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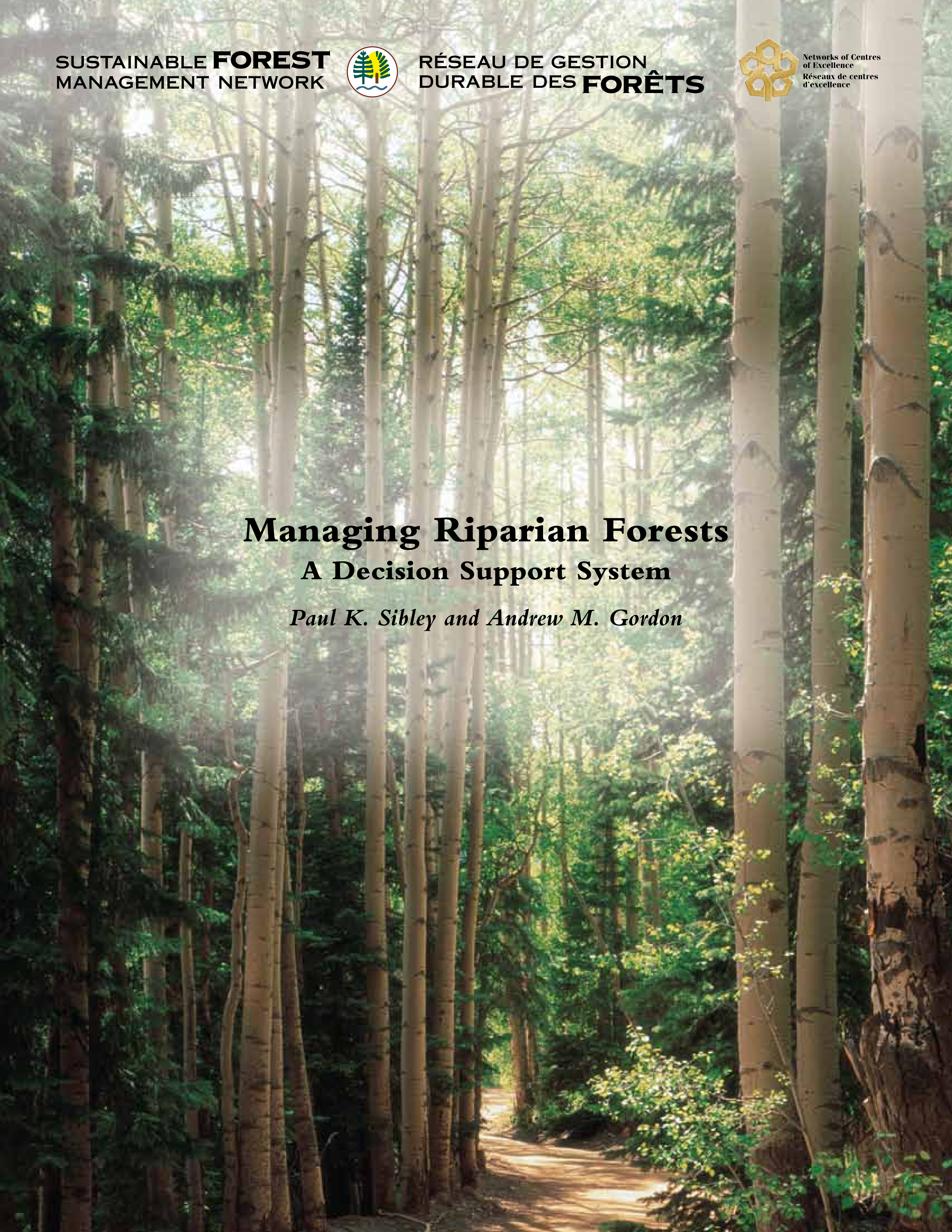

Managing Riparian Forests

A Decision Support System

Paul K. Sibley and Andrew M. Gordon

THE SUSTAINABLE FOREST MANAGEMENT NETWORK

Established in 1995, the Sustainable Forest Management Network (SFM Network) is an incorporated, non-profit research organization based at the University of Alberta in Edmonton, Alberta, Canada.

The SFM Network's mission is to:
- Deliver an internationally-recognized, interdisciplinary program that undertakes relevant university-based research;
- Develop networks of researchers, industry, government, Aboriginal, and non-government organization partners;
- Offer innovative approaches to knowledge transfer; and
- Train scientists and advanced practitioners to meet the challenges of natural resource management.

The SFM Network receives about 60% of its $7 million annual budget from the Networks of Centres of Excellence (NCE) Program, a Canadian initiative sponsored by the NSERC, SSHRC, and CIHR research granting councils. Other funding partners include the University of Alberta, governments, forest industries, Aboriginal groups, non-governmental organizations, and the BIOCAP Canada Foundation (through the Sustainable Forest Management Network/BIOCAP Canada Foundation Joint Venture Agreement).

KNOWLEDGE EXCHANGE AND TECHNOLOGY EXTENSION PROGRAM

The SFM Network completed approximately 334 research projects from 1995 – 2008. These projects enhanced the knowledge and understanding of many aspects of the boreal forest ecosystem, provided unique training opportunities for both graduate and undergraduate students and established a network of partnerships across Canada between researchers, government, forest companies and Aboriginal communities.

The SFM Network's research program was designed to contribute to the transition of the forestry sector from sustained yield forestry to sustainable forest management. Two key elements in this transition include:
- Development of strategies and tools to promote ecological, economic and social sustainability, and
- Transfer of knowledge and technology to inform policy makers and affect forest management practices.

In order to accomplish this transfer of knowledge, the research completed by the Network must be provided to the Network Partners in a variety of forms. The KETE Program is developing a series of tools to facilitate knowledge transfer to their Partners. The Partners' needs are highly variable, ranging from differences in institutional arrangements or corporate philosophies to the capacity to interpret and implement highly technical information. An assortment of strategies and tools is required to facilitate the exchange of information across scales and to a variety of audiences.

The KETE documents represent one element of the knowledge transfer process, and attempt to synthesize research results, from research conducted by the Network and elsewhere in Canada, into a SFM systems approach to assist foresters, planners and biologists with the development of alternative approaches to forest management planning and operational practices.

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Knowledge Exchange and Technology Extension Program (KETE)
Sustainable Forest Management Network

Managing Riparian Forests

A Decision Support System

By

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Sustainable Forest Management Network

Executive Summary

Riparian areas represent unique landscape features in which ecological processes interact with both economic and socio-cultural values. Traditional approaches to decision-making in forest management in these areas have largely been based on hydroecological criteria and their associated indicators as these have been well studied and most are easily measured. While hydroecological indicators remain a critical component of decision-making in forest management, increased emphasis has been placed on understanding the diverse ways in which people value riparian areas and incorporating this into the forest planning process. Some argue that the incorporation of socio-cultural values and their associated non-timber economic value is crucial to the development and implementation of sustainable forest management strategies. However, in practice this can be very difficult. In part, this difficulty stems from the fact that an economic value for socio-cultural values (e.g., cultural heritage sites, traditional hunting areas) is not easily determined and therefore it is difficult to weigh them against values whose economic value can be determined (e.g., timber).

With a greater understanding of the importance of, and relationships between, the multiple values of riparian areas, and the greater emphasis being placed on landscape-level approaches (e.g., emulation of natural disturbance patterns in Ontario), there is greater interest in developing more integrative approaches to forest management. This increases the complexity of the decision-making process as more values are considered. Decision-making in support of forest management plans is typically achieved in a hierarchical fashion, beginning with the broadest perspective in which the goals and objectives of management in a riparian area are clearly articulated. Ideally, this is driven by the perceived or known values of the riparian area and done with input from all potential stakeholders.

Once the goals have been established, the decision-making process may then proceed to consider available data that will facilitate the operational decisions required to undertake management activities. Typically coordinated by forest managers and/or government personnel, it is at this level that the application of a formal decision-making process may be most beneficial. This is the stage of the decision-making process where the various lines of evidence, in the form of indicators from agreed-upon criteria, are gathered and considered as a basis for rendering decisions on management practices (including harvesting). The process is greatly aided when a formal decision-making process, such as a decision-support system, is in place.

