, the filtration of sediments and nutrients entering streams, and the inputting of fine and large organic debris into streams. Riparian areas also provide habitats that sustain a range of biodiversity in both the stream and adjacent terrestrial areas, and provide corridors of habitats that may facilitate movement and dispersal of plants and animals. Much of our knowledge of the ecological functions of riparian zones comes from observations of the effects of forest harvesting on riparian ecosystems. In light of these observations, Riparian Management Areas (RMAs—strips of forest retained on either side of streams) have been used to mitigate these effects. This literature review focuses on how riparian communities respond to forest harvesting with retention of RMAs in particular reference to Acadian forest streams.

The Acadian forest spans the Maritime provinces of Canada and in the United States most of Maine, New Hampshire, and Vermont; part of Massachusetts and Connecticut; and a small portion of New York. The Acadian forest is considered a transitional forest, retaining elements of both the boreal forest to the north and the deciduous forest to the south. Although research addressing the effects of forest management on the ecological functions of the riparian systems of the Acadian forest is limited, it is fairly diverse, perhaps with a slight bias toward examining the water quality aspects of these systems. Studies demonstrate that RMAs maintain some of the ecological functions of riparian areas: maintenance of stream temperature and light levels, prevention of elevated sediment and exogenous nutrient inputs, promotion of biodiversity by acting as refugia for riparian as well as upland plants, and providing vital habitat for amphibians. None of the research on the riparian areas of the Acadian forest region reported in this document highlighted particular differences in the riparian functions of this region compared to the rest of North America, and RMA guidelines vary greatly across the provinces and states of the Acadian forest region, as do those for regions throughout North America.

Several aspects of RMAs are poorly studied in Acadian forests. Future research in the Acadian forest region should address forest harvesting effects on headwater streams, the microclimatic changes along the harvest edge of RMAs and the corresponding effects on riparian plant communities, as well as the response of these plant communities to variation in tree retention within RMAs. Research in this region should also evaluate recovery of riparian functions after disturbance and how management impacts compare with and interact with natural disturbances. It would be beneficial for more of the research regarding the Acadian riparian ecosystems to undergo peer review, both for quality assurance, and for greater accessibility by other researchers in this field. Future research should also concentrate on obtaining data regarding the potential uniqueness of the structure and function of Acadian forest riparian areas. Research is required to determine whether the riparian ecosystems of the Acadian forest are dynamically distinct from other forest regions in order to make suggestions for their appropriate management.

KEYWORDS

Acadian forest, buffer, Connecticut, ecological functions, ecotones, edge effects, habitat conservation, headwater streams, Maine, Massachusetts, microclimate, New Brunswick, New Hampshire, New York, Nova Scotia, Prince Edward Island, RMA, RMA guidelines, riparian, selective harvesting, Vermont, water quality

RELATED NCASI PUBLICATIONS

Technical Bulletin No. 908 (September 2005). *Riparian forest management and the protection of biodiversity: A problem analysis.*

Technical Bulletin No. 799 (February 2000). *Riparian vegetative effectiveness.*

Technical Bulletin No. 775 (January 1999). *Assessing effects of timber harvest on riparian zone features and functions for aquatic and wildlife habitat*.

Technical Bulletin No. 631 (June 1992). *The effectiveness of buffer strips for ameliorating offsite transport of sediment, nutrients, and pesticides from silvicultural operations*.

Technical Bulletin No. 602 (February 1991). *The new Alsea watershed study*.

Technical Bulletin No. 514 (February 1987). *Managing Oregon's riparian zone for timber, fish, and wildlife*.

RÔLES STRUCTUREL ET FONCTIONNEL DES ZONES D'AMÉNAGEMENT DES RIVES DANS LE MAINTIEN DES CARACTÉRISTIQUES NATURELLES DES COURS D'EAU DE LA FORÊT ACADIENNE

BULLETIN TECHNIQUE NO. 922
AOÛT 2006

RÉSUMÉ

Les processus hydrologiques et ceux de la dynamique géomorphologique maintiennent les fonctions écosystémiques des composantes aquatiques et terrestres des zones riveraines longeant les cours d'eau situés en milieux forestiers. Ces fonctions écosystémiques comprennent la modération de la température et de la lumière des cours d'eau, la filtration des sédiments et des nutriments qui se déversent dans les cours d'eau et l'apport de débris organiques fins et grossiers dans les cours d'eau. Les zones riveraines fournissent également des habitats qui soutiennent la biodiversité dans les cours d'eau mêmes ainsi que dans zones terrestres adjacentes. Elles constituent aussi des corridors d'habitats qui peuvent faciliter le mouvement et la dispersion des plantes et des animaux. La grande partie de notre connaissance des fonctions écologiques des zones riveraines provient des observations des effets de la récolte forestière sur les écosystèmes riverains. À la lumière de ces observations, on a utilisé les zones d'aménagement des rives (ZAR—tronçons de forêt intacts de chaque côté des cours d'eau) pour mitiger ces effets. Cette revue de littérature montre comment les communautés riveraines répondent à la récolte forestière en intégrant les pratiques de rétention des ZAR, en se référant plus particulièrement aux cours d'eau de la forêt acadienne.

La forêt acadienne s'étend des Provinces maritimes du Canada jusqu'aux États-Unis où elle est présente dans les états du Maine, du New Hampshire et du Vermont. Elle constitue également une partie du Massachusetts et du Connecticut ainsi qu'une petite portion de l'état de New York. La forêt acadienne est considérée comme étant une forêt transitionnelle, car elle contient des éléments de la forêt boréale plus au nord et de la forêt caduque plus au sud. Les recherches s'intéressant aux effets de l'aménagement forestier sur les fonctions écologiques des systèmes riverains de la forêt acadienne sont limitées, mais elles sont cependant diversifiées. On perçoit dans ces recherches un léger biais pour l'examen des aspects reliés à la qualité de l'eau des systèmes. Les études démontrent que les ZAR maintiennent certaines des fonctions écologiques des zones riveraines : maintien des niveaux de température et de lumière des cours d'eau, prévention de l'arrivée de quantités élevées de sédiments et de nutriments exogènes, promotion de la biodiversité en agissant en tant que refuge pour les plantes riveraines et celles des hautes terres et apport d'un habitat vital pour les amphibiens. Aucune recherche portant sur les zones riveraines de la région forestière acadienne mentionnée dans ce document faisait ressortir des différences entre les fonctions riveraines de cette région et celles du reste de l'Amérique du Nord. Les lignes directrices portant sur les ZAR varient grandement selon les provinces et les états couverts par la région forestière acadienne, tout comme celles que l'on retrouve partout en Amérique du Nord.

Plusieurs aspects des ZAR n'ont pas fait l'objet d'études approfondies dans les forêts acadiennes. Les recherches futures sur la région forestière acadienne devraient inclure les effets de la récolte forestière sur les cours d'eau de tête, les changements microclimatiques le long de la bordure de récolte des ZAR et les effets correspondant sur les communautés de plantes de même que la réponse de ces communautés de plantes par rapport à la variation de la rétention des arbres à l'intérieur même des ZAR. Les recherches dans cette région devraient également évaluer la récupération des fonctions riveraines après perturbation et comment les impacts de l'aménagement se comparent et interagissent avec les perturbations naturelles. Il serait bénéfique d'effectuer une revue de pairs dans les futures

recherches portant sur les écosystèmes riverains de la forêt acadienne, dans un but d'assurance qualité et afin d'améliorer l'accessibilité pour les autres chercheurs dans le domaine. Les futures recherches devraient également se concentrer sur l'obtention de données portant sur le potentiel unique de la structure et de la fonction des zones riveraines de la forêt acadienne. Des travaux de recherches sont également nécessaires pour déterminer si les écosystèmes riverains de la forêt acadienne sont dynamiquement distincts de ceux des autres régions forestières afin de faire des suggestions sur la gestion qui leur est appropriée.

MOTS CLÉS

Forêt acadienne, tampon, Connecticut, fonctions écologiques, écotones, effets de bordure, conservation de l'habitat, cours d'eau de tête, Maine, Massachusetts, microclimat, Nouveau Brunswick, New Hampshire, New York, Nouvelle Écosse, Ile du Prince Edouard, ZAR, lignes directrices des ZAR, riverain, récolte sélective, Vermont, qualité de l'eau

AUTRES PUBLICATIONS DE NCASI DANS CE DOMAINE

Bulletin technique no. 908 (septembre 2005). *Riparian forest management and the protection of biodiversity: A problem analysis.*

Bulletin technique no. 799 (février 2000). *Riparian vegetative effectiveness.*

Bulletin technique no. 775 (janvier 1999). *Assessing effects of timber harvest on riparian zone features and functions for aquatic and wildlife habitat.*

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Bulletin technique no. 602 (février 1991). *The new Alsea watershed study*.

Bulletin technique no. 514 (février 1987). *Managing Oregon's riparian zone for timber, fish, and wildlife*.

CONTENTS

TABLES

FIGURES

STRUCTURAL AND FUNCTIONAL ROLES OF RIPARIAN MANAGEMENT AREAS IN MAINTAINING STREAM VALUES IN THE ACADIAN FOREST

1.0 INTRODUCTION

The word riparian comes from the Latin word *riparius*, meaning "belonging to the bank of a river", and refers to the land adjacent to a water body (Naiman, Decamps, and McClain 2005). Taken literally, this does not include the aquatic component. However, since the strong terrestrial-aquatic linkages play critical roles in maintaining the structure and function of riparian systems, many researchers now support the view of defining riparian zone more broadly by incorporating the zone of land-water interface with the aquatic community (Gregory et al. 1991; Naiman and Decamps 1997). Riparian boundaries can be delineated by changes in soil conditions, geomorphology and topography, vegetation, and other factors that reflect this aquatic-terrestrial interaction (Naiman and Decamps 1997; Naiman, Bilby, and Bisson 2000).

The influence of the stream, primarily by flooding and elevated water tables, has a strong influence on vegetation which in turn, influences the aquatic and riparian habitat (Naiman and Decamps 1997). In their definition of the riparian zone, Ildhardt, Verry, and Palik (2000) emphasize the functional role of riparian ecosystems operating at multiple spatial scales, and describe these areas as three-dimensional ecotones of interaction that "extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the watercourse at variable width" (Figure 1.1). Disturbance-induced habitat heterogeneity and the adaptability of riparian organisms to habitat heterogeneity are the two principal drivers of riparian area biodiversity.

Disturbance in riparian areas can also have adverse effects on the habitat and on the structure and function of the biotic community through an increase in exotic or alien plant species (Rose and Hermanutz 2004). Recovery of riparian communities from anthropogenic disturbances is often related to the nature of the forest harvesting such as maintaining RMAs and observing restrictions to silvicultural activities adjacent to the riparian zone (Sarr et al. 2005).

The Acadian forest is considered unique and differs from regions to its north, south, and west. As a transition area between the northern boreal forest and the southern deciduous forest, the Acadian forest includes elements of both. It is yet unclear how the Acadian forest is functionally unique from other regions, and questions have arisen regarding how riparian areas in the Acadian forest (forest streams in particular) respond to forest harvesting and management. There is a need to determine how much is known regarding forest management impacts on riparian communities and the extent of the knowledge gaps compared to other regions of North America. By examining RMA guidelines across North America, it may be possible to distinguish patterns that may relate to the uniqueness of different forest regions. This literature review focuses on how the riparian functions of Acadian forest streams respond to forest management to determine whether management of these ecosystems deserves special consideration.

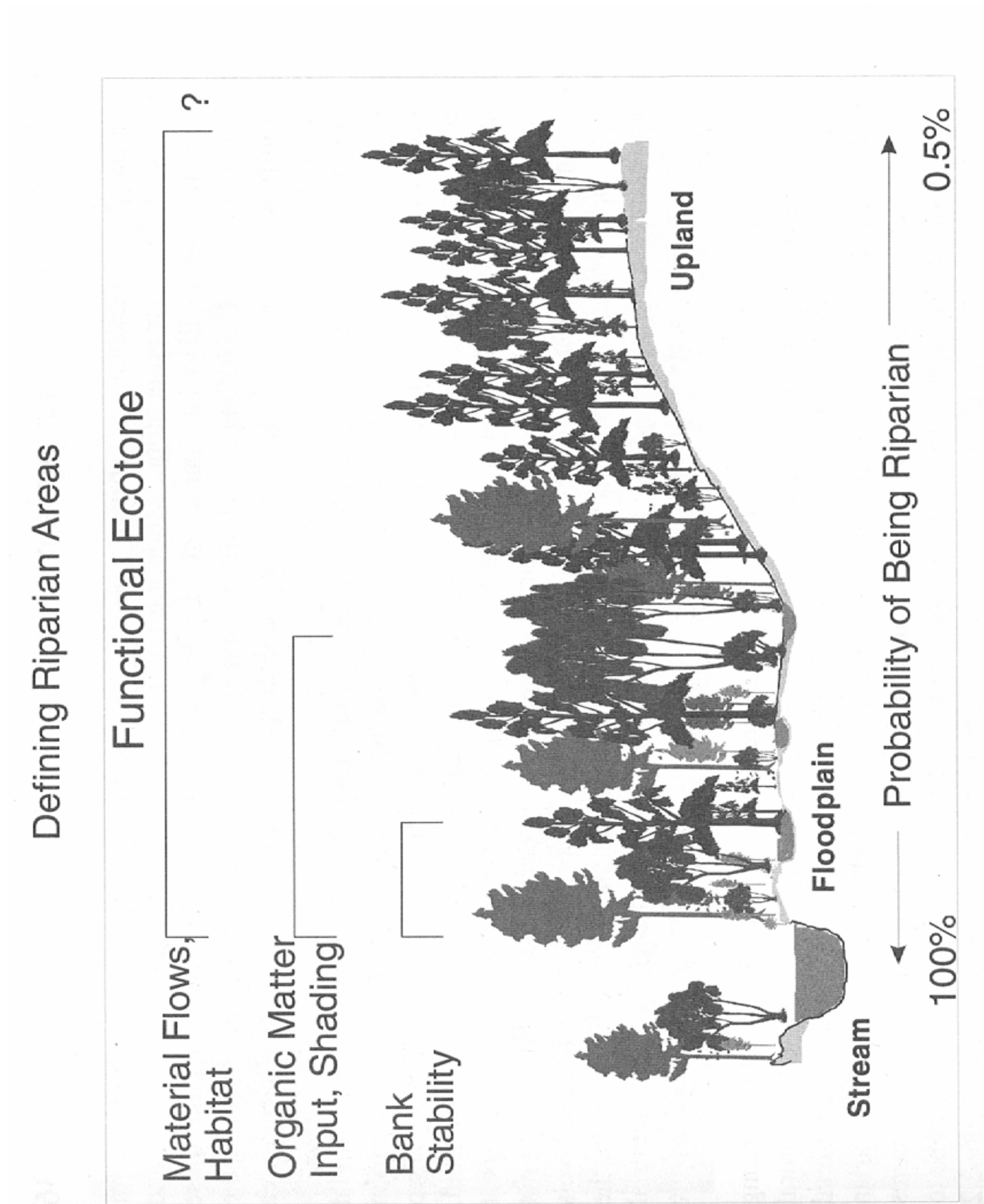

Figure 1.1 Cross Section of Riparian Zone Showing the Lateral Gradient from Upland Forest to Stream (reproduced with permission from Ildhart, Verry, and Palik 2000).