A decision support system is an approach which includes the systematic collection of information (data) and the accompanying techniques for the integration and interpretation of that data as a basis for making management decisions. There are numerous examples of decision support systems that have been applied in the context of forest management but there appear to be few instances of decision support systems being developed for the sole purpose of riparian management. This aspect of overall forest management has generally been included in decision support systems designed for broader forest management and planning purposes.

This synthesis report discusses the development of riparian management strategies and the important role that decision support systems can play in the implementation of such strategies. The report is divided into three sections. The first section provides an overview of boreal riparian systems, focusing on the unique structural and functional properties of boreal riparian systems and their relative sensitivity to anthropogenic and natural disturbance. In the second section, the report focuses on the attributes and importance of the three main values categories of riparian areas that must be considered in developing effective decision support systems: social-cultural, hydroecological, and economic. Finally, we provide a brief review of the types and application of decision support systems used in forest management, with particular focus on their application in riparian management in Canada. In this section, we also present a preliminary decision support system, the goal of which is to enable forest managers and planners to determine whether harvesting should be allowed in riparian areas and, if so, ***when*** and ***where*** to harvest, ***how much*** wood can/should be removed and ***how*** this can be achieved in an operationally safe and economical fashion.

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1.0 Introduction

Riparian areas represent a small but critical component of the landscape. These diverse areas of transition between terrestrial and aquatic environments experience complex spatiotemporal dynamics that are intimately linked to the landscape (Devito *et al*. 2000; Young 2000; Buttle 2002; Naiman *et al.* 2005). They exert disproportionate control over landscape-level processes and the productivity and quality of aquatic ecosystems by:

Riparian areas are diverse areas of transition between terrestrial and aquatic environments that exert disproportionate control over landscape-level processes and the productivity and quality of aquatic ecosystems.

- regulating the flow of energy and materials (Ewel *et al*. 2001; Naiman *et al.* 2005),
- acting as filters of nutrients, sediments, and water (Holland and Risser 1991; Risser 1995; Weller *et al.* 1998),
- providing unique microclimates and habitats (Brosofke *et al.* 1997; MacDonald *et al.* 2004), and
- serving as critical areas of biodiversity (Vuori *et al.* 1998; Carlsson and Spies 1999).

However, despite the diverse literature associated with riparian research (see review by NRC 2002 and books by Verry *et al.* 2000 and Naiman *et al.* 2005), current understanding of many aspects of the functional importance of riparian areas remains poor. This lack of knowledge has significant implications for understanding how riparian areas will respond to natural and anthropogenic disturbance. Historically, what is known about the role of riparian reserves in maintaining the ecological integrity of aquatic systems in disturbed landscapes has been studied predominantly in agricultural settings. Direct extrapolation of information from temperate agricultural systems to boreal systems, and their unique disturbance regimes, is questionable.

Riparian reserves, or buffers, are often left along lakes and streams to protect water quality.

Riparian reserves, or buffers, are often left along lakes and streams to protect water quality, although this practice has largely been legislated independently of any operational understanding of riparian function. With the move toward the development of landscape-level forest management across Canada, the hydroecological functions of these landscape boundaries, and their role in regulating the ecological integrity of aquatic ecosystems at different spatial scales, must be better understood if effective riparian forest management policy and practice is to be developed. The paucity of information on riparian response to disturbance makes the development of effective riparian forest management strategies and policy difficult. Riparian forests are complex and each riparian forest type may respond differently to natural and anthropogenic disturbance.

Harvesting in riparian areas in Ontario was permitted under previous guidelines but rarely done due to lack of guidance, poor understanding of aquatic system response, and low public acceptance.

Historically, riparian management practices in Ontario have been largely guided by the need to protect fish habitat (primarily coldwater species such as brook trout and lake trout) from harvesting disturbance (OMNR 1988a) as stipulated, in part, by the Fisheries Act (1985). In Ontario, until the recent introduction of the *Forest Management Guide for the Conservation of Biodiversity at the Stand and Site Scales* (SSG; OMNR 2010) which contains directives regarding the management of riparian areas and shoreline forests, guidelines for harvesting in riparian areas were stipulated under *the Code of practice for timber management operations in riparian areas* (OMNR 1991). Forest companies generally planned for riparian reserves (buffers) around lakes and streams in widths ranging from 30-90 m depending on the slope of adjacent hillslopes, although reserves could also be established using biological criteria such as moose aquatic feeding areas (OMNR 1988b). Harvesting in riparian areas was permitted under the old guidelines (when it could be demonstrated that harvesting activity did not pose a risk to fish or other animal habitat), however it was rarely done due to a lack of guidance on how harvesting operations should be conducted in riparian areas, a poor understanding of aquatic system responses to disturbance in riparian areas, and low public acceptance.

Key criticisms of this approach to riparian management were that they:

- focused too strongly on fish habitat protection,
- did not consider ecological elements of riparian systems that function at broader spatial scales, and
- did not incorporate disturbance patterns that occur as a result of natural disturbance regimes (Norris 1993; Buttle 2002; McNicol and Baker 2004).

Perhaps more importantly, the guidelines did not explicitly recognize other riparian values such as critical habitat, rare/endangered species or socio-cultural values such as those associated with historical and/or current use by Aboriginal peoples. The lack of science-based information and a framework within which to make informed decisions has constrained riparian forest management strategies that address competing riparian values. There are philosophical differences between industry, government, First Nations, and the public on how riparian forests should be managed in the future.

Based on the philosophy of maintaining biodiversity in managed landscapes through the emulation of natural disturbance patterns, the new Ontario Stand and Site guidelines promote disturbance in riparian areas through controlled harvesting.

Across Canada, provinces have been revising the way in which they manage forests. In Ontario, for example, forest management is shifting toward adoption of a landscape-level approach to forest management based on the emulation of natural disturbance patterns (OMNR 2001a, b; McNicol and Baker 2004). Historical riparian guidelines focused on protecting a sub-set of "key" species (e.g., fish) by the use of buffers where harvesting was prohibited. The new SSGs recognize the importance of integrating surrounding landscape attributes as well as competing ecological, social, economic, and recreational values of riparian use (OMNR 2010). Based on the philosophy of maintaining biodiversity in managed landscapes through the emulation of natural disturbance patterns, the SSGs promote disturbance in riparian areas through controlled harvesting.[3]

3 Controlled harvesting refers to modified or specialized harvest prescriptions.

The new guidelines provide greater flexibility for harvesting in riparian areas and corresponding guidance on when, where, and how much harvesting in riparian areas should occur. The effectiveness of this new guidance is constrained, in part, by:

- incomplete knowledge of hydroecological responses of riparian systems to harvesting disturbance,
- inexperienced forest operators who have largely avoided riparian areas and, perhaps most importantly,
- the absence of a framework within which informed decisions to guide riparian management can be made.

The standard practice of leaving buffers around water bodies may not be appropriate in the context of forest management that emulates natural disturbance patterns (MacDonald *et al.* 2004). Decisions to achieve relative balance between competing values in riparian areas will require large amounts of data, knowledge in different forms and qualities, and the capacity to account for multiple, often conflicting, management goals. Despite recent proposals for developing effective forest management policy (e.g., Rauscher 1999; Basnyat *et al.* 2000; Smith *et al.* 2003; Van Damme *et al.* 2003) and integrating riparian systems into that policy (Buttle 2002; Van Damme *et al.* 2003; Naiman *et al.* 2005), effective mechanisms that facilitate informed decision-making for managing riparian forests are still needed.

The standard practice of leaving buffers around water bodies may not be appropriate in the context of forest management that emulates natural disturbance patterns.

1.1 Objectives

This report discusses the development of riparian management strategies and the important role that decision support systems can play in the implementation of such strategies. The report originates from a Sustainable Forest Management Network-sponsored project designed to develop a broadly applicable, science-based decision support system that could be used by the forest industry and government for the management of riparian forests.

The report is divided into four sections. Section 2 provides an overview of boreal riparian systems, focusing on the unique structural and functional properties of these systems and their relative sensitivity to anthropogenic and natural disturbance. In Section 3 we focus on the social-cultural, hydroecological, and economic values of riparian areas that must be considered in the development of an effective decision support system. Section 4 provides a brief review of the types and application of decision support systems used in forest management, focusing, where applicable, on their application in boreal riparian management in Canada. In Section 5 we present a preliminary riparian decision support system, the goal of which is to provide a process by which forest managers can determine if harvesting is feasible in a riparian area and, if so, *when* and *where* to harvest, *how much* wood can/should be removed, and *how* this can be achieved in a safe and economical fashion.