1.1 Objectives

The primary objectives of this report were to a) determine how the biophysical properties of the riparian communities of Acadian forest respond to forest management practices, b) assess how these responses compare with those in riparian zones in the rest of North America, c) identify information gaps, and d) suggest future research needs.

2.0 METHODS

Several approaches were undertaken to achieve the above objectives. First, printed journal articles in this field were reviewed in conjunction with a detailed search and review of online peer-reviewed journal publications and databases. These included WebSPIRS™ databases (Forest Science Database, Biological and Agricultural Indexes, Biological Abstracts, Applied Science and Technology Index, Aquatic Sciences and Fisheries Abstracts), Scholars Portal databases (Applied Sciences Abstracts@Scholars Portal, Pollution Abstracts, Entomology Abstracts, ASFA1: Biological Sciences and Living Resources, ASFA3: Aquatic Pollution and Environmental Quality, Ejournals@Scholars Portal), and databases from ISI Web of Knowledge℠, Blackwell Synergy®, Elsevier Science Direct®, JSTOR, National Research Council Canada (NRC-CNRC), ProQuest® ABI/INFORM Trade and Industry, and Springer©. Keywords used for these searches were combinations of the following: riparian, Acadian, New England, New Brunswick, Nova Scotia, Prince Edward Island, Maine, Vermont, New Hampshire, forestry, streams, hydrology, geomorphology, RMAs, forest management, fire history, and disturbance. This approach was particularly useful for finding general information about riparian areas; however, only one relevant journal article regarding research in the Acadian forest was obtained using the keyword combination riparian and Acadian. Aside from primary literature, other documents reviewed were graduate theses, conference proceedings and technical reports.

One of the most successful approaches to finding research on riparian areas in the Acadian forest was to search the world wide web. Some of the more comprehensive sites include Nova Forest Alliance (http://www.novaforestalliance.com), Fundy Model Forest (http://www.fundymodelforest.net), Manomet Centre for Conservation Sciences (http://www.manomet.org), and the Cooperative Forestry Research Unit at the University of Maine (http://www.umaine.edu/cfru/). Another productive approach was to correspond via email and telephone with individuals doing research in the Acadian forest region (see Appendix A).

3.0 THE UNIQUE FEATURES AND FUNCTIONS OF RIPARIAN ECOSYSTEM

The ecosystem dynamics of riparian areas are controlled by physical (e.g., geomorphic, hydrologic, chemical etc.) and biotic processes. The combination of these processes creates diverse physical environments which in turn, promote and maintain high biodiversity in riparian areas (Crow, Barker, and Barnes 2000). The geomorphic processes associated with flowing water create varying landforms that experience periodic fluctuations in moisture and aeration from bank flooding (Naiman, Decamps, and McClain et al. 2005). These processes manifest their influence through longitudinal controls of vegetation structure and composition both laterally and longitudinally along the stream channel (Ildhart, Verry, and Palik 2000).

Longitudinally, a typical stream profile from the headwaters to the mouth has the steepest gradients near the headwaters; the gradients gradually become less steep downstream. A gradient in sediments occurs where larger sediments deposit in the upstream and the finer sediments are carried farther downstream. Organic inputs follow this gradient as well, where many of the input (e.g., leaves and woody debris) coming from upstream headwaters move down and are retained along the stream's course (Fisher and Likens 1973; Newbold et al. 1981). Invertebrates flow downstream from headwaters and are a food source for fish in larger order streams (Wipfli and Gregovich 2002).

The lateral gradient of streams, from stream bed towards the upland, is created by erosion due to water flow and periodic flooding (Figure 1.1). Flooding creates diversity in microsites, leading to higher species diversity in riparian zones than in upslope habitats. The geomorphic environmental gradient from the stream to the upland reflects the spatial patterns of riparian plant and animal communities (Gregory et al. 1991). The lateral gradient has also been described as an ecotone where not only can there be discontinuity in the species abundance and distribution but also discontinuity in plant traits, i.e., plants have acquired traits that help them adapt to the lateral microclimatic gradient (Lamb and Mallik 2003). In fact, Lamb, Mallik, and Macereth (2003) found that the vegetation community in riparian zones was not strongly affected by disturbances occurring in the upland vegetation. In addition, the lateral meandering of streams can modify the pattern of riparian vegetation by cutting into older plant communities and depositing sediments that allow a younger plant community to develop at the inner margin of the meander (Gregory et al. 1991). Nilsson et al. (1991) examined whether vascular plant species richness in riparian areas along rivers in Sweden was similar between small and large rivers. They found that the highest species richness for all rivers occurred where the channel was moderately steep and the soil had moderate texture.

The structural habitat diversity created through geomorphic controls on the lateral and longitudinal gradients of riparian areas supports species diversity made up of riparian obligates and riparian associates. Riparian obligates are organisms that absolutely require riparian areas for at least some portion of their life cycle (e.g., some piscivores, benthivores and amphibians spend their larval stages in streams and remain as riparian associates in their juvenile and adult stages). Other obligates include some vascular plants and bryophytes (Hylander et al. 2002). Riparian facultative organisms are associated with riparian areas, because of the high productivity and particular microclimates, e.g., grizzly bears foraging for berries and returning salmon at certain times of the year (Prenda, Lopez-Nieves, and Bravo 2001).

The dynamic nature of riparian habitats and their biotic communities provide distinct ecological functions that maintain the unique biophysical characteristics of this terrestrial-aquatic interface (Table 3.1). The terrestrial vegetation of riparian zone provides beneficial functions to their adjacent aquatic systems by cooling stream temperature through shading (Curry, Scruton, and Clarke 2002; MacDonald, MacIsaac, and Herunter 2003; Johnson and Jones 2000), and attenuating light reaching the stream surface (Vannote et al. 1980; Roberts, Sabater, and Beardall 2004; Kiffney, Richardson, and Bull 2003). Light filtering by riparian vegetation plays a critical role in controlling aquatic primary production (Vannote et al. 1980). In some cases aquatic productivity may be lowered by shading from riparian vegetation (Wilzbach et al. 2005) and targeted forest management, such as one-sided RMAs, is being tested as a method of achieving both water quality and habitat protection and also stimulating aquatic productivity (Newton and Cole 2005).

Table 3.1 Key Ecological Functions of RMAs and Ecosystem Response to Their Removal

Riparian attributes		Role of RMA	Absence or insufficient width of RMA	Authors
Water quality	Stream temperature	Riparian vegetation shades streams and prevents increases in water temperature.	A) Fish are negatively affected. B) Changes in macroinvertebrate communities can occur.	A) Thomas et al. (1980), Beschta et al. (1987) B) Vanotte and Sweeney (1980)
	Stream light	Riparian vegetation shades streams by filtering sunlight.	Can change the aquatic community dynamics by providing more light to photosynthetic periphyton	Kiffney et al. (2003), Roberts et al. (2004), Murphy et al. (1981), Newbold et al. (1980)
	Sediment-ation	Riparian vegetation filters sediments entering streams. Without RMA, stream turbidity increases with the addition of silt on stream bed.	A) Siltation of stream bed changes habitat thus changing the macroinvertebrate communities. B) Siltation fills substrate spaces required for fish egg development.	A) Fuchs et al. (2003), Murphy and Hall (1981), Rosenberg and Wiens (1978) B) Lisle (1989), Newcombe and MacDonald (1991)
	Erosion	Streamside riparian vegetation provides stability based on root structures without which siltation occurs (see above).	Effects of siltation (see above)	Hicks et al. (1991)
	Nutrients	Riparian vegetation filters exogenous nutrients entering stream.	A) Significant increases in periphyton can cause increase in bacteria and decrease DO which is deleterious to some macroinvertebrates. B) Changes in periphyton communities can cause a change in macroinvertebrate communities.	A) Ensign and Mallin (2001) B) Noel et al. (1986)
	Organic inputs	Although some is transported, most particulate inputs come from surrounding riparian areas.	Detrital-based food webs depend on these fixed carbon sources without which the dynamics of these food webs would change.	Fisher and Likens (1973), Robinson and Beschta (1990)
Habitat and biodiversity	Aquatic	Significant portion of large woody debris (LWD) comes from riparian zones.	LWD provides important habitat for A) fish and B) macroinvertebrates.	A) Murphy et al. (1986), Bisson et al. (1987) B) Anderson and Sedell (1979),
	Terrestrial	RMAs provide critical habitat to both riparian obligates (require area to complete a portion of its life cycle) and riparian associates (use the area but not a necessity for completing life cycle).	Significant decrease in biodiversity may result in A) plants, B) amphibians and reptiles, C) birds and D) mammals	A) Hylander et al. (2002), Fenton and Frego (2003) B) Semlitch and Bodie (2002) C) Shirley and Smith (2005), Whitaker and Montevecchi (1999), Darveau et al. (1995), Kilgo et al. (1998)
Movement corridors		Provide dispersal and migration corridors	Potential decrease in regional abundance and biodiversity may result	Gregory et al. (1991), Machtans et al (1996), Knopf and Samson (1994)

Soil binding properties of root systems and the above-ground cover of riparian vegetation provides stream bank stability (Hicks et al. 1991) and trapping of sediments (Nieminen et al. 2005; Kreutzwieser and Capell 2001; Gomi, Moore, and Hassan 2005), as well as uptake and cycling of excess nutrients from groundwater (Ensign and Mallin 2001; Castelle, Johnson, and Connelly 1994). The importance of root structures in maintaining soil stability is well established (e.g., Hartanto et al. 2003). Since riparian zones are located near the base of a watershed, they play critical roles in controlling the flux of nutrients entering into streams from the entire watershed (Gregory et al. 1991). Riparian vegetation also controls the type and quantity of terrestrially derived organic matter entering streams (Gregory et al. 1991; Bilby and Likens 1980; Guyette et al. 2002; Kreutzweiser, Capell, and Beall 2004). Particulate matter is deposited in the form of senesced leaves of herbs, shrubs and trees, needles from conifers, and herbaceous material enter the stream during floods (Gregory et al. 1991). Small forested streams often receive the largest portion of their biologically available energy as litterfall (Richardson, Bilby, and Bondar 2005). Organic material must be retained within the stream to function either as habitat or a nutrition source for aquatic invertebrates and directly as a food resource for herbivorous and detritivorous fish (Gregory et al. 1991). Woody debris from riparian zones obstructs the flow of particulate matter downstream creating pools and lateral habitats.

The terrestrial vegetation of riparian areas provides critical habitat for riparian obligates (Perkins 2005; Perkins and Hunter in press; Hylander et al. 2002; Prenda, Lopez-Nieves, and Bravo 2001), productive habitats for riparian associated species (McLellan and Hovey 2001; McComb, McGarigal, and Anthony 1993; Grindal, Morissette, and Brigham 1999), and corridors of habitat for these organisms that may facilitate their dispersal (Gregory et al. 1991; Machtans, Villard, and Hannon 1996; Knopf and Samson 1994).

4.0 ROLE OF NATURAL DISTURBANCE IN RIPARIAN ECOSYSTEM FUNCTION

The dynamic hydrological processes acting on the geomorphic features influence the structure of riparian ecosystems. The frequency and intensity of flooding play vital roles in shaping the biophysical characteristics of the riparian zone. For example, medium-power, intermediate floods can shape tree community zonation, whereas low-power floods that occur annually determine the short-term patterns of seed germination, and seedling survival and establishment (Naiman and Decamps 1997). Alternatively, at higher stream stages, the action of floods mechanically disturbs plants by soil erosion and abrasion (Naiman and Decamps 1997) and may reset riparian vegetation succession.

As discussed by Prowse and Culp (2003), in cold regions, annual river-ice breakup has been considered to be a “dominant controller of hydrological events”. Flood levels during ice break up are higher than those of equivalent discharge under open-water conditions because of the added flow resistance of the ice. The combination of high flow velocity, high stage, and the mechanical action of the ice make break up a highly erosive process for channels, banks and adjacent riparian areas (Prowse and Culp 2003). Dissolved oxygen can be affected in various ways: increased due to the intense turbulent mixing accompanied with the break up, or decreased where significant quantities of organic material are metabolized because of increased water temperatures. Ice breakup also affects the riparian and aquatic vegetation communities through ice scour, which can denude river banks of vegetation (Prowse and Culp 2003).

In forest ecosystems, composition, structure and successional dynamics are strongly influenced by the size, frequency, and severity of fires (Halpern and Spies 1995). According to Dwire and Kauffman (2003), research on fire regimes in riparian areas compared to upland areas indicates that fire frequency and severity varies by region and forest type. Riparian-related characteristics that may influence fire behaviour and spread in forests and rangeland landscapes of the western U.S. include high fuel loads, high fuel moisture, and fuel discontinuity due to active channels, gravel bars, and wet meadows that may function as natural fire breaks. Their position as lowest points in the landscape, and their cooler, moister microclimates may lessen fire intensity and rate of spread. Due to their adaptations to frequent disturbance such as flooding, riparian vegetation can also recover rapidly from fire (Lamb, Mallik, and Mackereth 2003). Adaptations that facilitate survival include epicormic and basal sprouting and thick bark, and those that facilitate recolonization include windborne seeds, water-dispersed propagules, fire-enhanced flowering and fruit production, refractory seeds buried in the soil, and on-plant seed storage (Dwire and Kauffman 2003). However, McGreer (1996) discussed a study describing a fork in the Clearwater River in Idaho which, 21 years after being burned, was totally exposed to the sun with only brush and occasional snags bordering the banks.

Andison and McCleary (2002) examined the fire regime in the Foothills Model Forest of Alberta and concluded that the relationship between fire and riparian zones is likely mostly controlled by local fire weather. Although there are some tendencies towards fire stopping at or leaving veteran trees in riparian areas, there is no evidence these areas act as fire refugia. They concluded from their observation of higher than expected levels of continual regeneration, that fire disturbance is a necessary process in maintaining characteristic riparian communities. Andison and McCleary (2002) argued that “young” riparian areas created by fire are as important as “old” riparian areas, and that the trees and coarse woody debris created by fire provide habitat for other organisms and play a crucial role in energy flow and nutrient cycling.

The beaver (*Castor canadensis*), plays a significant role in altering the riparian ecosystem. As listed by Naiman, Melillo, and Hobbie (1986), beaver activity a) modifies channel geomorphology and hydrology; b) increases retention of sediment and organic matter; c) creates and maintains wetlands (Barnes and Mallik 1997); d) modifies nutrient cycling and decomposition dynamics by wetting soils, by altering the hydrologic regime, and by creating anaerobic zones, in the soils and sediments; e) modifies the riparian zone by changing the species composition (Barnes and Mallik 1996, 2001) and growth form of plants, their chemistry (lignin, nitrogen, and defensive compounds), and the quantity of allochthonous inputs (i.e., derived from outside the stream, such as the leaves and cones of terrestrial plants that fall into the stream); f) influences water quality and materials transported downstream; and g) modifies habitat, which ultimately influences community composition and diversity.

Blowdown or windthrow in RMAs is a commonly observed phenomenon (Ruel 2000; Ruel, Pin, and Cooper 2001; NSDNR 2003). Trees left at the edge of clearcuts are exposed to stronger winds making them more susceptible to windthrow (Gardiner et al. 1997). Although Ruel, Pin, and Cooper (2001) found that windthrow was not related to strip width or thinning, Nova Scotia’s Department of Natural Resources found that the narrowest RMAs with the greatest percent thinning had the greatest loss of basal area due to blowdown (NSDNR 2003).

5.0 ROLE OF RMAS IN MITIGATING THE EFFECTS OF FOREST MANAGEMENT

Much of our knowledge of the ecological functions of riparian zones comes from observations of the impacts of unregulated forest harvesting on riparian communities. In light of these observations, RMAs (strips of forest retained on either side of streams) have been used to mitigate negative effects. With increased understanding of the riparian ecosystem, questions regarding the efficacy of simple RMA retention of predetermined width have arisen (e.g., Andison and McCleary 2002). It has also been shown that no one size RMA can protect every riparian function (e.g., see review by Loftin, Bank, and Hagan 2001; Richardson 2004).

The absence of RMAs has been found to negatively affect many aspects of water quality. The quality of the water is important to stream communities of periphyton, aquatic invertebrates, and fish, as well as to humans who may consume the water (Dissmeyer 2000). One very important aspect of water quality associated with stream organisms is temperature. The removal of riparian vegetation increases solar radiation on the stream surface which in turn changes the quantity and quality of light available for the aquatic primary producers (Gregory et al. 1991). Potential increases in primary production can alter the community structure of aquatic invertebrates (Kiffney, Richardson, and Bull 2003; Fuchs, Hinch, and Mellina 2003; Murphy, Hawkins, and Anderson 1981; Newbold, Erman, and Roby 1980; Wilzbach et al. 2005). Stream light levels can also affect the behaviour of fish. From a walleye telemetry study in stained and clear lakes, Metcalfe et al. (2006) reported that light and temperature conditions are key elements of walleye habitat. Brosofske et al. (1997) concluded that an RMA at least 5 m wide was required for maintenance of the natural light regime for a headwater stream. Solar radiation also contributes energy to the stream in the form of heat. Removal of riparian vegetation has been shown to increase stream temperatures (Barton, Taylor, and Biette 1985; Johnson and Jones 2000). According to Gregory et al. (1991), the upstream length of the forested channel, riparian vegetation width and density, canopy opening and groundwater all influence stream temperature. Increases in stream temperature can have negative effects on fish (Thomas et al. 1986; Beschta et al. 1987), and aquatic invertebrates (Vannote and Sweeny 1980).

The removal of riparian trees can increase the amount of sediments in streams. In a review of this topic, G. Ice (pers. comm.) concluded that RMAs reduce sediment by three mechanisms: a) maintaining the channel and bank integrity, b) reducing disturbance in riparian areas, and c) filtering sediments, most of which occurs immediately adjacent to the stream. Increased suspended sediment concentrations can be detrimental for stream biota (Gomi, Moore, and Hassan 2005) by causing direct damage to fish gills, interfering with their sight and feeding, and by causing the siltation of bed materials which can hamper incubation of fish eggs (Lisle 1989; Newcombe and MacDonald 1991). Fine sediment accumulation in stream substrates also reduces oxygen availability to benthic macroinvertebrates, which in turn reduces habitat heterogeneity (Rosenberg and Wiens 1978; Murphy and Hall 1981). Riparian vegetation has been shown to filter and absorb, take up, and recycle exogenous nutrients. Rates of denitrification in riparian soils decreased with distance from streams (Gregory et al. 1991). Increased nutrients can be used by primary producers, increasing periphyton levels resulting changes in stream invertebrate communities (Ensign and Mallin 2001).

The absence of RMAs can also significantly decrease the allochthonous organic matter input to streams. Fisher and Likens (1973) found that approximately 98% of stream organic matter was supplied by the surrounding forest. Of course disturbance that removes forest cover near streams may also increase autochotonous primary production in the stream. Riparian areas are important sources of large woody debris, which is important in controlling stream flow (Robinson and Beschta 1990), and in enhancing fish habitat through the provision of cover (Bisson et al. 1987; Murphy et al. 1986). Large woody debris jams in streams also create habitat for aquatic invertebrates (Anderson and Sedell 1979), increase sediment storage (Megahan 1982) and reduce nutrient spiraling lengths.

Riparian areas are important habitat for many terrestrial organisms including bryophytes (Hylander et al. 2002), liverworts (Fenton and Frego 2003), amphibians and reptiles (Semlitch and Bodie 2002, deMaynadier and Hunter 1995), birds (Darveau et al. 1995; Shirley and Smith 2005; Whitaker and Montevecchi 1999; Kilgo et al. 1998), and mammals (McComb, McGarigal, and Anthony 1993; Darveau et al. 2001; Cockle and Richardson 2003; Doyle 1990). In addition, some researchers suggest that the cutting of riparian areas will eliminate important movement corridors for many riparian organisms (Gregory et al. 1991; Machtans, Villard, and Hannon 1996; Knopf and Samson 1994).

5.1 Variation in RMA Guidelines Due to Geography and Climate

Lee, Smyth, and Boutin (2004) examined regional differences in RMA guidelines across North America. They divided provinces and states into six broad ecological regions and compared guidelines within and among these regions. They found that regions selected either relatively simple guidelines or more complex guidelines that incorporated a number of factors. Factors such as the presence of fish and bank slope were prominent and played important roles in creating complexity in guidelines (Lee, Smyth, and Boutin 2004). The Pacific region tended toward more complex guidelines, while the Midwest retained relatively simple guidelines. The authors suggested that the differences observed between regions may not necessarily stem from an inherently more complex underlying riparian ecology. In the Pacific ecoregion, flow rate and downstream sediment threat were the two modifying factors influencing RMA width. In the Northeast region, which encompasses the Acadian forest region, drainage basin area was the only modifying factor shared with one other region, the Boreal. The most common modifying factors in determining RMA guidelines were water body type and slope (Lee, Smyth, and Boutin 2004).

6.0 ACADIAN FOREST RESEARCH

6.1 Location, Structure and Function of Acadian Forest

Geographically, the Acadian forest region was first defined by Halliday (1937) then refined by Rowe (1959) and in Canada, includes most of the area of the Maritime provinces between 43 and 48° N latitude (Figure 6.1; Loo and Ives 2003) including Nova Scotia, New Brunswick, and Prince Edward Island, as well as the Eastern Townships and the Beauce regions of Quebec (Davis et al. 2001). In the United States, the Acadian forest spans all but the southwestern corner of Maine, the Champlain Valley of Vermont and the coastal plain of New Hampshire, northwestern Massachusetts and extreme northwestern Connecticut, as well as a small portion in the eastern portion of New York (Figure 6.1; National Geographic Society 2004; Davis et al. 2001). However, Nichols (1935) included the Acadian forest region with the New England States, southern Quebec, and the areas in Canada and the U.S. surrounding the Great Lakes in the “Hemlock-White Pine-Northern Hardwood Region”.

This forest type lies between, and includes elements of both the northern boreal coniferous forest and the primarily deciduous forest to the south and west (Loo and Ives 2003). The wide distribution of red spruce (*Picea rubens*) and red pine (*Pinus resinosa*) distinguishes this ecoregion from the predominantly deciduous woodlands of the Great Lakes Lowland Forests and the mixed woods of the Eastern Forest/Boreal Transition area. The range of vegetation types is due to several factors, including topography, geology and climate, including the proximity to the ocean (Loo and Ives 2003).

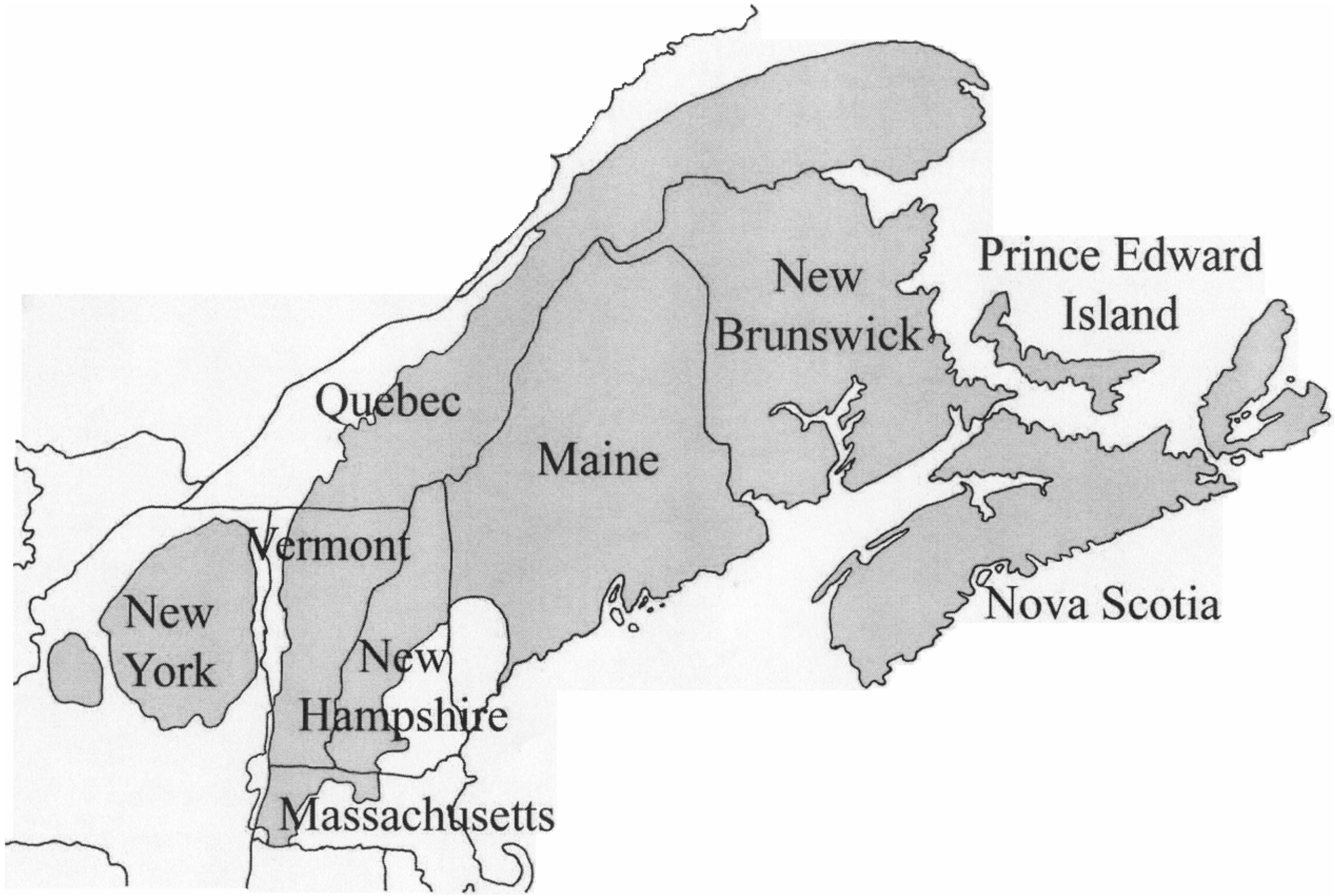

Figure 6.1 The Acadian Region of the Canadian Maritime Provinces and Northeastern United States. [Please note that most but not the entire region is covered by the Acadian Forest type (from Harriet Irving Botanical Garden website http://www.acadiau.ca/KCIrving_Centre/resources/KCIrvingCentre_presentation.pdf)]

In the Canadian Maritimes, the major forest types of the Acadian forest were classified by Loucks (1962) and others (Rowe 1959; Simmons et al. 1984) and include rich tolerant hardwood (like areas in the south), spruce-fir forest (similar to the northern boreal forests) and an array of coniferous, deciduous, and mixed intermediate types (Loo and Ives 2003). Tree species considered characteristic of the Acadian forest include red spruce, yellow birch (*Betula alleghaniensis* Britt.), sugar maple (*Acer saccharum* Marsh) and balsam fir (*Abies balsamea* (L.) Mill.) (Loo and Ives 2003).

The World Wildlife Fund's online Wild World Report provides an excerpt of the book *Terrestrial Ecoregions of North America: A Conservation Assessment*" which describes the "New England-Acadian Forests" (Davis et al. 2001). The region is described as hilly to mountainous and consisting of mountains, plateaus, and lowland plains which were shaped by glaciers. The geology of this area is complex due to volcanic activity, millions of years of erosion, and the presence of serpentine bedrock—all of which supports uncommon ecological communities (Davis et al. 2001). This variation in topography contributes to the patchwork of different soil and forest types classified within the scope of the Acadian forest. The climate of this ecoregion is characterized by warm, moist summers and cold, snowy winters, with maritime air masses present year-round on the eastern seaboard. Precipitation is evenly distributed throughout the year as rain, snow and, in some areas, a high incidence of fog.

Generally, the forests vary with elevation (Davis et al 2001). Conifers tend to dominate low elevations with shallow soils, hardwood forests occur predominantly with hemlock in the valleys, mixed coniferous and deciduous forests are observed on mountain slopes, and pure stands of balsam fir and red spruce are observed at higher elevations (Davis et al. 2001). Typical of the transitional nature of this ecoregion, the southernmost species of eastern North American arctic vegetation also occur here. On a few of the highest mountain peaks, numerous arctic species occur as disjunct populations (Davis et al. 2001).

In Nova Scotia, there are three systems of uplands: surrounding the Annapolis Valley along the northern edge hills rise to about 250 m; in the central part of the province hills rise to an elevation of 300 m; and on the northern part of Cape Breton Island plateaus between 300 and 450 m are present, with some hills reaching 520 m (Wein and Moore 1979). The climate is related to this topography, where winds along the coast may be strong, causing windthrow of trees (Johnson 1955). The highest potential evaporation is the interior regions of the southwestern half of the province, while summer droughts can occur in the northern Annapolis Valley and the Isthmus of Chignecto (Loucks 1962).

The Pockwock and Bowater watersheds in southwestern Nova Scotia represent important research sites in this region (research discussed in more detail later). These watersheds occur on hummocky or hilly terrain underlain with coarse, variably drained, granite derived till soils. Most of the area consists of mature softwood stands (predominantly spruce). The distribution of species harvested in 2005 from the Bowater watershed has been reported as 85% red or black spruce (*Picea mariana*), 10% red maple (*Acer rubrum*) and white birch (*Betula papyrifera*) and 5% white pine (*Pinus strobus*). The distribution of species harvested in the Pockwock watershed has been reported as 77% spruce, 19% balsam fir, and 4% red maple and white birch (NFA 2005).