2.0 Riparian Ecosystems

2.1 Definitions

Definitions of riparian areas vary depending on whether the definition originates from soil or aquatic biologists or whether it originates from an ecological or operational perspective. The term "riparian" derives from the Latin word *riparius* meaning "of or on a river bank" (Oxford Dictionary of Current English 1996) and simply refers to land adjacent to a body of water (Ilhardt *et al.* 2000).

From an ecological perspective, Naiman *et al.* (1993) define a riparian area as

> *"the stream channel and that portion of the landscape from the high water mark toward the uplands where vegetation may be influenced by the elevated water tables or flooding and the ability of soils to hold water".*

Ilhardt *et al.* (2000) define a riparian area as

> *"three dimensional ecotones of interaction that include terrestrial and aquatic ecosystems, 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 water course at a variable width".*

The latter definition recognizes riparian function at different spatial scales and may therefore be appropriate as a guide for the management of riparian resources. From an operational perspective, some agency definitions exclude the water component in defining a riparian area. This seems rather short-sighted from a management standpoint in light of the important role that water plays in the structure and functioning of riparian systems and the goal of minimizing effects on aquatic systems when developing forest management plans.

Numerous terms have been used to describe riparian areas potentially affected by forest management activities, including "buffer zones" or "buffer strips" and "streamside management zones," and "riparian management zones". Such terms are typically accompanied by the specification of a fixed or variable minimum width of vegetation to be retained following harvest, depending on tree/plant and animal species composition, age, geomorphology (e.g., soil composition and slope), adjacent land uses, etc. Historically, the most common attribute for determining buffer width in managed forest landscapes is the slope of adjacent hillslopes (steeper slopes generally dictating wider buffers). It is worth noting that both ecologists and forest managers often use the terms "shoreline area/zone" or "shoreline forest" interchangeably with riparian area/zone. **For the purpose of this report, we will use the term "riparian area".**

2.2 Function of Riparian Areas

Regardless of how a riparian area is defined, it is generally accepted that these proportionally small areas of transition between terrestrial and aquatic environments exert a disproportionate influence over landscape-level processes.

Riparian landscapes:

- involve complex spatio-temporal dynamics,
- serve multiple ecological functions,
- are intimately linked across multiple spatial scales,
- exert considerable control over the productivity and quality of aquatic ecosystems (Devito *et al.* 2000; Young 2000; Buttle 2002; Naiman *et al.* 2005),
- regulate the flow of energy and materials (Ewel et 2001; Naiman *et al.* 2005),
- act as filters of nutrients, sediments, and water (Holland and Risser 1991; Risser 1995; Weller *et al.* 1998; Hazlett *et al.* 2007; Knoepp and Clinton 2009),
- provide unique microclimates and habitats (Brosofke *et al.* 1997; MacDonald *et al.* 2004; Peterson and Semlitsch 2009),
- serve as critical areas of biodiversity (Vuori *et al.* 1998), and
- have increasingly recognized important socio-cultural values.

Riparian areas are considered to have high conservation value (Naiman 2005). Current understanding of the role of riparian areas in maintaining the ecological integrity of aquatic systems in disturbed landscapes has largely been derived from studies in agricultural landscapes. Agricultural riparian areas may or may not respond similarly to forest riparian systems faced with unique disturbance regimes such as forest fires, pest outbreaks, and windthrow. Thus, the application of management practices developed for riparian areas in temperate agricultural systems to forest riparian systems is questionable.

Management practices developed for riparian areas in temperate agricultural systems may not be appropriate in boreal riparian areas.

The limited understanding of how riparian systems might respond to disturbance, in conjunction with the perceived ecological importance of riparian areas, has generally led to conservative approaches regarding riparian management. Historically, the predominant practice in Canada has been to retain undisturbed and unmanaged forest or shoreline vegetation, usually in the form of specified buffers, to minimize adverse effects on the riparian area and, by association, adjacent aquatic systems. However, recent perspectives in forest management suggest that some disturbance may be ecologically beneficial, notably in terms of increased biodiversity, and this has led to considerable discussion regarding the advantages and disadvantages of actively disturbing and managing riparian forests (Palik *et al.* 2000; Lindenmayer and Franklin 2002).

2.3 Management of Riparian Areas

Forest ecosystems experience periodic natural disturbances, including wildfires, disease, insect infestations, and physical disturbance (windthrow, ice storms) at all spatial and temporal scales. These disturbances affect all components of the forest on the landscape, including riparian areas. Forest ecosystems have evolved over millennia under the influence of periodic disturbance. Allogenic (physical) or biogenic (biological) natural disturbance events may result in changes in:

- the rate of succession,
- the trajectory of succession (the system may be moved to an earlier seral stage in the process of succession, continue at its current seral stage, or accelerate to a subsequent seral stage), or
- the pathway of autogenic succession (alter the sequence of seral stages) at a given point in time (Kimmins 2004).

Fixed buffers are easier to implement and monitor in terms of regulations but are atypical landscape features and have few known ecological precedents.

While an altered or new state may result from a given disturbance regime, the structural and functional integrity of a forest ecosystem often persists due to the resilience (ability of the system to absorb changes) inherent within it (Holling 1973). Ecological theory predicts that the greatest number of species in ecosystems (i.e., diversity) occurs at intermediate levels of disturbance. The intermediate disturbance hypothesis (Connell 1978) suggests that disturbance may be ecologically beneficial to ecosystem structure and function. The historical practice of leaving undisturbed, fixed-width buffers around water bodies may ignore the potential positive effects that harvest disturbance can have on riparian structure and function. Fixed buffers are easier to implement and regulate in terms of regulations from a forestry perspective, but are atypical landscape features in boreal forests and have few known ecological precedents. Natural disturbances rarely lead to uniform boundaries. Boundaries are more likely to be determined by interactions between the disturbance vector(s) and various allogenic and biogenic features of the landscape.

Riparian areas are exposed to disturbance regimes comparable in frequency to other landscape features.

Riparian areas are exposed to disturbance regimes comparable in frequency to other landscape features (MacDonald *et al.* 2004; Kardynal *et al.* 2009). While our understanding of natural disturbance regimes is rudimentary from an ecological context, it has been argued that forest management practices should be conducted in a manner that emulates natural disturbance patterns (Attiwill 1994; McRae *et al.* 2001; Harvey *et al.* 2002). For riparian areas, such an approach is almost certainly more realistic than the practice of leaving buffers.

In recent years, the concept of managing forests in the context of emulating natural disturbance patterns has gained considerable traction within some government agencies and the forest industry (Perera and Buse 2004; Kimmins 2004). This emerging philosophy reflects the desire to move from the traditional stand-level approach to forest management to a more integrative landscape-level approach. The basis for this perspective is that natural disturbance regimes, while affecting multiple spatial and temporal scales, have important implications for ecosystem structure and function at the landscape level. Kimmins (2004) defines natural disturbance emulation in the context of forestry as:

> *"management over ecologically significant temporal and spatial scales that attempts to emulate the ecosystem effects of physical (allogenic) or biotic (biogenic) disturbance events, the frequency and/or severity of which have been changed by human action but which have historically determined the potential pathways,*

patterns, and rates of autogenic successional development in the ecosystem in question. Such emulation aims to maintain the historical range of variation, or a socially acceptable subset thereof, in desired ecosystem conditions and functions over defined spatial and temporal scales."

The notion of creating disturbance in riparian areas may be counter-intuitive for an industry that has relied predominantly on the use of fixed buffers to protect against disturbance to aquatic systems. However, the idea that limited and controlled disturbance in and outside of riparian areas may be beneficial to them has received increasing attention (Anderson *et al.* 2007; Anderson and Meleason 2009; Bauhus *et al.* 2009). In Ontario, the approach of emulating natural disturbance patterns has received legislative status (Perara and Buse 2004) and will be incorporated into forest guidelines for that province as they are developed (OMNR 2001). The adoption of this approach in Ontario is based on recognition of the artificial practice of leaving buffers and the potential ecological benefits of disturbance in riparian areas (OMNR 2010):

The idea that limited and controlled disturbance in and outside of riparian areas may be beneficial to the riparian areas has received increasing attention.