The southwestern half of the province of New Brunswick is primarily lowland, except for the coastline along the Bay of Fundy, where highlands reach up to 400 m. The rest of the province has much greater topographic diversity, with most elevations above 350 m to a maximum elevation of 830 m (Wein and Moore 1977). Climatically, this province is generally continental; however, the coastal areas experience a maritime climate. Summer temperatures are high and drought is common in the northeast and in the area near the east coast and parallel to the Bay of Fundy (Loucks 1962). Some apt descriptions of New Brunswick's Acadian forest region come from Catamaran Brook and the Hayward Brook watersheds. In Catamaran Brook, the second growth Acadian forest consists of

55.5% mature trees at 65% coniferous and 35% deciduous species. The geology consists of volcanic and sedimentary rock over which till and glaciofluvial deposits of loam to sandy loam was deposited (Alexander et al. 2003). The Hayward Brook area is characterized by a secondary growth, mixed forest approximately 80 years old. In terms of basal area, dominant tree species include red spruce, red maple, balsam fir, trembling aspen (*Populus tremuloides*), white pine and white birch, with speckled alder (*Alnus incana*) also common (Parker, Pomeroy, and Chiasson 1998). Fenton and Frego (2003) found a total of 86 bryophyte species in undisturbed forest of the Hayward Brook watershed. Most of these were infrequent and had low cover values. The five abundant species common to these sites were *Brachythecium starkei*, *Dicranum scoparium*, *Jamesoniella autumnalis*, *Pleurozium schriberi*, and *Ptilidium pulcherrimum*. Fenton and Frego (2003) reported that RMAs initially contained greater cover by liverworts than upland sites. Fish species captured in Hayward and Holmes Brooks included brook trout (*Salvilinus fontinalis*) slimy sculpin (*Cottus cognatus*), American eel (*Anguilla rostrata*) and three spine stickleback (*Gasterosteus acuieatus*) (Chiasson 1998).

According to Lorimer (1977), historically, much of the northern Maine forest was mixedwood. Perkins (2005) described the western Maine study area as mountainous with forests composed of northern hardwoods: American beech, sugar maple, and yellow birch, and mixed conifers such as red spruce and balsam fir. In other study areas of western Maine, forests were dominated by hardwood (sugar and red maple, yellow and white birch, American beech, balsam poplar (*Populus balsamifera*), and trembling aspen) and mixedwood forest (previous species list plus red spruce and balsam fir) in elevations between 548 and 823 m (Hagan and Whitman 2000b). Spackman and Hughes (1995) examined naturally forested third and fourth order streams in Vermont and described their vegetation structure, and bird and mammal communities. Although richness of trees and shrubs varied little between stream and highwater mark (HWM) of up to 50 m away from stream, species richness of herbs (flowering herbs and fern/fern allies) was significantly higher from stream to HWM than higher upland; this was mostly due to sharp decline of flowering herbs with distance away from stream (Spackman and Hughes 1995). While graminoid plants were limited to the geolittoral zone (stream to HWM), 55% of the annual and biennial species grew within the geolittoral zone and none were found > 30 m from the HWM. Although most non-native herbs were ruderal and grew near the stream, more native herbs were found in the geolittoral zone than elsewhere. Specifically, plants of the Liliaceae family were well represented away from the stream and plants of the Asteraceae family were well represented in the geolittoral and just above HWM (Spackman and Hughes 1995).

Results of bird surveys in the Acadian forest have been conflicting. Spackman and Hughes (1995) reported that most bird species were found within 150-175 m from streams and that 34% of the birds observed were warblers (Parulidae). Parker and Hache (1998), however, reported from the Hayward Brook watershed that none of the breeding bird species using the riparian forest were exclusively associated with riparian habitat.

Mammal use of riparian forest was examined by Spackman and Hughes (1995). In the area studied, evidence of movement of white-tailed deer (*Odocoileus viginianus*), coyotes (*Canis latrans*), raccoons (*Procyon lotor*), foxes (*Vulpes vulpes* and *Urocynon cinereoargenteus*), snowshoe hares (*Lepus americanus*) and voles occurred either in the geolittoral or within a few meters above HWM. Areas away from streams were mostly traveled by red squirrels (*Tamiasciurus hudsonicus*), and by some porcupine (*Erethizon dorsatum*). Travel by mink (*Mustela vison*) and muskrat (*Ondatra zibethicus*) was mostly along streambanks, and signs of beaver (*Castor canadensis*) and river otter (*Lutra canadensis*) were mainly found in geolittoral zone (Spackman and Hughes 1995). In Maine, Loftin, Bank, and Hagan (2001) noted that mammalian riparian species include water shrews (*Sorex palustris*), starnose mole (*Condylura cristata*), and rock voles (*Microtus chrotorrhinus*).

6.2 Natural Disturbance Regime

According to Loo and Ives (2003), the most common natural disturbances in Acadian forest are fire, insects, disease, and windthrow. Fires cause large-scale forest replacement, whereas insect-, disease- or windthrow-related mortality cause individual tree or small-patch replacement (Loo and Ives 2003). Before 1900, insect outbreaks occurred at 42 to 75 year intervals, but over the last century they have occurred every 19 to 34 years (Blais 1983). The increase in even-aged stands of balsam fir may have increased the severity and frequency of spruce budworm outbreaks, given that balsam fir are less resistant to the insect (Loo and Ives 2003). Introduction of the gypsy moth has also had a major impact on certain tree species (Niering 1998). Other human-introduced diseases impacting the tolerant hardwood forest types include beech bark disease, Dutch elm disease and butternut canker (Loo and Ives 2003).

Until fire suppression was successfully practiced, fire frequency increased as a result of human activity. Today, most fires are human-caused and may be more numerous, but smaller, than the lightning-caused fires that occurred in the pre-suppression era (Loo and Ives 2003). Data collected by Wein and Moore (1979) showed that for the period between 1926 and 1975, lightning caused only 1 % of the fires in Nova Scotia. The fire rotation period for this province (after fire suppression was initiated) was estimated to be 1000 or 2500 years (depending on whether the mean or median percentage of total land burned is used) and over 30% of the fires burned in the month of May (Wein and Moore 1979). The different forest types of Nova Scotia also experienced different fire rotations. The red spruce–hemlock–pine, the spruce–fir, and the sugar maple–hemlock–pine vegetation types which occupy about 42 % of the area of the province had fire rotation periods of 2000 years. In contrast, the rotation period for the most fire-prone area (red spruce–hemlock–pine) was just over 65 years (Wein and Moore 1979).

Methven and Kendrick (1995) obtained a preliminary picture of the historical fire regime of the Fundy Model Forest area of New Brunswick by examining both the historical records of fire occurrence and the current inventory of age class distributions. In the field, stands containing fire-adapted species were sampled to determine the age and fire origin dates and trees with fire scarring were analyzed for precise fire dates. In addition, computer simulations were performed for land where landscape and fuels remain relatively undisturbed by human intervention. Methven and Kendrick (1995) concluded that fire was common in the region through the early part of the century, with large fires burning for extended periods. From the two red pine stands where fire scarring was found, one had a mean fire return interval of 11.5 years and the other 27 years (Methven and Kendrick 1995). Computer simulations determined that average fire size was 788 ha, while the largest fire was 111,000 ha. Methven and Kendrick (1995) also concluded that fire probably burned on a cycle from 50 to 300 years. Data collected by Wein and Moore (1977) suggest that the fire rotation of this province is over 650 years if the mean percentage of total land burned is used, or well over 3000 years if the median percentage is used. If calculations are based on the percentage of forested land burned, the fire rotation periods are about 1000 and 5000 years for the mean and median, respectively (Wein and Moore 1977). Similar to Nova Scotia, in New Brunswick the month of May had the greatest mean number of fires. The most common vegetation type (red spruce–hemlock–pine) was calculated to have a fire rotation period of 340 years (Wein and Moore 1977).

In Prince Edward Island approximately 1000 ha have burned in 370 fires in the years between 1960 and 1978; hence, fire control has not been of major importance because so much land has been cleared for agriculture (McKnight 1976 as cited in Wein and Moore 1978).

According to Wein and Moore (1977), their figures for fire rotation (650 or 3000 years) and percentages of land burned calculated for New Brunswick are in general agreement with Maine wildfire records (Coolidge 1963). Fobes (1944) calculated that 15% of fires in northern Maine were caused by lightning, while the annual number of lightning fires per unit area was about 0.45/1000 km^2. However, according to Lorimer (1977), the average recurrence of fire and large-scale windthrow for a given site in Maine was estimated to be 800 and 1150 years, respectively. Fire was found to have a higher frequency in the tolerant mixedwood forest type than in hardwood forest, but historically, return time was long enough to allow development of relatively stable, late-successional forest. It takes approximately 70 years following a fire for the early successional stage to be completed and mid- to late-successional species to become established (Lorimer 1977).

Fire probably plays the most important natural disturbance role in forest dynamics of the Acadian forest region (Davis et al. 2001). Because of the spatial and structural heterogeneity of vegetation types, climate and general regional differences in topography and human land use and management, fire rotation times vary not only among provinces and states but also among different forest types. In other regions wildfires in a watershed can have dramatic impacts on associated riparian and stream systems. Ice, Neary, and Adams (2004) summarized the effects of wildfire on soil and watershed processes. These effects can include loss of the forest floor (reducing infiltration rates), development of hydrophobic soil conditions, and loss of watershed and riparian canopy and cover. Dramatic increases in runoff and sediment loads to streams can occur and there can be substantial pulses of large wood inputs to streams. Long-term erosion rates from a study in Idaho suggest that fire and major runoff events can create orders of magnitude increases in sediment loads to streams (Kirchner et al. 2001).

Due to the Acadian forest region latitude, some of the precipitation falls as snow in the winter. Thus, flooding events from spring melts would be the most significant periodic natural disturbance shaping the riparian landscape and ecological patterns. In addition, rivers covered in winter ice would experience spring break up influencing channel morphology, sediment loads, dissolved oxygen levels and riparian flora (Prowse and Culp 2003). The forest dynamics in areas along the Atlantic Ocean are strongly influenced by sea salt spray and wind (Davis et al. 2001). The presence of beaver in the Acadian forest also may have a significant disturbance influence on the riparian ecosystem.

Widespread human influence in the Canadian Acadian forest has caused an increase in relatively young, often even-aged, early successional forest types, and a decline in the abundance and old-aged late-successional species such as sugar maple, red spruce, eastern hemlock (*Tsuga canadensis* L. Carrière), yellow birch, cedar (*Thuga occidentalis* L.), and American beech (*Fagus grandifolia* Ehrh.) (Loo and Ives 2003; NCASI 2005). Loo and Ives (2003) estimate that in the Canadian Maritimes, overall approximately 0.27% of Acadian forest land is planted with softwood species each year, which is consistent with the moderately high proportion of softwood species making up the Acadian forest. However, at this rate, more than 10% of the Acadian forest will consist of softwood plantation by 2010, rather than softwoods being represented in mixed stands.

Research addressing the effects of forest management on the ecological functions of the riparian systems of the Acadian forest is limited. Several studies examined in this review not only defined riparian zones by including both the aquatic and adjacent terrestrial system but also considered the dynamics of the watershed as a whole and its influence on riparian ecosystem functions (e.g., Smith et al. 2005a, 2005b; see Ildhart, Verry, and Palik 2000 for a more functional definition).

6.3 Riparian Habitat Gradients

A few studies in the Acadian forest address how both the longitudinal and lateral gradients of streams are influenced by riparian zone management. By examining the water quality, Smith et al. (2000a) postulated that soil and water temperature within the RMAs would be affected longitudinally by the input of warm or cold water additions to the stream along the catchment-to-stream confluence points, and laterally by sun exposure and related net radiation balances as well as heat conduction at the soil and water surface. Hagan (2000a) observed the cooling effects of underground stream diversion, which influence the longitudinal stream temperature gradient.

Hagan and Whitman (2000a) also demonstrated the importance of RMAs in maintaining the microclimate of the riparian system in headwater streams, where the air temperature of a clearcut adjacent to a RMA was 5-6°C warmer than the same riparian adjacent area that consisted of intact forest. They also demonstrated the influence of the surrounding watershed on the maintenance of riparian functions. In particular, the lateral gradient of air temperature showed that the outer edges of RMAs adjacent to clearcuts were approximately 2-4°C warmer than the same area in the intact forest (Hagan and Whitman 2000a).

Fisher and Likens (1973) found that 66% of the organic matter entering Bear Brook, New Hampshire, was not used by the consumers there but was exported via currents to downstream ecosystems. This input represents about 1% of forest productivity, two thirds of which is exported from the watershed. While 66% of the litter entered the stream as leaves, approximately 21% of this input occurred through lateral transport of other particulate matter by wind (Fisher and Likens 1973).

Parker, Pomeroy, and Chiasson (1998) describe the design of the Hayward Brook watershed study in New Brunswick where the post-harvest effects of various RMA treatments were examined. For this study, two of the following treatment streams were selected: control (riparian zones surrounded by no cutting), BMP (best management practices with clearcutting and selection cutting), 30 m RMA (intact) and 60 m RMA (intact). No other details of the BMP treatment were provided, however (Parker, Pomeroy, and Chiasson 1998). Parker and Hache (1998) investigated whether there was a lateral gradient in the populations of birds using riparian and adjacent areas for breeding. They found that the overall densities of birds did not vary with distance from the stream and suggested that it was likely due to a narrow riparian area and little difference between the vegetation structure of the riparian area and upland forest. However, they did notice a longitudinal gradient, where breeding bird densities tended to be lower in the upper reaches of the watershed than on the lower reaches (Parker and Hache 1998).

Perkins (2005) examined the lateral gradient of biodiversity for amphibians in uncut riparian forests of Maine. He found from pitfall traps and drift fences placed at varying distances from headwater stream channels that the total and average species richness of amphibians was highest in the trap location closest to the stream. He concluded that “the riparian zone as defined by amphibian species occurrence and abundance along the headwater stream is relatively narrow (8-9 m), yet distinguishable due to high diversity and unique species occurrence” (Perkins 2005).

6.4 Effects of Forest Management on Riparian Aquatic and Terrestrial Components

Table 6.1 provides a summary of the research that has been conducted to examine the effects of forest management on riparian aquatic and terrestrial components in the Acadian Forest region. Noel, Wayne, and Federer (1986) examined the effect of clearcutting along forest streams in three watersheds in New England (New Hampshire, Vermont and Maine) by comparing recently (2-3 year old cut) clearcut streams with the nearby reference (uncut) streams. For two of the four of the streams within the clearcuts, a narrow (8 and 9 m) RMA was retained. By their study design, the effects of cutting on the stream habitat and community dynamics within the stream could be assessed; however, they were not able to compare streams with and without RMAs since these streams were located in different watersheds. They found, however, that despite the differences in geography, geology, topography, vegetation and soils, each of the streams responded similarly to clearcutting. In particular, each stream within the clearcuts showed a significant increase in solar radiation, as well as an increase in temperature, which Noel, Wayne, and Federer (1986) suggest is associated with the significant increase in periphyton and macroinvertebrates in these streams. Similarly, increased detritus (woody logging debris) may have provided increased macroinvertebrate habitat and food. This, along with the increased temperature, may have increased leaf litter processing, making it a more readily available food source for macroinvertebrates (Noel, Wayne, and Federer 1986).