"In contrast to the Timber Management Guidelines for the Protection of Fish Habitat (1988), direction in the new guide not only permits, but encourages management in shorelines areas, primarily to meet ecological objectives"

While the potential merit of harvesting in riparian areas may be founded on ecological principles, changes in management practices that promote controlled harvesting in riparian areas must also consider potential effects on socio-cultural values. Riparian areas may be of importance to both Aboriginal and non-Aboriginal people for hunting purposes or as places of historical significance. Riparian areas may also contain both economic and non-economic recreation opportunities (such as fishing resorts, guide outfitters or picnics). These values should be considered in a balanced manner, however this may be difficult to achieve due to perceived differences in the relative importance of different values by stakeholders. It may be facilitated by:

Management practices that promote controlled harvesting in riparian areas for ecological values must also consider potential effects on socio-cultural and economic values.

- a clear understanding of the specific values associated with riparian areas,
- a cooperative, integrative, and science-based approach to decision-making, and
- an effective mechanism by which decisions can be made (decision support system).

3.0 Riparian Values

Understanding the diverse ways in which people value riparian areas and incorporating this into the forest planning process is crucial to the development and implementation of sustainable forest management (Dwyer *et al.* 2000). Emerging philosophies regarding the management of riparian areas, whether in a forestry context or otherwise, are beginning to recognize the importance of incorporating non-ecological values as an integral part of the decision-making process (Naiman 2006):

> *"Landscape approaches are not really landscape approaches if they lack the human and societal dimension"…understanding the human and societal dimensions of riparia may be the new important challenge we face at the present time"*

For some attributes economic valuation is usually possible but for others, such as viewscapes or cultural heritage sites, valuation is a challenge.

Consistent with this emerging perspective on forest management there is greater interest in undertaking integrative approaches to decision-making in which socio-cultural, ecological and economic values are considered. This tripartite perspective is depicted schematically in Figure 1. Such a vision demands that management be conducted in a manner that explicitly recognizes the relative value of the socio-cultural, ecological, and economic attributes of riparian areas. For some attributes (e.g., timber), economic valuation is usually possible but for others, such as viewscapes or cultural heritage sites, valuation is often not possible because of the difficulties in converting an intrinsic sense of worth into concrete units such as dollars (NRC 2005; Roquette *et al.* 2009). Numerous methods for valuation of non-marketable values have been developed (e.g., Roquette *et al.* 2009) but these are rarely formally applied in forest harvest planning. Nonetheless, non-economic valuation is important because it can help to ensure that many of the non-quantifiable or non-traded attributes of, or services provided by, riparian areas and their associated aquatic ecosystems receive explicit treatment in the decision-making process.

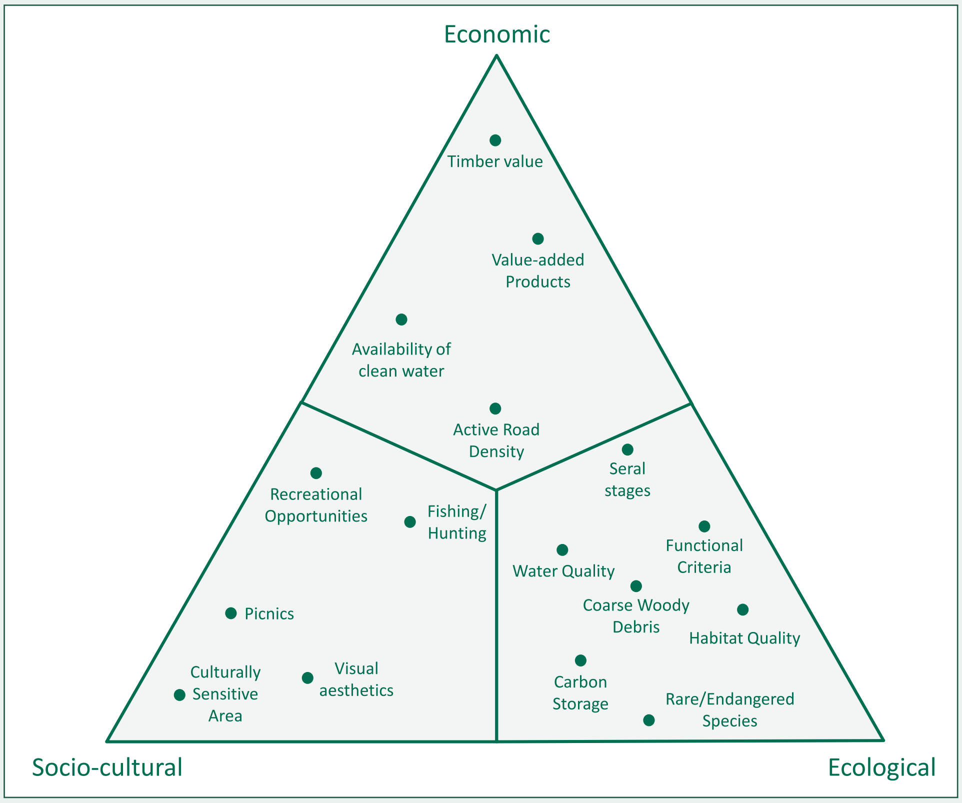


Figure 1. Tripartite relationship between socio-cultural, ecological, and economic values of riparian areas showing examples of the types of values that should be considered in each area. Adapted from Seely *et al.* (2004).

3.1 Hydroecological Values

Hydroecological characteristics of riparian areas have, arguably, been the most widely studied and are, consequently, the best understood. Although riparian areas represent only a small proportion of the landscape, they are recognized as critical zones of transition, capable of exerting a disproportionate influence on numerous landscape-level processes. As zones of transition between terrestrial and aquatic environments, riparian areas:

- provide unique microclimates and habitats,
- often exhibit high vegetative and animal diversity compared to in-stream or upland areas alone,
- strongly regulate the flow of water, energy and materials from the landscape, acting as filters of nutrients, sediments, and water (see review by NRC 2002 and books by Naiman *et al*. 2005 and Verry *et al*. 2000) and have been referred to as "the kidneys of the landscape," and
- are important sites for biogeochemical cycling and in this functional capacity serve as a critical link between upland processes that control the productivity and quality of aquatic systems, at multiple spatial scales.

To date, the forest planning process has relied extensively on a limited set of hydroecological criteria and indicators to make decisions regarding forest management and the design of riparian buffers to reduce post-harvest effects on riparian areas. For example, in Ontario, historical guidelines for the establishment of riparian buffers were based almost exclusively on slope and the potential for erosion and sedimentation with the primary goal of reducing the potential for impacts on fish habitat from these environmental stressors. However, buffers are also established to conserve habitat quality for certain species such as moose (e.g., 120 m buffers around moose aquatic feeding areas) and osprey (90 m radial buffers around nesting sites). In some cases, small buffers are also retained around hydrologically sensitive areas (HSAs). In many cases these areas are too small to be detected on commonly used topographical maps and are only buffered if recognized by on-the-ground operations crews at the time of harvesting. Despite the known ecological complexity of riparian areas, and a wide range of potential indicators, few additional hydroecological indicators are typically applied in the forest management process when determining riparian management options.

To date, the forest planning process has relied extensively on hydroecological criteria and indicators to make decisions regarding the design of buffers to reduce post-harvest effects on riparian areas.

There are three broad categories of hydroecological values that should be considered when making forest management decisions for riparian areas: **1) ecosystem services, 2) aquatic values and 3) terrestrial values** (Figure 2). Each value has associated indicators around which decisions can be made. Ecosystem services of riparian areas might include:

- protection and sustainability of water supplies for drinking water purposes,
- retention of vegetation for sequestration of carbon,

- enhanced biodiversity,
- the presence of plants with medicinal uses, and
- functional processes such as biogeochemical cycling and decomposition of organic material.