Table 6.1 Summary of Research on the Impacts of RMAs (Proposed, Underway or Completed) in the Acadian Forest Region of North America

Riparian Attribute	Approach	Findings	Authors
Water quality Stream temperature	Examined four streams each in a different watershed and with different RMA widths. Pre- and post-harvest stream temperature measured hourly.	Stream temperature was sensitive to harvest operations especially during first post-harvest summer and was not eliminated by leaving RMA strips along stream channels. Temperature effect proportional to the amount of area harvested per entire watershed basin.	Smith et al. (2005b), NS
	Fifteen perennial streams each randomly assigned: no RMA, 10 m partial cut RMA, 23 m partial cut RMA, 200 m partial cut unit, or no harvest, measured temperature at 6 stations separated by 100 m pre- and post-harvest.	Preliminary data show that the only substantial temperature change was observed in the 0 m RMA the year following harvest.	Hagan & Wilkerson (2003 and 2004), ME
	Three control and 3 treated streams with 23 m RMA. Temperature measured hourly at 5 locations during July and August 1999.	Water in headwater streams surrounded by 23 m RMAs remained within range suitable for brook trout, a key indicator of stream health.	Hagan (2000b), ME
	One stream: upper 400 m surrounded by intact forest, next 300 m surrounded by intact forest on one side and a 23 m RMA on the other, last 300 m with RMA beside clear cut. Hourly temperature measured June-Sept. 1998.	Stream went underground at the hottest part of the sampling period causing extreme cooling, hence no conclusions.	Hagan (2000a), ME
	Two streams: with control, BMP (best management practices) with clearcutting and selection cutting) 30 and 60 m intact RMAs. Pre- and post-harvest temperature measured hourly.	Only pre-harvest data reported.	Pomeroy (1998), NB
	Piezometers placed in four-year old clearcut and RMA. Temperature measured at various depths below ground.	Ground surface in RMA cooler than in clearcut (0.7±2.2 °C), shallow groundwater at the mid-point of the RMA cooler than clearcut (1.0±0.7 °C) and deep groundwater at the mid-point of the RMA cooler than other locations, and the clearcut (0.7±0.5 °C).	Alexander et al. (2003), NB
	Retained 10-30 m RMA in New Hampshire and Maine.	Streamflow from harvested areas that did not have RMAs was 2-4 °C warmer than streamflow from areas with RMAs.	Pierce et al. (1993), NH, ME
	Examined 16 streams within clearcut areas ranging from 4-20 years, four of which drained a reference watershed, and stream temperature was measured in each stream continually between early June and mid-November, 1993.	Thermal regimes of streams draining recent clearcuts were most similar to those of the reference streams because legislation introduced in the early 1980s required the retention of RMA strips. One stream in a clearcut from the 1970s had a maximum summer temperature of 23.8 °C (34 days > 17 °C) compared to 15.3 °C (0 days >17 °C) in one of the reference streams.	O'Brien and Freedman (1998), NB
	All vegetation in the watershed was cut, and stream temperature was measured.	Streamwater temperatures were higher after deforestation than the undisturbed condition during summer and winter. Temperature fluctuated 3-4 °C during the day in the summer unlike the relatively constant temperature in undisturbed streams.	Likens et al. (1970), NH

(Continued on next page. See notes at end of table.)

Table 6.1 Continued

Riparian Attribute	Approach	Findings	Authors
Stream light	(designed as noted above) Rock scrapings were analyzed for concentrations of chlorophyll-a.	Concentration of chlorophyll-a increased in all treatment streams in at least one of the post-harvest years.	Hagan & Wilkerson (2003 and 2004), ME
Sediment-ation	At four streams each in a different watershed, each with different RMA widths, stream turbidity measured before and after harvest.	Generally, pre- to post-harvest differences are not readily discerned from these data without further analysis.	Smith et al. (2005a), NS
	(designed as noted above) Turbidity measured at least monthly before and after harvest.	Only pre-harvest data reported.	Pomeroy (1998), NS
	(designed as noted above) Measured turbidity at six stations separated by 100 m before and after harvest years.	No change in pH, dissolved O_2, turbidity, and conductance as a result of harvest.	Hagan & Wilkerson (2003 and 2004), ME
	All vegetation in the watershed was cut and stream turbidity was measured.	Particulate matter output increased fourfold after deforestation. Whereas the particulate matter consisted of 50% inorganic matter normally, after deforestation, estimates of the proportion of inorganic matter were approximately 76%.	Likens et al. (1970), NH
	(design as noted above) Three 500 ml nalgene bottles were dug into the sampling riffle of each stream such that the mouth was flush with the streambed and contents were dried and sieved into large and small categories and weighed, 1993.	Results not reported	O'Brien and Freedman (1998), NB
	Retained 10-30 m RMAs in New Hampshire and Maine.	RMA protected streams against increases in turbidity.	Pierce et al. (1993), NH, ME
	Measured water quality in completely harvested watershed, strip cleared areas in a series of corridors, whole tree harvest using mechanized equipment and mechanized loggers' choice clearcutting.	Disturbances increased sediment yields by 10-30 fold but levels returned to near control levels within 3-6 years after harvest.	Martin and Hornbeck (1994), NH
Nutrients	At four streams each in a different watershed, each with different RMA widths, stream conductivity measured before and after harvest.	A post-harvest effect on electrical conductivity in the stream discharge was noticeable, the overall effect was quite low, and this effect was quickly lost within the next 2 yrs.	Smith et al. (2005c), NS
	(designed as noted above) Turbidity measured at least monthly before and after harvest.	Only pre-harvest data reported.	Pomeroy (1998), NS
	(designed as noted above) Pre- and post-harvest water samples taken and analyzed for ortho-phosphate.	No change in pH, dissolved O_2, turbidity, and conductance occurred as a result of harvest. Concentrations of ortho-phosphate showed no marked change after harvesting.	Hagan & Wilkerson (2003 and 2004), ME
	(designed as noted above) Sampled nutrient concentrations early July, early August and early September, 1993.	The biotic regulation of nutrient exports recovered with time since the smallest concentrations of dissolved substances were recorded in reference streams and the greatest concentrations occurred in streams draining the most recent clearcuts.	O'Brien and Freedman (1998), NB
	All vegetation in the watershed was cut, and nutrient levels measured	Large increases in dissolved nutrients observed after deforestation, and electrical conductivity increased approximately six fold.	Likens et al. (1970), NH

(Continued on next page. See notes at end of table.)

Table 6.1 Continued

Riparian Attribute	Approach	Findings	Authors
Organic inputs	Measured organic inputs from several sources	98% of the energy available to the stream is allochthonous. Of the total input of organic matter, approximately 44% enters directly from the surrounding forest and leaf litter alone represents 29% of the annual input of energy to the system. The autumn leaf fall represents about 90% of the total annual leaf fall for the forest and approximately 54% of the total litter input.	Fisher and Likens (1973), NH
	(designed as noted above) Quadrats: substrate composition in 1st 10 pools of each site, sketches: woody debris in 1st 50 m in lower, middle and upper reach of one 30 m RMA and one control, minnow traps: in each 100 m section of lower, middle and upper reach, in pool, run, and riffle of each section, electrofishing in each site.	Only pre-harvest data are reported: no correlations between physical habitat measurements (substrate, woody debris, wet length, depth and width of pools, runs and riffles) and fish abundance and distribution.	Chiasson (1998), NB
Terrestrial Habitat	In uncut RMA, and uncut, indirectly disturbed (some trees left, no physical disturbance) and directly disturbed (trees removed, forest floor damaged) "tree islands", assessed pre- and post-harvest bryophyte cover in quadrats.	No significant change in bryophyte cover in RMA and uncut after harvest, while either indirect or direct disturbances caused significant decline in total cover. RMAs did not contain most of the species at risk in the clearcuts, and contained a number of "special" species that would be put at risk if RMAs were disturbed (e.g., disturbance in selectively harvested RMAs may adversely affect bryophyte communities).	Fenton and Frego (2003), NB
	Treatments include 0 m, 11 m and 23 m uncut RMAs (clearcuts adjacent) and 200 m partially harvested unit and pre- and post-harvest captures of amphibians using pitfall traps and drift fences. Retrospective approach: selected twelve streams; 4 streams had a 23m RMA with adjacent clearcut, 4 had a 200m partially harvested unit (harvests took place 4-10 years previously), and 4 served as a control.	Prior to harvesting, wood frogs, eastern red-backed salamanders, and spotted salamanders had higher abundance in the downstream treatment than in the upstream and after harvest this difference was either smaller or in some cases the pattern was reversed. Wood frog abundance decreased downstream relative to the upstream area, although the control streams had similar capture rates between the upstream area and the downstream for all three years. In the downstream segments, red-backed salamander and spotted salamander captures were significantly lower in the RMA than in the partial harvest or control treatments. Red-backed salamander and spotted salamander capture rates were significantly lower in the RMAs than the partial harvest and control.	Perkins (2006), ME
	Used pit fall traps and drift fences located at varying distances away from stream to trap amphibians.	Abundances of spring salamanders, two-lined salamanders, and dusky salamanders (*Desmognathus fuscus*) were highest in two trap locations closest to the stream. Species richness was highest in trap locations nearest to the stream.	Perkins (2005), ME
	(designed as noted above) Randomly selected one ha plots within larger riparian zone plots established to study small mammals. Snap traps placed in or around woody debris for eight consecutive nights during August for each sampling years	Species declined in overall abundance during the last 2 yr of the study likely due to natural population cycle in red-backed vole, and due to severe winter weather rather than forestry operations. Species found in general order of abundance: red-backed vole, deer mouse, masked shrew made up the majority of the specimens and woodland jumping mouse, short-tailed shrew (typical of small mammal populations found in most second growth mixed Acadian forests (Parker 1989)).	Parker (1998), NB
	(designed as noted above) Areas within plots 150 m perpendicular to each side of stream extending 650 m to 1 km along stream flagged to analyze bird populations. Tree nest selection by cavity nesting birds and forage tree selection by species of woodpeckers examined.	Pre-harvest data show that none of the birds breeding were exclusively associated with riparian habitat but could be assigned to either 1) prefer mature deciduous and mixed coniferous-deciduous stands, 2) prefer conifer dominated stands and 3) non-selective to specific forest stands.	Parker (1998), NB

Table 6.1 Continued

Riparian Attribute	Approach	Findings	Authors
	Pairs of riparian and upland sites of similar forest types and pairs of riparian sites with RMAs and un-harvested sites of similar forest type.		NFA (2003), NS
	Examined the trends in species richness (plant, bird and mammal species) of six naturally forested stretches along third and fourth-orders streams.	RMAs 150 and 175 m were necessary to include 90-95% of the bird species. For plant species, no single riparian width for species inclusion was appropriate for all streams examined. Concluded that RMA width for species conservation depends upon the stream and taxon of concern, and that appropriate corridor width must be evaluated on a stream by stream basis.	Spackman and Hughes (1995), VT

ME = Maine, NB = New Brunswick, NH = New Hampshire, NS = Nova Scotia, VT = Vermont

6.4.1 *Sedimentation and Stream Turbidity*

Smith et al. (2005a), working with the Nova Forest Alliance (NFA), compared water turbidity before and after timber harvesting along streams in watersheds that were treated differently with regard to RMA retention. Their analyses were one aspect of a broader study called the Pockwock-Bowater watershed project. For this project, two sites were examined (Pockwock and Bowater), and at each site there were four watersheds receiving different treatments with respect to RMA retention and management. Each site had a section of stream with adjacent uncut forest (control), a section of stream with a 20 m uncut RMA adjacent to a clearcut, a section of stream with a 20 m selectively thinned RMA, and a section of stream with a 30 m selectively patch cut RMA (NFA 2005). They found that the timing of turbidity peaks was generally not related to harvesting episodes or to weather events, and the control watershed displayed as much turbidity as two of the treatment watersheds. They also observed that the amplitudes of the turbidity peaks were generally low, and suggested that the streams of this study area did not have high sediment loads (Smith et al. 2005a).

Hagan and Wilkerson (2003, 2004) reported on turbidity levels in their study of riparian management in headwaters streams in Maine. They randomly selected 15 perennial streams (streams that have flowing water within and between years) and assigned the following treatments: streams with no harvest, harvest without any RMA, with 10 m partial cut RMA, 23 m partial cut RMA and 200 m partial cut RMA. They observed no change in turbidity after harvest for any of the treatments (Hagan and Wilkerson 2003, 2004). However, in a previous study, Pierce et al. (1993) examined the effects of retaining 10-30 m wide RMAs in New Hampshire and Maine and they concluded that the RMAs protected the stream from increased turbidity.

Martin and Hornbeck (1994) examined the sedimentation in streams of the Hubbard Brook watershed in New Hampshire that were subjected to various levels of disturbance and found that whole tree clearcuts significantly increased sediment yields in associated streams compared to streams in areas that had not been harvested for the past 50 years. In fact, the experimental disturbances increased sediment yields by 10- to 30-fold, although these yields returned to near control levels within 3-6 years after the disturbance ended. They also concluded that the maintenance of RMAs and the control of water on roads and skid trials could reduce water quality effects (Martin and Hornbeck 1994). These results are consistent with research elsewhere that BMPs such as waterbars on skid trails, adequately spaced drainage to take road runoff away from streams, and buffers to reduce disturbance near the channel can dramatically reduce water quality impacts (Ice 2004). But buffers cannot completely overcome poor upland practices if those practices dramatically increase erosion and sediment delivery in concentrated flows.

6.4.2 *Moderating Stream Temperature and Light*

Several studies in the Acadian region examined the influence of riparian vegetation retention on stream temperature. At the Pockwock-Bowater watershed study (described above), Smith et al. (2005b) observed that stream temperature increased after harvest operations especially during the first post-harvest summer and was not completely eliminated by leaving RMAs along stream channels. Smith et al. (2005b) suggest that this inability of the RMA to moderate the effect of solar radiation on temperature was due to the numerous fully exposed small channels entering the stream. These channels would have temperatures similar to the adjacent exposed soil and hence the heat of that water would be transmitted to the main channel. Also, on a larger scale they found the temperature effect to be proportional to the amount of area harvested in the entire watershed basin (Smith et al. 2005b).

Hagan (2000a, 2000b) and Hagan and Wilkerson (2003, 2004) examined the effect of RMA retention on headwater streams in Maine. Hagan (2000a) examined the change in stream temperature along a single stream where the upper 400 m was surrounded by intact forest, the next 300 m was surrounded by intact forest on one side and a 23 m RMA on the other, and the last 300 m was surrounded by a 23 m RMA with clearcuts on both sides. During the hottest part of the summer, in the clearcut, the headwater streams flowed underneath the ground which caused significant cooling (Hagan 2000a). In a later work, Hagan (2000b) compared three headwater streams that were completely surround by clearcut with three that had intact 23 m RMAs. He found that factors affecting variability in temperature appeared to be groundwater inflow and stream source, rather than the presence or absence of a RMA. From preliminary data analysis of a more recent study, Hagan and Wilkerson (2003, 2004) found that the only substantial temperature change observed in the 0 m RMA occurred one year post-disturbance.

Alexander et al. (2003) examined the difference in soil and water temperature between a 60 m RMA strip and its adjacent clearcut at Catamaran Brook, New Brunswick. Using a series of probes at different depths, they found that the ground surface in the RMA was cooler than in the clearcut by 0.7±2.2°C. The shallow groundwater at the mid-point of the RMA was also cooler than the clearcut by 1.0±0.7°C and the deep groundwater at the mid-point of the RMA was cooler than other locations, and the clearcut (by 0.7±0.5°C). Their work demonstrates that the maintenance of a RMA can reduce the increase instream temperature by cooling the groundwater flowing into the stream.

O'Brien and Freedman (1998) examined 16 streams near Fundy National Park, New Brunswick. Some of the streams were located within clearcut areas 4-20 years old and had been regenerated as conifer plantation. Four of the streams drained a reference watershed and were surrounded by mature mixedwood forest. Each stream was sampled for bottom substrate, water temperature, nutrient concentrations, riparian vegetation, sedimentation, channel morphology and benthic invertebrates. These authors found that the thermal regimes of streams draining recent clearcuts were most similar to those of the reference streams due to the retention of RMAs, required by legislation introduced in the early 1980s. Streams draining 1970s clearcuts still had higher maximum temperatures and greater diurnal fluctuations than did streams in forests harvested during the 1980s. One stream in a clearcut from the 1970s had a maximum summer temperature of 23.8°C (34 days > 17°C), compared to 15.3°C (0 days >17°C) in one of the reference streams (O'Brien and Freedman 1998).

Pierce et al. (1993) evaluated the effects of retaining 10-30 m wide RMAs in New Hampshire and Maine and concluded that streamflow from harvested areas that did not have RMAs was 2-4°C warmer than areas with RMAs. After total deforestation of a watershed at Hubbard Brook in 1965 and with re-growth prevented in the following three years with the use of herbicides, Likens et al. (1970) concluded that the high nutrient concentrations, the increased amount of solar radiation, as well as the higher temperatures in the exposed stream, resulted in the significant algal blooms they observed after treatment. Later, Noel, Wayne, and Federer (1986) concluded that primarily the higher light levels of the cutover streams they studied in New England resulted in higher cell densities of green algae.

6.4.3 *Fine and Large Organic Debris Input*

In Bear Brook, New Hampshire, more than 98% of the measured energy available to the stream is allochthonous (Fisher and Likens 1973). Of the total input of organic matter, approximately 44% enters directly from the surrounding forest (versus from drainage water), and leaf litter alone represents 29% of the annual input of energy to the system. The autumn leaf fall represents about 90% of the total annual leaf fall for the forest and approximately 54% of the total litter input (Fisher and Likens 1973). A later study examined the importance of organic debris dams on the transport of nutrients downstream and found that these structures account for much more organic matter than would be expected based on the streambed area they cover (Bilby and Likens 1980). Bilby and

Likens (1980) concluded that these structures are very important in smaller stream ecosystems for storing organic matter.

The study by O'Brien and Freedman (1998) of the streams within clearcuts of different ages in the vicinity of Fundy National Park, suggests that streams of clearcuts from the 1970s and early 1980s with no RMAs will experience long-term lack of large-dimension woody debris (O'Brien and Freedman 1998). Selection and clearcutting in the riparian zones of six of the streams they examined had depleted the long-term supply of inputs of large woody debris and they suggested that this would degrade trout habitat by decreasing the number of pools, amount of cover, and retention of fine sediments in the streams (O'Brien and Freedman 1998). In other regions, harvesting in the near-stream riparian area can result in short-term increases in wood in streams but may result in reductions over the long term (McGreer and Andrus 1992).

6.4.4 *Nutrients*

After total deforestation and suppression of vegetation recovery at Hubbard Brook, New Hampshire, Likens et al. (1970) observed large increases in dissolved nutrients after deforestation, and electrical conductivity increased approximately sixfold. Smith et al. (2005a) measured pre- and post-harvest stream conductivity at four streams, each in a different watershed, and found that although a post-harvest effect on electrical conductivity in the stream discharge was noticeable, the overall effect appeared to be quite low, and was lost within the next two years. In their retrospective study in the area surrounding Fundy National Park, O'Brien and Freedman (1998) found that the biotic regulation of nutrient exports appeared to recover with time, as the smallest concentrations of dissolved substances were recorded in the reference streams, and the greatest concentrations occurred in streams draining the most recent clearcuts.

6.4.5 *Aquatic Biodiversity*

Noel, Wayne, and Federer (1986) examined abundance, diversity, and composition of macroinvertebrate communities in three watersheds of New England. They found that streams with adjacent clearcuts had a significantly higher abundance of macroinvertebrates than their corresponding reference streams within uncut forest. They concluded that harvesting changed the structural character of the invertebrate communities as well, where one logged site had significantly higher abundance of *Ephemerella* than the control stream (Noel, Wayne, and Federer 1986).

Chiasson (1998) examined fish populations for the Hayward Brook watershed study (see Section6.3 for experimental design). The author only reports pre-harvest data where no correlations were found between the treatments with respect to physical characteristics of the habitat (substrate, woody debris, wet length, depth and width of pools, runs and riffles), and fish abundance and distribution. According to Parker, Pomeroy, and Chiasson (1998), another aspect of the Hayward Brook watershed study included plots 150 m perpendicular to each side of the streams, and extending 650 m to 1 km along the length of streams, with aquatic invertebrates collected at various sites within each plot. No data regarding this sampling had been reported, and this may represent a potential source of future information.

O'Brien and Freedman's 1998 study of the streams within clearcuts of different ages in the vicinity of Fundy National Park, New Brunswick found that high temperatures in streams that were cut in the 1970s and early 1980s were sufficient to cause physiological stress to trout in those streams. For these streams, RMAs were not retained. However, adequate stream temperatures for trout were found in more recent clearcuts and uncut reference streams where RMAs had been retained. They also found low dissolved oxygen (DO) concentrations in at least two cutover streams may have adversely affected the swimming performance and growth rates of trout in those streams (O'Brien and Freedman 1998). Reduced DO is greatest where water turbulence is low, water temperatures are high, and there is high oxygen demand (e.g., fresh slash). The reduced DO observed by O'Brien and Freedman (1998) may have been due to the significant increases in temperature observed in those streams.

6.4.6 *Terrestrial Biodiversity*

6.4.6.1 *Plants*

Fenton and Frego (2003) examined the bryophytes of the Hayward Brook watershed (New Brunswick) situated in uncut RMAs, as well as in uncut, indirectly disturbed (some trees left, no physical disturbance) and directly disturbed (trees removed, forest floor damaged) "tree islands" before and after harvest. They found no significant change in bryophyte cover in RMAs and uncut tree islands after harvest, while either indirect or direct disturbance sites showed significant declines in total cover and a significant decrease in species richness up to one year after harvesting. In particular, there was a sharp decline in liverworts with no recovery after direct disturbance (Fenton and Frego 2003). They also found that RMAs did not contain most of the species at risk in the clearcuts; however, the RMAs contained a number of species that would be put at risk if the RMAs were subjected to disturbance (Frego pers. comm.).

Whitman and Hagan (2000) conducted a study to determine whether a) forest remnants could maintain the same plant communities found in interior forest, b) riparian forest surrounding first and second order streams had plant communities that were similar to those in upland forest, and c) upland remnants had plant communities more similar to those in intact forest or to clearcuts. They compared plant communities in riparian forest (> 213 m from clearcut), RMAs (32 m RMA flanked by clearcut), upland forest (> 213 m from clearcut), upland RMAs (76 m strips surrounded by clearcut) and clearcuts (6-8 years old, > 20 acres in size). At each site, they surveyed vascular plants in 5 x 50 m plots. Clearcuts and RMAs had more species and more wetland species than the other sites. Riparian forest and upland forest had similar number of species (Whitman and Hagan 2000). The species composition of RMAs was more similar to riparian forest than other sites, and those of upland areas was more similar to upland forest. Clearcuts were most similar to upland areas and had the lowest percentage of species in common with RMA and riparian forests. Riparian forest and RMA sites were not more species rich than upland forest and these forests had plant communities similar to adjacent upland areas. However, 13 forest species were found only in riparian areas, three of which occurred only in intact riparian forest (Whitman and Hagan 2000). Three species were infrequently detected: coralroot (*Corallorhiza trifida*), lesser pyrola (*Pyrola minor*), and white snakeroot (*Ageratina altissima*); however, all of these species occurred in the RMA. Whitman and Hagan (2000) suggest that maintaining these species in intensively managed landscapes may have been enhanced by the retention of the RMA. They also believe that since many species were not found in clearcuts but found in either RMAs or clearcut separation zones, remnants could serve as refugia from which these species can recolonize clearcuts at some future time (Whitman and Hagan 2000).

O'Brien and Freedman (1998) examined the stream qualities and riparian vegetation in clearcuts of different ages and found that the presence of RMAs along streams draining recent clearcuts ensured a rapid recovery of allochthonous inputs of biomass. The riparian vegetation of the RMAs in recent clearcuts was similar to that of the reference streams, characterized by low shrub densities, high instream moss cover, and higher than average tree and snag densities, whereas the riparian vegetation of the clearcuts from the 1970s and early 1980s were found to have a high shrub density (O'Brien and Freedman 1998).

6.4.6.2 *Amphibians*

Perkins and Hunter (in press) studied 15 headwater streams in western Maine for one year before harvest and two years after harvest to determine the effects of different riparian management practices on amphibian communities. Each stream was randomly assigned the following treatments: no RMA, 11 m uncut RMA retained, 23 m uncut RMA retained, partial harvest up to stream bank (23-53% of the basal area removed), and un-harvested controls. Pitfall traps and drift fences were used to sample amphibians along these streams (both in treatment area and upstream), as well as laterally away from these streams. Prior to harvesting, wood frogs (*Rana sylvatica*), eastern red-backed salamanders (*Plethodon cinereus*) and spotted salamanders (*Ambystoma maculatum*) had higher abundance in the downstream treatment than in the upstream area and after harvest this difference was either smaller or in some cases, the pattern was reversed. This response was most marked for the wood frog; after harvest, wood frog abundance decreased downstream in the treatment relative to the upstream area, although the control streams had similar capture rates between the upstream area and the downstream treatments in all three years. In addition, post-harvest capture of wood frogs was significantly higher than pre-harvest in the untreated upstream sections of the partial cut stream section (Perkins and Hunter in press).

Perkins and Hunter (in press) also studied riparian management practices retrospectively, by examining 12 headwater streams in the following categories: a 23-35 m RMA with adjacent clearcut; a partial harvest unit adjacent to the stream; extending 100 m away from the stream and control streams that had not been harvested during the past 50 years. Harvest in the RMA treatment and partial harvest occurred 4-10 years prior to sampling (Perkins and Hunter in press). In the downstream segments, red-backed salamander and spotted salamander captures were significantly lower in the RMA treatment than in the partial harvest or control treatments. Red-backed salamander and spotted salamander capture rates were significantly lower in the RMAs than in the partial harvest and controls, indicating that RMAs in the range of 23-53 m wide may not be adequate to maintain riparian species abundances similar to unharvested areas. Perkins and Hunter (in press) concluded that partial harvests may be an effective way to maintain the amphibian communities along headwater stream; no differences were found between partial harvests and control stream for any species in this part of the study.

6.4.6.3 *Birds*

The Hayward Brook watershed study examined both communities of breeding birds and small mammals (see Section 6.3 for experimental design). Parker (1989) found that small mammal abundance declined two years following forest harvesting. However, he suggested that it was likely due to the natural population cycle in red-backed voles (*Clethrionomys gapperi*) and to severe winter weather, rather than forestry operations.

Spackman and Hughes (1995) examined the trends in species richness of six naturally forested stretches along third- and fourth-orders streams in Vermont to determine how wide the RMAs should be to conserve riparian species. Using unharvested RMAs, they found that for bird species, RMA width between 150 and 175 m is necessary to include 90-95% of the bird species. For plant species, they suggested no single riparian width for riparian species inclusion. They concluded that an appropriate corridor width for species conservation depends upon the stream and taxon of concern, and that appropriate corridor width must be evaluated on a stream by stream basis and on variables that affect how the stream interfaces with the terrestrial landscape (Spackman and Hughes 1995).

6.4.7 *Plant and Animal Movement Corridors*

None of the studies in the Acadian forest region examined in this report have addressed the use of riparian zones as movement corridors for plants and animals.

6.5 RMA Guidelines

RMA guidelines vary considerably between the Canadian provinces and the U.S. states located within the Acadian forest region. Stream classifications also vary considerably depending on width, drainage, steam bank stability, and slope. All Canadian provinces include slope as a factor in determining RMA widths, but only New Hampshire includes slope in their guidelines of streamside management zones in the U.S. Acadian forest. No information was found for RMA guidelines in Connecticut (Table 6.2).

Table 6.2 Riparian Characteristics and Values Considered in Developing RMA Guidelines for Acadian Forests and Those of the Rest of Canada

Forest Type/Region	Drainage and RMA Width	Slope and RMA Width	Width of Stream and RMA	Fish/Fish Habitats	Harvest within RMAs	Terrestrial Habitats	Other Values
Acadian forest: NS		>20%, add 1 m to RMA for every 2% increase	>0.5 m = 20 m RMA		40% basal area		
NB	<600 ha = 15 m ; > 600 ha = 30 m RMA	>24% = 60 m	<0.5 m = 3 m RMA		30% basal area		
PEI		>9% slope = 30 m RMA	All streams = 20 m RMA		1/3 of trees		
ME	1) >50 mi^2 = 76 m ; 2) <25 mi^2 = 23 m, > 25 mi^2 = 76 m RMA				40% basal area		
VT	A) large belt width and floodplain requirement B) opposite above	A) >10% B) <10%				A) wildlife travel corridor/riparian dependent species/significant natural community B) none of above	Class A = 30 m RMA; Class B = 15 m RMA
NH		0-10% = 15 m, 11-20% = 21 m, 21-30% = 27 m, 31-40% = 33 m; add 6m for each 10%	4^{th} order = 46 m - for all other see 'slope'				
MT			All streams = 30 m RMA				Perennial streams = 61 m RMA
Rest of Canada: NL		1.5 times the slope in % where slope exceeds 30%	>1 m = 20 m RMA				
QC			All streams = 20 m RMA		30% basal area		
ON		0-15% = 30 m; 16-30% = 30 m; 31-45% = 70 m; 46-60% = 90 m RMA		0-15% = 30 m, 16-30% = 30 m, 31-45% = 70 m, 46-60% = 90 m RMA	50% basal area		
MA	A) <50 km^2 B) >50 km^2		All streams = 100 m RMA	A) sport fish present; B) sport fish absent		200 m RMA if it is habitat for endangered species, recreational areas, waterfowl, raptor nesting or areas with natural springs or seeps.	RMAs < 100 m if approved by a provincially recognized Resource Management team.
SK	A) <50 km^2 = 15 m RMA; B) >50 km^2 = 30 m RMA		A) ≤3^{rd} order = 15 m RMA; B) >3^{rd} order = 30 m	B) if fish present = 90 m RMA	When ground is frozen or well-drained and dry		

(Continued on next page. See notes at end of table.)