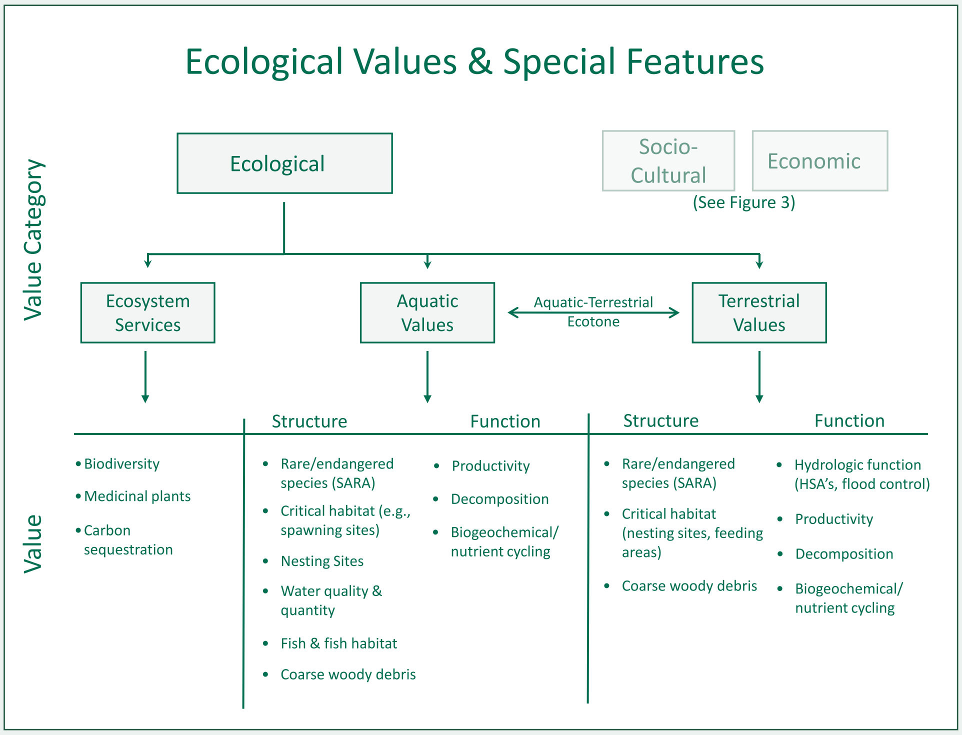


Figure 2. Examples of the structural and functional components of ecological values associated with the aquatic and terrestrial components of riparian areas, and some of the ecological services that riparian areas provide. Socio-cultural and economic values are presented in Figure 3.

In some cases (e.g., water supply for drinking water purposes), it may be possible to place an economic value on the "service" that a riparian area might provide but in most cases, assigning a valuation function for ecological features and ecosystem services is difficult.

Process-oriented (functional) criteria and their indicators, while clearly relevant from an ecological standpoint, typically respond slowly to disturbance.

It is also important to realize that process-oriented (functional) criteria (such as biogeochemical cycling and decomposition) and their indicators, while clearly relevant from an ecological standpoint, typically respond slowly to disturbance, or respond only after significant change has been sustained. Moreover, they can be difficult, time-consuming and resource-intensive to measure and monitor relative to their structural counter-parts. Not surprisingly, functional criteria tend to be perceived as impractical and are used infrequently as a basis for decision-making in forest management.

It is far more common to use structural attributes (e.g., number of species, biomass, diversity, the amount and availability of groundwater, etc.) as a basis for decision-making. Not only are these relevant as indicators of ecological conditions and response to stress, they are more likely to respond quickly and, in many cases, with high sensitivity to disturbance. From a practical standpoint, they are also easier to measure compared to functional endpoints. Among the potentially useful structural indicators that could be included are:

Structural attibutes are easily measured, relevant ecological indicators and are more likely to respond quickly and with high sensitivity to disturbance.

- traditional indicators used in forest management such as slope and soil structure,
- the presence/absence of species at risk (SAR),
- the presence of hydrologically sensitive areas,
- the potential for changes in coarse woody debris dynamics in both terrestrial and aquatic habitats,
- changes in the occurrence and relative abundance of key species (such as fish),
- changes in water chemistry and productivity (e.g., eutrophication as indicated by increased chlorophyll a), and
- discharge (peak/low flow).

With such a large number of potential hydroecological indicators available it is reasonable to ask which ecological indicators should be used in decision making and how should they be prioritized relative to indicators of other values. It is not practical, nor desirable, to include all possible hydroecological indicators so it will be necessary to prioritize indicators based on their perceived or known structural or ecological importance. Those with high ecological relevance should be prioritized above those that contribute less to the protection of structural and functional attributes of riparian systems. The relative priority of indictors will likely vary in different regions of Canada so prioritization will need to be done on a regional basis.

It will be necessary to prioritize indicators based on their perceived or known structural or ecological importance.

The selection of indicators should consider practical aspects such as the relative ease with which they can be measured and monitored. For example, indicators that are difficult, tedious, or time-consuming to measure may be a poor choice to include in a decision support system. It is important to note that some indicators can serve as protective surrogates for others. For example, slope is often used as a basis for establishing the area to be retained in a managed reserve as it is a good indicator of the potential for erosion (the greater the slope, the larger the reserve). Slope might also be a good surrogate indicator for functional processes such as biogeochemical cycling and decomposition. Slope-based retention of riparian reserves will ensure greater and possibly longer soil water retention in areas vulnerable to drying out post-harvest. Riparian reserves in these areas could also maintain and possibly enhance rates of nutrient and elemental mineralization, preventing their transport to adjacent water bodies. Thus, it may not be necessary to measure and monitor a large number of riparian structure and function attributes as a basis for decision-making as these will be addressed by using other judiciously selected indicators as surrogates.

The selection of indicators should consider practical aspects such as the relative ease with which they can be measured and monitored.

The definition and application of socio-economic criteria and indicators may vary across social, cultural, and ecological boundaries.

3.2 Socio-Cultural Values

Riparian forest management planning, like the broader forest management planning process, is multi-faceted and must incorporate criteria and indicators that reflect the multiple values that characterize riparian areas. The definition and application of criteria may vary across social, cultural, and ecological boundaries (Karjala and Dewhurst 2003). The importance of a more holistic approach to the sustainable management of riparian forests is reflected in the criteria and indicators report by the Canadian Council of Forest Ministers published in 2003 (CCFM 2003). Criterion six, termed "society's responsibility," highlighted the importance of social values as a basis for sustainable forest management. Sustainable management of riparian forests must reflect the best interests of the three essential components of a healthy and sustainable forest sector: the environment, the economy and social well-being (CCFM 2009).

Examples of various socio-cultural values of riparian areas are presented in Figure 3. Riparian areas may have important implications for the human dimensions of these ecosystems (Dwyer *et al.* 2000). For example, riparian areas may offer unique opportunities for experiences, such as recreational activities (fishing, trapping, canoeing, swimming, etc), aesthetic experiences (e.g., picnics, areas of solitude, etc.), or tourism opportunities (e.g., resorts, cottages, etc.) that depend on the aquatic-terrestrial interface. However, the limited spatial extent of riparian areas means that recreational uses of these areas may also lead to conflict when people and wildlife compete for these different uses (Dwyer *et al.* 2000; Miller and Hobbs 2000).

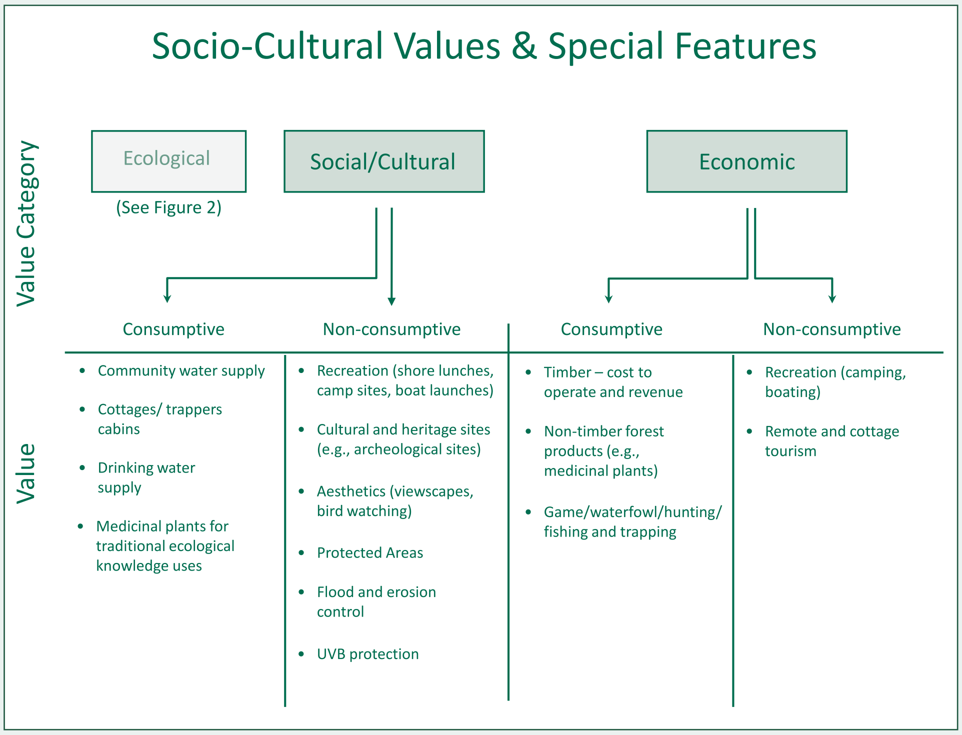


Figure 3. Example of consumptive and non-consumptive values associated with socio-cultural and economic attributes of riparian areas.

Beyond recreational and tourist opportunities, riparian areas may hold significance as culturally sensitive areas to Aboriginal peoples, as traditional areas for hunting, fishing, and trapping, or the location of previous habitation sites (registered or potential archeological sites) and burial sites. They may also be perceived importantly in terms of their aesthetic value and provision of viewscapes. Each of these will be perceived more or less importantly depending on the user/observer and therefore potentially affect decision-making in the forest planning process. For example, Aboriginal peoples often feel excluded from the forest planning process (Karjala and Dewhurst 2003), including planning for riparian areas, despite the fact that riparian areas represent important sites for hunting, trapping, fishing, and, in some cases, cultural heritage. In Canada, many provinces have guidelines to ensure that social and cultural values are recognized and addressed early on in the planning process, although the specific criteria for decision-making and their use in the planning process often proceeds without input from Aboriginal peoples.

Riparian areas may have unique cultural significance.

The perceived or known social value of riparian areas is difficult to quantify from a valuation perspective. While it may be possible to quantitatively estimate the economic worth of some social values (e.g., recreational hunting and fishing, lodge-based tourism, boating opportunities), doing so in the specific context of riparian areas may be difficult due to a lack of information. Moreover, values that are perception-based (e.g., the value of a viewscape) are often very difficult to quantify and appear to be attempted infrequently in the context of decision-making in the forest planning process. In light of the uncertainty associated with establishing the economic value of social values associated with riparian areas, integrating information pertaining to social values into a decision support system in a quantitative fashion is a challenge.

Integrating information pertaining to social values into a decision support system in a quantitative fashion is a challenge.

3.3 Economic Values

Historically, decisions in forest management have largely been based on economic considerations such as merchantibility of wood, access and harvest costs. Economic values represent one of several important considerations when deciding on riparian management strategies (Naiman *et al.* 2005). Little is known about the magnitude of the foregone net-benefits of harvesting in riparian areas and studies aimed at undertaking detailed economic analyses of the opportunity costs associated with riparian areas under current regulatory frameworks are needed.

A key aspect in establishing the economic feasibility of accessing timber in riparian areas is the need for improved understanding of the tradeoffs between economic, social and ecological values and the motivation for their consideration. However, the tripartite intersection of socio-cultural, ecological, and economic values, and their perceived value by various stakeholders, renders any attempt to accurately estimate the economic value of riparian areas difficult. Numerous riparian attributes may have economic value (e.g., flood control, preservation of biodiversity, recreational opportunities) depending on the end user (Figure 4). However in light of the paucity of information on riparian function valuation, we are left with an uncertain sense of the intrinsic value of such attributes and few indicators on which to base decision points to aid riparian management.

An improved understanding of the tradeoffs between economic, social and ecological values is needed to establish the economic feasibility of accessing timber in riparian areas.

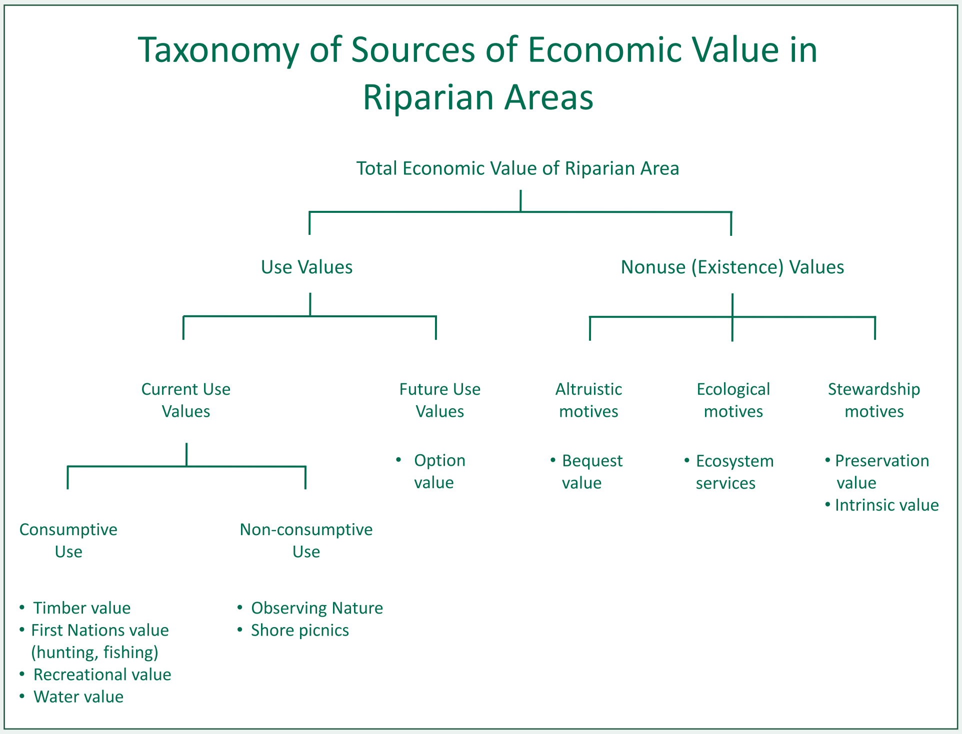


Figure 4. A taxonomy of the various categories of economic values associated with riparian areas. Adapted from Naiman *et al.* (2005).

The one economic attribute in riparian areas whose value can be easily calculated is timber. Often, the value of timber in riparian areas can be very high since the generally wetter conditions and corresponding reduced susceptibility to fire yields older and larger trees with higher quality wood. Timber is a consumptive value which, along with recreational, hunting and fishing opportunities, could, in part, comprise a basis for decision-making in a riparian decision support system. For example, numerous studies have attempted to estimate the economic value of riparian areas in agricultural landscapes, typically in the context of retiring land to convert into forested or grassed buffers for the purpose of mitigating non-point source pollution transport to aquatic systems and improvement/preservation of water quality (Lant and Tobin 1989; Qui and Prato 1998; Basnyat *et al.* 2000) or for conversion of buffer areas to sources of income utilizing non-timber products (Robles-Diaz-de-Leon and Kangas 1999). For example, Basnyat *et al.* (2000) estimated the cost associated with retiring land to create riparian areas of varying widths to mitigate the transport of nitrogen to streams in agricultural areas to range from $0-$3067 per ha. Burns *et al.* (1999) estimated the opportunity costs of leaving timber in riparian zones of Texan streams for the purpose of retaining wildlife habitat. They estimated lost opportunity costs (based on timber value only) of $2.60, $2.04, and $11.13 US per acre for narrow, medium, and wide riparian zones, respectively, if harvesting was not undertaken.

These types of quantifiable economic criteria lend themselves to inclusion as decision points within a decision support system. Importantly, the economic worth of these values must be weighed against the known or perceived economic value of other riparian functions, not all of which can be readily quantified. Few studies have attempted to evaluate the economic value of non-timber riparian attributes in boreal forests (see Hunt *et al.* 2005). In some cases, it may not be necessary to know the economic value of an attribute in order for it to provide useful information in decision making. For example, for some social values (e.g., historically important areas, First Nations cultural/heritage sites), the perceived or understood importance may transcend the need to ascribe a quantitative value and may simply be incorporated as yes/no decision points in a decision support system based on presence/absence.