Table 6.2 Continued

Forest Type/Region	Drainage and RMA Width	Slope and RMA Width	Width of Stream and RMA	Fish/Fish Habitats	Harvest within RMAs	Terrestrial Habitats	Other Values
AB			Small stream = 30 m RMA large stream with valley >400 m = 60 m RMA		Single tree or group removal		
BC			A) ≥ 100 m RZ = 0, MZ = 100 m; B) < 20 m RZ = 50 m, MZ = 20 m ; C) > 5 ≤ 20 m RZ = 30, MZ = 20 m ; D) 1.5 ≤ 5 m RZ = 20, MZ = 20 m; E) < 1.5 m RZ = 0, MZ = 30 m; F) > 3 m channel width RZ = 0, MZ = 30 m; G) ≤ 3 m RZ = 0, MZ = 20 m	F) and G) not a fish stream	A) MZ selective harvest = 50%; B) MZ harvest = 50%; C) MZ harvest = 50%; D) MZ harvest = 50% ; E) MZ harvest = 25% F) MZ harvest = 25%; G) MZ harvest = 5%		
YT			All stream = 30 m RMA				

AB = Alberta, BC = British Columbia, MA = Manitoba, ME = Maine, MT = Massachusetts, NB = New Brunswick, NH = New Hampshire, NL = Newfoundland, NS = Nova Scotia, ON = Ontario, PEI = Prince Edward Island, QC = Quebec, SK = Saskatchewan, VT = Vermont, YT = Yukon Territories

6.5.1 *Nova Scotia*

According to Nova Scotia Department of Natural Resources (Duke 1997), for streams that are less than 0.5 m in width, complete harvest is allowed to streamside, however, there is a 5 m no machine zone and harvest-related sediment must not enter the waterway. For streams that are greater than 50 cm, a 20 m RMA must be retained and for streams with slope greater than 20%, an extra 1 m must be added to the RMA width for every 2% increase in slope. The maximum RMA width in this case is 60 m (Duke 1997).

No more than 40% of the basal area is allowed to be selectively harvested within the RMAs. In addition, at least 20 m^2 per hectare of the basal area within the RMA must be retained, no canopy opening within the RMA greater than 15 m across is allowed, and no machinery is allowed within 7 m of the watercourse. Snags in the RMAs must also be retained and no sediments from forestry operations may enter the stream (NSDNR 1999).

6.5.2 *Prince Edward Island*

RMAs are required on all watercourses and wetlands. Those with a slope less than or equal to 9% must have a 20 m RMA and those with a slope greater than 9% must have a 30 m RMA (Decker 2003). Selective harvest is permitted within the RMA zone, where one-third of the live trees may be removed over a 10 year period; however, machinery is not permitted within 10 m of the watercourse. Patch cuts up to 0.2 ha are allowed as long as 0.1 ha remains uncut between patches (Decker 2003).

6.5.3 *New Brunswick*

New Brunswick has the most complex guidelines of the Canadian Maritime provinces. For streams that are less than 0.5 m, a 3 m RMA is required (DNRE 1999; MacLauchlan 1994). RMAs of 15 m are required for watercourses draining less than 600 hectares. For a stream draining more than 600 hectares, a 30 m RMA must be retained if its slope is less than 24%; however, if its slope is greater than 24%, a RMA zone of 60 m must be retained. A 60 m RMA zone is also required for streams in areas dominated by shallow rooted trees, areas with high erosion potential, or areas with critical fish habitat. Areas that are protected for waterfowl require either a 60 m or 100 m RMA depending on Environment Canada's ranking for wetlands as waterfowl habitat (DNRE 1999). RMAs bordering streams, bogs, and ponds that provide a travel corridor are 50 m wide. Corridors along larger rivers and lakes RMAs are 100 m wide. Within riparian travel corridors $18m^2$/ha basal area must be retained, a tree height greater than 10 m, and canopy cover must be greater than 50% (Woodley and Forbes 1997).

Harvesting within RMAs of up to 30% of the basal area is allowed within a 10 year period. The canopy openings of the harvest area must not exceed 10 m and 50% pre-harvest canopy must be retained, with a 10 m tree height. Also, no more than 30% of snags may be removed (DNRE 1999). Streams that may provide a travel corridor for wildlife require a 50 m RMA with retention of 18 m^2 basal area, average tree height greater than 10 m and canopy cover greater than 50% (Woodley and Forbes 1997).

The Watershed Protected Area Designation Order was created to protect 30 municipal watersheds beyond the 30 m RMA and consists of 3 distinct zones. Protected areas A, B, and C each have different guidelines; A is the watercourse, B is a 75 m setback zone bordering the watercourse, and C encompasses the remainder of the watershed drainage area. In southern New Brunswick, selective cutting is approved between 30 and 75 m in the setback zone, and in northern New Brunswick selective harvesting between 15 and 75 m of the setback zone is allowed but no more than 30% can be removed once every 5 years. Also, outside the setback zone, in protected area C, clearcutting in blocks can be no larger than 25 hectares, and between each clear-cut a 100 m wide RMA strip must be retained. This strip can be selectively harvested but not clearcut for at least 10 years after initial harvest or when natural regeneration on the adjacent cut block is 2 m high (Decker 2003).

6.5.4 *Maine*

Maine legislation for RMAs is divided between the organized townships (those with a municipal government) and the unorganized townships (those with no municipal government). For unorganized townships, streams that drain more than 50 mi^2 (~13,000 ha) require a 76 m RMA, and for streams that drain less than 50 mi^2 (~13,000 ha) sufficient vegetation must be retained along streams to "maintain shading of surface waters" (Loftin, Bank, and Hagan 2001).

In organized townships, streams that drain greater than 25 mi^2 (~ 6,500 ha) require a 76 m RMA where no more than 40% of the basal area may be removed in a 10 year period. Also, no clear-cut openings are allowed within 23 m of the water body and no openings greater than 10000 ft^2 (~ 5 ha) are allowed between the 23 m and 76 m line. Openings greater than 5000 ft^2 (~ 3.5 ha) must be separated by at least 30 m and a minimum unscarified strip of at least 23 m is required; this increases with increasing slope. Streams that drain less than 25 mi^2 (~ 6,500 ha) require a 23 m RMA and no more than 40% basal area can be removed within a 10 year period. No clearcut openings are allowed within 23 m of stream (Loftin, Bank, and Hagan 2001).

6.5.5 *Vermont*

The Vermont Agency of Natural Resources (VANR 2005) classifies streams into two categories. Those requiring a 100 ft RMA (30 m) have the following attributes: large belt width (drainage size as measured by deviance of the meander from the channel centerline) and flood plain requirements; a wildlife travel corridor; and/or riparian-dependent species and/or significant natural communities. These streams also have highly erodable soils or slopes generally greater than 10%.

Streams requiring a 50 ft RMA (15 m) have small belt width and flood plain requirements, no wildlife attributes (as described above) in close proximity to or directly downstream from the harvest site; these streams have low-to-moderately erodable soils and slopes generally less than 10% (VANR 2005).

Required RMA width can be greater than maximum in the following instances: streams with rare, threatened, endangered, or sensitive species, sensitive significant natural communities, and/or necessary habitats that are either directly associated with or in close proximity to the harvest site; streams with unstable channels undergoing channel lengthening; and in the instance of floodplain development processes imperative to the reestablishment of channel stability and aquatic habitat (VANR 2005).

RMA width can be smaller than minimum in the following instances: the stream riparian functions and values will be adequately protected by a narrower RMA, such as sites adjacent to small, stable intermittent streams; or the location and extent of existing encroachments severely limits the ecological benefits that would be derived from a wider RMA (VANR 2005).

6.5.6 *New Hampshire*

In New Hampshire's best management practices document (NH 2004), both woodland RMAs and streamside management zones are defined. Woodland RMAs must be retained within 46 m of the public boundary line on fourth-order streams. On these waterways, not more than 50% of the basal area of trees and a maximum of 50% of the total number of saplings can be removed in a 20-year period. A healthy, well-distributed stand of trees, saplings, shrubs, and ground covers and their living, undamaged root systems must be left in place. For forestry practices, within 46 m of fourth-order streams, 50% of the pre-harvest basal area must be maintained, and 50% of the pre-harvest basal area must be maintained within 15 m of all perennial streams, rivers, and brooks (NH 2004). Streamside management zones depend on the slope adjacent to the stream where slopes of 0-10% require 50 ft (15 m) RMA, 11-20% slopes require 70 ft (21 m), 21-30% slopes require 90 ft (27 m) RMA, slopes of 31-40% require 110 ft (33 m) RMA and for each additional 10% of slope above this, 20 ft (6 m) more should be added to the RMA (NH 2004).

6.5.7 *Massachusetts*

According to Boyd (2001), a 100 ft (~ 30 m) RMA is required around any creek or stream. For activities within the RMA, those responsible for any "negative" activity within the RMA are required to file a Notice of Intent with the local conservation commission. Rivers (including perennial streams but not intermittent streams) have a 200 ft (61 m) RMA of protection from negative activities (Boyd 2001).

6.6 Implementation and Effectiveness of RMA Guidelines: Crown Land vs. Private Land

In Canada, most forest land is in government ownership. But in the Acadian forest region of Canada, most of the forested land is privately owned (Provincial: 44%; Federal: 2%; Private: 55%) (Natural Resources Canada 2003). In Nova Scotia, 69% of forested land is privately owned and 60% of all timber harvested in 1998 was from private woodlots (Decker 2003). Guidelines have been provided to private woodlot owners by the Nova Scotia Department of Natural Resources (NSDNR), and their website includes downloads for their Code for Forest Practices, Wildlife Habitat and Watercourses Protection Regulations (http://www.gov.ns.ca/just/regulations/regs/fowhwp.htm), Forest Act Amendments (NSDNR 2005a), and a number of other useful publications for all private woodlot owners (NSDNR 2005b). A high percentage of Nova Scotia's forests are owned by larger industrial companies, e.g., Irving, Bowater Mersey, and Stora Enso.

In addition to the provincial guidelines requiring a 20 m RMA, each of these companies adheres to its own more conservative RMA guidelines. Bowater Mersey currently uses 30 m RMAs, J.D. Irving uses 30-60 m RMAs, and Stora Enso established 50 m and 100 m RMAs as described in a 2003-04 NFA study involving Stora Enso and FERIC (Forest Engineering Research Institute of Canada) (NFA 2003). In fact, much of the research presented in the NFA report has been in collaboration with one or more of the industrial forest companies as well as the Nova Forest Alliance and NSDNR (Beyeler 2002). Nova Forest Alliance plays a key role in the successes of these collaborations towards improving forestry practices in Nova Scotia's Acadian forest, as well as providing the *Contractors and Operators Best Management Practices Manual* and training program (Beyeler 2002). As for the effectiveness of maintaining RMAs in Nova Scotia's Acadian forest riparian zones, the RMA report suggests that RMAs do maintain some of the ecological functions of riparian areas.

Forest comprises only 51% of Prince Edward Island's (PEI) land area and of this, 92% is privately owned (Decker 2003). The PEI Department of Agriculture, Fisheries and Aquaculture provides a page (http://www.gov.pe.ca/af/falrm-info/index.php3) that links woodlot owners to the province's Forest Management Act. No research on riparian zones in the Acadian forests of PEI has been obtained for this report.

In New Brunswick, 51% of forested land is privately owned (Decker 2003). New Brunswick also has an organization called the Fundy Model Forest (FMF) which creates partnerships to share ideas and information, evaluate the impact of various approaches to resource management, and undertake research to assist in better forest management (FMF 2004). A large portion of the privately owned forest of New Brunswick is managed by J.D. Irving Limited. This company has partnered with the

FMF on research pertaining to Acadian forest management in New Brunswick (FMF 2005). The New Brunswick Department of Natural Resources and Energy provides woodlot owners with a number of forestry-related publications at http://www.gnb.ca/0078/reports/index-e.asp.

7.0 COMPARISON OF RIPARIAN MANAGEMENT IN ACADIAN FOREST AND THE REST OF NORTH AMERICA: DATA GAPS

None of the research on riparian areas of the Acadian forest region reported in this document examined differences in riparian functions between this region and the rest of North America. In particular, the unique Acadian forest hydrologic mechanisms that control water quality and hydrologic response were not compared to other regions of North America in most of the studies examined. Some possible characteristics of the Acadian forest that could lead to unusual riparian behavior include the shallow soils, slow vegetation growth rates (compared to other forested regions), snow hydrology, and the unique set of riparian species (see Table 7.1).

The research conducted regarding the use of RMAs in the riparian areas of the Acadian forest region is fairly diverse, perhaps with a slight bias toward examining the water quality aspects of these systems, as opposed to other biological aspects. The influence of the retention of an RMA on stream temperature was investigated in a number of the Acadian forest regions; however, results are not consistent among these studies. Where some of the studies demonstrate that the retention of RMAs prevented changes to stream temperatures (Alexander et al. 2003; O'Brien and Freedman 1998), other studies are not as clear. In these other studies, either there was little change in stream temperature after cutting (Hagan and Wilkerson 2003, 2004; Hagan 2000a, 2000b), or the increase that was observed was also observed in streams where a RMA was retained (Smith et al. 2005b). Consistent, however, is the reference to the effects of groundwater and hyporheic exchange in maintaining stream temperature. Because of the topography and geology of the Acadian forest region, the protection of groundwater temperature may play a significant role in maintaining stream temperatures. Some studies suggest that in addition to the benefits from riparian shade and reduced solar radiation, forest management practices that protect groundwater temperatures may also have stream temperature benefits. This idea deserves further study, given the conflicting results from studies in this region.

There are some significant gaps in the data for this region. For example, no study was found that examined the use of riparian areas as movement corridors for wildlife, and very few studies examined the importance of riparian terrestrial habitat on biodiversity. These studies do not address the issues of slash in the forest harvesting process, including a) whether or not slash is allowed to remain in the harvest zones; or b) if the slash is left, what effects its presence and decomposition may have on the chemistry of the stream (e.g., on dissolved oxygen); or c) if the slash is left, what effects its presence and decomposition may have on the adjacent terrestrial habitat of the stream for both plant and animal communities. Jackson, Strum, and Ward (2001) found that large amounts of slash in the stream channel increase the efficiency of sediment trapping of that channel. In addition, there are no studies in the Canadian Maritimes examining the influence of managed RMAs on erosion and organic inputs into streams. In particular, understanding of the significance of organic inputs would be benefited by study examining the manual replacement of coarse woody debris after harvesting.

Table 7.1 How Do Acadian Riparian Communities and Their Response to Forest Management Compare with the Rest of North America?