In some cases, it may not be necessary to know the economic value of an attribute in order for it to provide useful information in decision making.

4.0 Decision Support Systems for Riparian Management

The forest industry has long incorporated decision support systems as part of the planning process but few of these have been used specifically for the purpose of managing riparian forests. Historically, a lack of motivation due to regulatory constraints related to harvest activities in riparian areas has generated little interest in adopting riparian-specific management strategies other than relying on the simplistic approach of using buffers in the form of donuts around lakes and ribbons along streams (Buttle 2002). However, with some provinces moving toward a landscape-level approach to forest management that emphasizes emulation of natural disturbance patterns, an approach that recognizes that disturbance regimes at various spatial scales affect riparian areas, the traditional approach of relying solely on static buffers has been questioned. Commensurately, there has been increased acceptance that other options may be appropriate for managing riparian areas. Some jurisdictions have been evaluating alternative approaches, such as partial harvesting in designated management zones of riparian areas, as a basis for managing riparian areas. However, there remain few instances in which decision-making frameworks have been used as the basis for determining the full scope of operational practice and management in riparian areas.

Due to riparian harvest regulatory constraints little interest has been generated in riparian-specific management strategies other than the simplistic approach of using buffers.

4.1 What is a decision support system?

A decision support system is an approach for the systematic collection of information (data) and the accompanying techniques for the integration and interpretation of those data as a basis for making management decisions. They are structured, transparent, repeatable and defendable. Initially, the user must provide input in the form of data. In the case of forest systems, data may be derived from existing knowledge (e.g., literature) or previous experience (including traditional ecological knowledge), collection and measurement, remote sensing and modeling. In most cases, the data will need to be organized and analyzed in some manner which may require user knowledge and expertise. Once the appropriate

Decision support systems are structured, transparent, repeatable and defendable.

data have been collected and analyzed, they can then be used as a basis on which to make decisions pertaining to the entity to be managed. Some decision support systems may be accompanied by a software interface (e.g., database) to aid the decision-making process but this is not always the case. Others can be as simple as a decision tree.

4.2 Decision Support Systems in Forest (and Riparian) Management

There are few instances of decision support systems developed for the sole purpose of riparian management.

Numerous decision support systems have been developed to aid decision-making in forest management (see overview by Lexor and Brooks 2005). These decision support systems range from broad in perspective and application (Varma *et al.* 2000; Van Damme *et al.* 2003; Nute *et al.* 2004; Seely *et al.* 2004) to those that focus on specific aspects of forest operations (e.g,. Brauner *et al.* 2005) and environmental factors, such as fire and wind, for which damage prediction is desired (Iliadis 2005; Mickovski *et al.* 2005; Olofsson and Blenow 2005; Zeng *et al.* 2007). Broad-based decision support systems often explicitly recognize and incorporate decision points on social, ecological and economic criteria (Seely *et al.* 2004). Kangas and Kangas (2005) note that decision support methods are needed for multiple criteria evaluations and for the comparison of alternative forest plans. In addition, there appear to be few instances of decision support systems being developed for the sole purpose of riparian management. This aspect of overall forest management has generally been included in decision support systems designed for broader forest management and planning purposes or riparian areas have been excluded (buffered out) from analysis of the harvestable landbase.

Decision support systems are most effective when they identify potential conflicts between competing objectives, provide an interface for the integration of value perceptions, and include preferences of decision makers and stakeholders.

Decision support systems for forest resource management are generally most effective when they include the identification of potential conflicts between competing objectives, provide an interface for the integration of value perceptions, and include preferences of decision makers and stakeholders. Rauscher *et al.* (1999) describe a hierarchical perspective on the application of decision support systems which is instructive in the context of forest systems (Figure 5). In this approach, they identify, at the broadest perspective, the "ecosystem management decision environment." At this level, the goals and objectives of harvesting in a riparian area should be clearly articulated. For example, in Ontario, new riparian guidelines encourage controlled harvesting in riparian areas in order to create disturbance that will potentially increase ecological diversity and function. In some cases, a "disturbance" approach may not be acceptable depending on the values that may be affected by the disturbance. Thus, it is critical that all socio-cultural, ecological and economic values unique to the riparian area(s) under consideration for harvest are clearly identified, along with any limitations or uncertainties pertaining to those values that may affect the decision-making process (e.g., information that is missing or possibly not attainable).

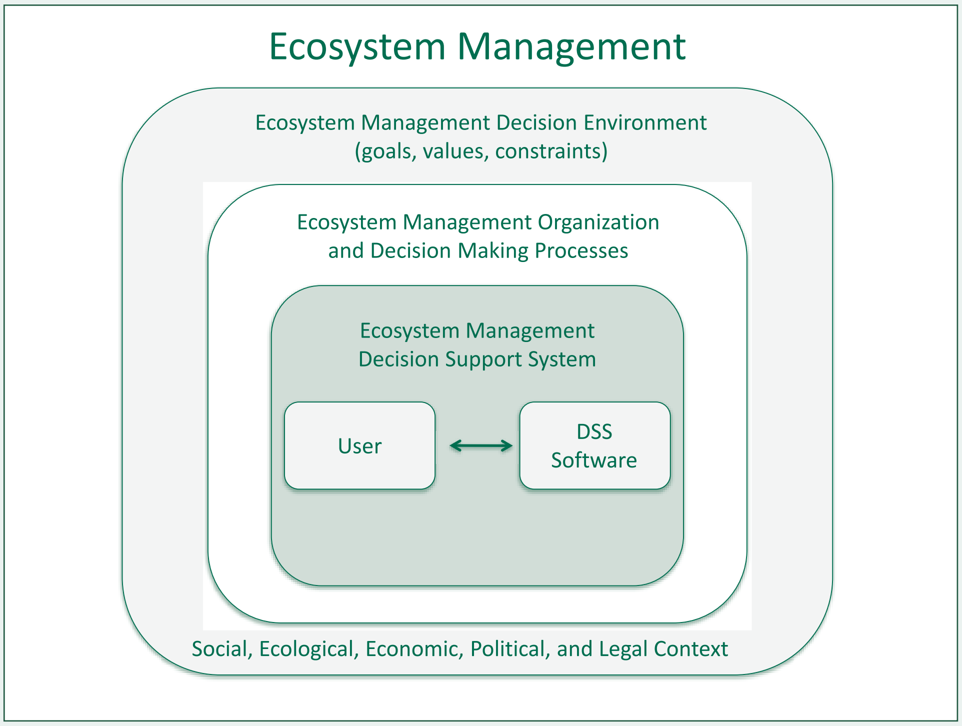


Figure 5. Hierarchy of the management and decision support environment used in the forest planning process. Adapted from Rauscher (1999).

This level in the decision environment is the most important stage in forest management as it clearly establishes how the decision-making process will proceed. As there is increasing demand for public involvement in forestry decision-making, the decision-making process should be developed in a consultative environment (participatory decision-support) with input from all potentially affected stakeholders and the application of multi-criteria analyses (Sheppard 2005; Sheppard and Meitner 2005). In practice, however, there are few instances in which this has occurred in the context of sustainable forest management (Sheppard 2005). With the broad range of social values potentially associated with shoreline areas, a riparian-based decision support system may provide an excellent opportunity for participatory decision-making in which stakeholders are provided with an opportunity to participate up front and throughout the decision-making process.

The decision-making process should be developed in a consultative environment (participatory decision-support) with input from all potentially affected stakeholders and the application of multi-criteria analyses.

Within this broad ecosystem management decision environment, there is nested an "ecosystem management organization and decision-making environment" (Figure 5; Rauscher *et al*. (1998)). It is at this level that application of the decision-making process takes place, typically coordinated by forest managers and/or possibly government personnel. At this stage of the decision-making process the various lines of evidence, in the form of indicators from agreed-upon criteria, are considered as a basis for making decisions on management practices (including harvesting). In some cases, this may also be a place for inclusion of traditional ecological knowledge, though in practice this is far more the exception than the rule.