Key Attributes	Similarities	Differences	Data gaps	Authors
Structure and Function: *Geomorphology*	Small-scale variation in geomorphology similar to other NA regions.	General large-scale geological patterns unique to the Acadian forest.	What is the variation in the distance of the riparian/upland ecotones in the Acadian forest?	Loo and Ives (2003); Davis et al. (2001)
Climate	Acadian forest regions share the general northern NA climate and seasonal transitions.	Due to its predominantly maritime location, the Acadian forest's climate includes significant fog and also overall oceanic climate moderation.		
Biota	General plant community structure. Many of the bird and mammal species are the same as those in the boreal forest region.	Plant species composition.		
Natural Disturbance	Acadian riparian regions are primarily influenced by flood processes. Fire plays a significant role in disturbance regime.	Insect outbreaks play a significant role in the disturbance regime in some areas.	What is the burn incidence specifically of riparian zones?	Loo and Ives (2003); Methven and Kendrick (1994); Andison and McCleary (2002); Wein and Moore (1977, 1979)
Forest Management: *RMA Guidelines*	RMA guidelines among regions in the Acadian forest are as diverse as those across the rest of North America.	There are no particular factors in guidelines that are unique to any region of the Acadian forest.	How effective are the guidelines in one region compared to another in terms of preserving riparian ecological functions?	Decker (2003)
Response to Forest Management: *Aquatic*	General responses of aquatic functions are similar to other regions	Few	How do the terrestrial biota, especially animal communities, respond to forest management?	Parker and Hache (1998); Perkins (2005)
Terrestrial	Some of the responses of terrestrial biota are similar	Unclear		

However, McCurdy et al. (2004) describe the ongoing work in the Pockwock-Bowater project in Nova Scotia, examining the influence of post-harvest disturbance and permanent infrastructure (roads and stream crossings) on water quality. Following harvest, they report that mechanized traffic was the most common disturbance found. Although McCurdy et al. (2004) suggest that the permanent infrastructures of roads and stream crossings may give rise to potential off-site effects, no data on these effects were reported.

The Pockwock-Bowater study in Nova Scotia examined the effect of RMA thinning on the incidence of blowdown or windthrow. Researchers (NSDNR 2003) found that blowdown primarily occurred as uprooted trees and was very high in flow accumulation (convergency) areas. The narrowest RMAs with the greatest percent thinning had the greatest loss of basal area due to blowdown, but research on threshold values of minimum RMA widths to prevent blowdown is lacking. The researchers also concluded that tree selection was important in riparian management, since more deeply rooted trees were less susceptible to blowdown.

Information regarding the effectiveness of retaining streamside vegetation to preserve riparian biodiversity is lacking. Few data for the Acadian forest region were found regarding the instream changes due to forest harvesting and RMA retention and changes to communities of periphyton, aquatic invertebrates and in particular, fish. More terrestrial data are needed regarding the effects of RMA retention on plant communities in particular, as well as effects on birds, mammals, and amphibians. Similarly, no studies have examined the potential use of RMAs as corridors for movement by Acadian forest organisms. Finally, more study is needed to determine the dynamics of natural disturbances in Acadian forest riparian areas, and how forest harvesting may act to produce similar ecological effects.

Overall, there are few recent studies in the peer-reviewed primary literature reporting the effects of riparian management in Acadian forests. However, as with many of the recent studies in the rest of North America, much of the recent research regarding managed RMAs in the Acadian forest explores the effects of selective harvesting within RMAs.

8.0 COMPARISON OF RMA GUIDELINES IN ACADIAN FOREST AND THE REST OF CANADA

Newfoundland and Labrador require a 20 m RMA for any streams greater than 1 m wide, with 1.5 times the slope in percent where the slope exceeds 30% (Scruton et al. 1997). Quebec allows selective harvesting within 20 m RMAs, with a maximum allowance of 30% timber removed but no machinery allowed in the RMA (Decker 2003).

Ontario Ministry of Natural Resources (OMNR) guidelines for RMAs are based on the presence of fish or fish habitat (OMNR 2004). For streams with no fish, harvesting is permitted right to edge of the waterbody. RMA width, however, is based on slope: from 30 to 90 m (0-15% = 30 m RMA; 16-30% = 50 m RMA; 31-45% = 70 m RMA; 46-60% = 90 m RMA). Areas with high windfall potential require wider RMAs. Harvesting within the RMA zone is permitted up to a maximum of 50% by selective cutting, selection patch cutting, and strip cutting (Archibald et al. 1997). A portion of snags, small trees, and mature trees must be retained for habitat diversity and regeneration.

Manitoba requires a minimum of 100 m RMA adjacent to all watercourse classifications (Wedeles and Williams 1995). Their guidelines are based on two classifications of drainage: streams that drain greater than 50 km^2 with sport fish and streams that drain an area less than 50 km^2 with no sport fish. Wetlands may have RMAs less than 100 m if approved by a provincially funded Integrated Resource Management team, or 200 m if harvesting occurs in areas regarded as special habitat for endangered species, recreational areas for society, waterfowl and raptor nesting sites, or areas containing natural springs or seeps (Peacock 1996).

In Saskatchewan, third-order or lower streams draining less than 50 km^2 (by this definition no sport fish), require the retention of a 15 m RMA. Streams greater than third-order and draining more than 50 km^2 (with no fish) require a 30 m RMA. If these latter streams have fish, a 90 m RMA is required. Selective harvesting is permitted in the RMA when the ground is frozen or dry and well drained (Decker 2003).

In Alberta, a 30 m RMA is required for small permanent and intermittent streams and a 60 m RMA is required for large permanent streams with valleys greater than 400 m across. Selective harvesting by single tree or group removal is permitted, but no slash or debris should enter the watercourse (Kneeshaw et al. 1999) and machinery is not permitted within 20 m of the high water mark.

British Columbia has the most complex guidelines of the Canadian provinces. RMAs consist of two zones: a reserve zone where no harvesting permitted, and a management zone where selective harvesting is allowed. Streams are classified by channel width, the presence of fish, and presence in a community watershed. A channel width greater or equal to 100 m requires no reserve zone but a management zone of 100 m within which selective harvesting up to 50% basal area removal (BAR) is permitted. A channel width of greater than 20 m but less than 100 m requires a reserve zone of 50 m and a management zone of 20 m within which selective harvest of up 50% BAR can occur. A channel greater than 5 m but less than or equal to 20 m requires a 30 m reserve zone and a 20 m management zone, within which selective harvest is permitted up to 50% BAR. A channel 1.5 m wide and less than or equal to 5 m requires a reserve zone of 20 m and a management zone of 20 m within which selective harvest of up to 50% BAR is permitted. A channel less than 1.5 m only requires a management zone of 30 m within which selective harvest of up to 25% BAR is permitted. Streams that do not contain fish and are not in a community watershed have different requirements. Streams of this type greater than 3 m wide have no reserve zone, and have only a management zone of 30 m within which the forest can be selectively harvest up to 25% BAR. Streams of this type that are less than 3 m wide have no reserve zone but only a 20 m management zone within which 5% of the trees can be selectively harvested (Decker 2003; Young 2000).

According to Decker (2003), there is a recent territorial document for the Yukon stating that legislation was soon to be implemented: 30 m RMA around all watercourses and 90 m around sensitive areas and community water supplies (Anon. 2001). No information was found for the Northwest Territories and Nunavut.

Generally, most of the guidelines for RMA widths in Canada are based on the width of the stream or stream order (Table 6.2). In the Acadian forest region, however, Maine and Vermont RMA widths are based on the area that the stream drains. Unlike the provinces or states in the Acadian forest region, Ontario, Manitoba, Saskatchewan, and British Columbia all consider fish presence or habitat in determining RMA widths. Conversely, the western provinces (i.e., not including Ontario) do not consider the slopes of stream and river banks in their guidelines for RMA widths. Harvest within RMAs is permitted in all Canadian provinces except Manitoba, while only the state of Maine (Acadian forest) allows harvests within their RMAs. Only two regions consider terrestrial habitat in their guidelines for RMA width: Manitoba (Boreal forest) and Vermont (Acadian forest).

There appears to be no consistent pattern to the variation in RMA guidelines either within regions (i.e., Acadian forest region versus the rest of Canada), or between regions. Incorporation of modifying factors (e.g., presence of fish) in RMA guidelines, varies from one province or state to the next. Similarly, the general width of RMAs for various classifications differs within and between regions.

9.0 SUGGESTIONS FOR FUTURE RESEARCH

Concern over the effectiveness of retaining RMAs to conserve terrestrial habitat and biodiversity has arisen with the examination of riparian areas and edge effects. There is conflicting evidence for edge effects for birds using RMAs (Whitaker and Montevecchi 1997; LaRue, Belanger, and Huot 1995). Edge effects were, however, observed up to 20 m into the RMA from the cut edge in plant communities, where moss growth was influenced by the change in microclimate arising as a result of forest harvesting (Stewart and Mallik in press). More research in this area is required to determine how much the original riparian structure is conserved in the RMA after the upland forest is removed. This is particularly important where the RMA is harvested with selective cutting. Although the increase in canopy openings caused by harvesting may promote better regeneration, perhaps it may also result in more competition in the understory plant communities.

Another area that has been not been sufficiently investigated is the use of variable retention RMAs, particularly along small headwater streams. MacDonald, MacIsaac, and Herunter (2003) reported on the effects of variable vegetation retention on the temperature of small streams and Chan et al. (2004) reported preliminary results of a multi-disciplinary study examining variable retention of vegetation on most aspects of the riparian ecological functioning of headwater streams. Both of these studies, however, were performed in the Pacific Northwest. More of this type of investigation is needed in the Acadian forest region. In fact, only a few of the Acadian studies have focused on headwater streams (e.g., Hagan 2000 a, 2000b).

Little is known about the effects of RMA retention on plant communities of riparian areas of the Acadian forest. The study of bryophyte community response to harvesting by Fenton and Frego (2003) is the only investigation of the habitat conservation potential of retaining RMAs along harvested forest streams. Gregory et al. (1991) and Naiman and Decamps (1997) have discussed the idea of riparian areas as corridors for exotic and alien plant species (see also Planty-Tabbacchi et al. 1996; Pysek and Prach 1993). Rose and Hermanutz (2004) found that light availability, bare ground and soil pH were important for invasion of alien plant species in riparian zones. Do Acadian forest riparian areas also act as conduits for exotic plant dispersal and to what extent? How does the retention of RMAs either mitigate or promote the spread of alien plants? Research is needed to answer these questions.

Unlike most other land use activities, forestry involves a long-term cycle of conditions. Forests are adapted to disturbance and recovery. Recovery can occur either naturally or through active management. A key to understanding the significance of management impacts to riparian functions is not only to learn how much change occurs but also how long it persists. For example, how long after disturbance to the riparian zone will it take for the microclimate to recover to favourable conditions that provide suitable habitat for sensitive amphibian communities? Can amphibians disperse easily or do forest and riparian conditions affect recolonization of disturbed sites? Can special riparian practices, such as leaving downed logs or snags, moderate negative impacts? How can our management of riparian forests be used to emulate natural disturbance patterns that are essential to maintain riparian functions?

In general, research on the effects of RMAs in the riparian communities of the Acadian forest region would be enhanced through increased participation in the peer review process. New research could therefore be assessed for quality assurance and also made more accessible to others investigating in this field. Unfortunately, for a number of studies that were discovered through this review, final results were not accessible.

A recent study by Lee and Barker (2005) sought to determine the amount of older seral stage forest existing after 200 years of timber harvest. They used real world wood supply requirements and current software to simulate four RMA-defining scenarios of riparian management. Inputs to the simulation allowed applications, constraints and objectives for both forest and business indicators. One of the scenarios consisted of a "few-sizes-fits-all" approach, but with supplemental field interpretation including corrections for inappropriately labelled or classified water bodies on the map layers, the presence of streams found in the field but not marked on maps, as well as the application of wider RMAs due to local topography and erodible soils. The initial riparian area in the most conservative scenario was approximately three times that of others, while the amount of older seral stages maintained for the last 50 yrs was 3-7 times. Lee et al. (2005) concluded that although the targeted older seral stage requirements (in terms of percentage of land base) could not be satisfied by RMAs alone, fish-bearing guidelines provide the most efficient combination of protecting a significant riparian indicator while providing the most older seral stage forest.

Retaining unharvested RMAs in the Acadian forest may be a significant mechanism for conserving this forest type across the region by ensuring "that examples of all landscape types, all natural community types, and all native species are well-represented, in all their natural variability, in conservation areas throughout the ecoregion." (Davis et al. 2001). More research, however, is required to determine whether older seral stage characteristics may be lost through mortality of large trees, mixed cohort development, and an overall decline in tree volume (Lee et al. 2005).

10.0 CONCLUSIONS

Although RMA guidelines vary among provinces and states, riparian ecosystems values in the Acadian forest region in general appear to be conserved by the retention of vegetated RMAs. Research has been conducted to determine the effectiveness of these RMAs in maintaining riparian ecosystem functions and how harvesting within these RMAs may influence their structure and function. This review summarizes the research conducted so far. However, data are lacking for a number of riparian attributes.

Several studies have been conducted to determine how RMAs mitigate the effect of forest harvesting on water quality. Although results regarding water temperature are not consistent, RMAs were found to protect Acadian forest streams from the effects of increased stream light (Hagan and Wilkerson 2003, 2004; Noel, Wayne, and Federer 1986), and the influx of sediments (Martin and Hornbeck 1994; Pierce et al. 1993; Likens et al. 1970) and nutrients (O'Brien and Freedman 1998; Likens et al. 1970). Studies have also demonstrated the importance of retaining these RMAs for the input of organic material into streams (Bilby and Likens 1980; Fisher and Likens 1973).

Very few studies have been conducted in the Acadian forest region to examine the role of RMAs in the maintenance of biodiversity, although research has demonstrated the importance of these RMAs on amphibians (Perkins 2005; Perkins and Hunter in press). Parker (1998) initiated research on the importance of RMA retention on bird populations; however, complete data were not reported, and his data on small mammals were inconclusive. In a general survey of intact riparian areas, Spackman and Hughes (1995) reported on their use by mammals and birds and described vegetation composition of the riparian areas.

Fenton and Frego (2003) demonstrated that protection for bryophytes can be achieved in minimally disturbed RMAs, and that these areas may provide refuge for species at risk. Research by Whitman and Hagan (2000) found that many plant species are not found in recent clearcuts, but are found in either RMAs or clearcut separation zones, and suggest that remnants could serve as refugia from which these species can recolonize clearcuts at some future time. Although data are lacking on the potential protection afforded by RMAs to fish and aquatic invertebrates, Noel, Wayne, and Federer

(1986) found significant changes in both the primary producers and the aquatic invertebrates in streams where RMAs were not retained. None of the studies in the Acadian forest region examined in this report have addressed the use of riparian zones as movement corridors for plants and animals.

Though there is a persistent perception that the Acadian forest is unique due to the combined effects of topography, climate, and geology, there is little discussion regarding how these factors may also be responsible for creating unique riparian ecosystems. In fact, this issue has been identified by individuals in the region: a recently initiated project by the North Mountain Old Forest Society (NMOFS) is endeavoring to create a document entitled *A Guide to Restoring Acadian Forest Ecosystems* which will be a "source that is pertinent to the unique patterns, processes, and challenges of the Acadian Forest Region" (NMOFS 2004).

None of the studies of riparian areas in the Acadian forest region discuss the potentially unique hydrologic mechanisms that may have arisen from the distinct climate, vegetation, and geologic variations of the region. There may be a perception that the Acadian forest is different from forests to the north, south and east; however, data are lacking that demonstrate this potential uniqueness. More research (especially peer-reviewed) is required to determine whether the riparian ecosystems of the Acadian forest are dynamically distinct from other forest regions of North America, before meaningful suggestions can be made regarding the best management practice of its riparian areas.

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