In many cases, the decision-making environment is aided by the development of a decision support system (the third tier in the hierarchy of Rauscher *et al.* (1998)), which may consist, operationally, of personnel, a framework for decision-making, and software allowing for the input of collected or modeled data. Throughout the decision-making process, it is essential to re-evaluate the results in the context of the previous stage(s) particularly in terms of ensuring that all stated and agreed-upon goals and objectives are being met and changes implemented as needed (adaptive management). Periodic re-evaluation is also critical in terms of monitoring the effects of implemented plans to provide direct feedback into the adaptive management process.

5.0 A Proposed Decision Support System for Riparian Forest Management

In 2005, the RIPNET (RIParian Research and Management NETwork) research team initiated a project, funded by the Sustainable Forest Management Network, to develop a decision support system that could be applied to planning decisions pertaining to the harvesting and management of boreal riparian forests with a focus on a DSS for application within Ontario. The goals of this project were:

1) To provide an effective mechanism to help all parties find an agreeable balance between competing values for riparian use

2) To provide forest planners with the information necessary to make effective decisions regarding how shoreline forests should be managed at both stand-level and watershed scales

3) In the context of 1 and 2, to guide forest planners in selecting appropriate management options when harvesting is permitted in riparian areas.

The province of Ontario recently introduced a series of forest management guidelines (FMGs) to consolidate forest management directives into 5 guides that will constitute the foundation on which forest management planning in Ontario is developed in the future (OMNR 2006). Within the general forest guidelines, new, specific, guidelines for riparian management at the stand and site scale (SSG) have been developed (OMNR 2010). The philosophical foundation of Ontario's new approach to riparian management is founded on the ecological premise that some disturbance is natural and potentially beneficial, and may promote greater diversity (as per the intermediate disturbance hypothesis). This approach will increase the flexibility for forest industry to operate in riparian areas primarily to meet ecological objectives.

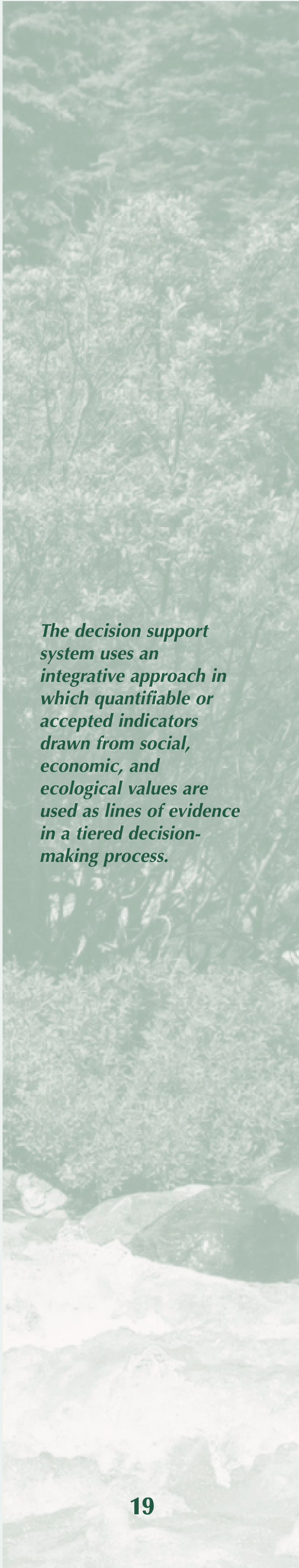
While there is increased provision under the SSG to operate in riparian areas, there may be situations in which socio-cultural considerations override this goal. In such cases, alternative directions for riparian management may need to be pursued as per the stipulations of appropriate socio-cultural and tourism-based guides. The SSG, in conjunction with the socio-cultural and tourism guides, was developed to provide clear guidance on what entities must be excluded from management activities, the limits of wood extraction, and how forest companies should operate in riparian areas. However, specific guidance regarding when, where and how much wood should be extracted from riparian areas, and how this can be achieved operationally in a safe and economic fashion, is still largely lacking. Many of these questions can be answered by consideration of the various ecological and socio-cultural restrictions and constraints (exclusions) associated with riparian areas. Many of these restrictions and exclusions are amenable for inclusion in a decision support system.

Below, we present a decision support system specifically designed for application in riparian management. The decision support system was developed to address several key questions related to harvesting in riparian areas:

1) Why should we consider harvesting in riparian areas?

2) If harvesting can be conducted, when and where should it occur?

3) How much wood can/should be harvested?



The decision support system uses an integrative approach in which quantifiable or accepted indicators drawn from social, economic, and ecological values are used as lines of evidence in a tiered decision-making process.

The decision support system uses an integrative approach in which quantifiable or accepted indicators drawn from social, economic, and ecological values are used as lines of evidence in a tiered decision-making process. Specific decision points are derived from decision trees/keys in which questions, related to a specific value or attribute, are posed. Due to the interest of our project partners to develop a DSS for application in Ontario, it would be inefficient to develop a decision support system different from, and potentially at odds with, Ontario's SSG. The decision support system for the RIPNET project was developed to accommodate the stipulations of these guidelines and incorporate decision points based on the information required by the Guide. While the decision support system was largely developed based on forest management and planning processes specific to Ontario, many elements of forest planning and management will be common across Canada. As such, aspects of the decision support system will be applicable to other forest regions across Canada. We recognize that our decision support system will not be suited in all respects to other regions of Canada. To address this, we also present generic versions (Figures 9, 11) of some of the various decision keys with the hope that they can be adapted for potential application in other regions of Canada that may be revising management policies for riparian areas.

Functionally, the framework employs a tiered approach, with decision points based on operational, economic, hydroecological, and socio-cultural lines of evidence (Figure 6). In total, there are four tiers:

1) Values and special features assessment;

2) Developing the lines of evidence (LOE);

3) Assessing the weight of evidence (risk characterization); and

4) Developing a harvesting plan.

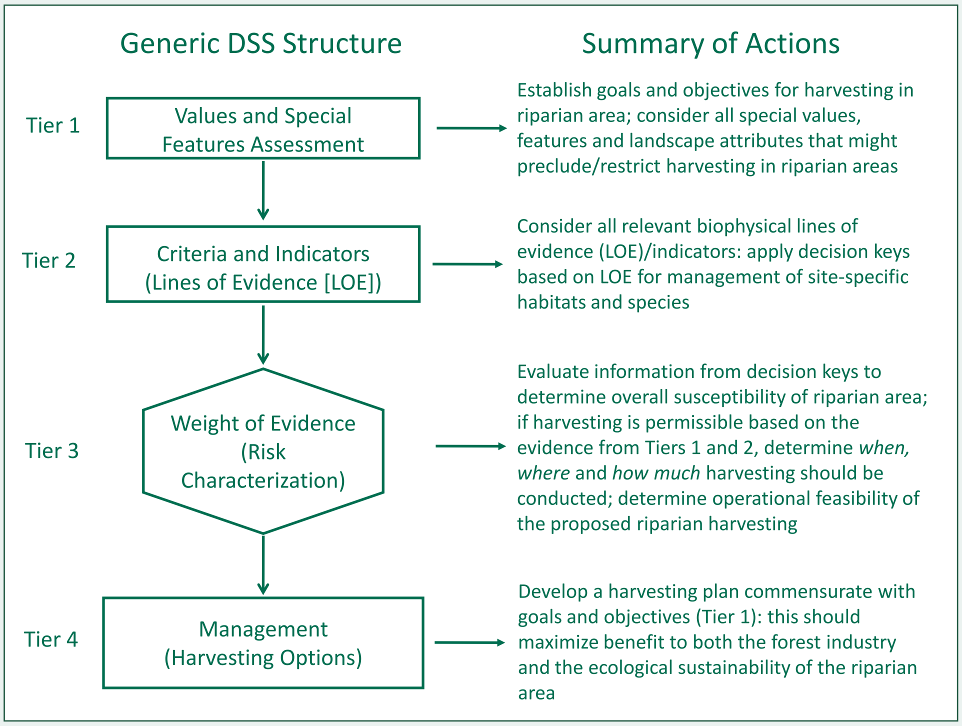


Figure 6. Generic structure for a riparian decision support system showing tiered approach and summary of actions at each tier.

5.1 Tier 1: Values and Special Features Assessment

Goals and Objectives

The first tier of the decision support system has two primary functions. First, it should constitute the point in the decision-making process in which the goals and objectives for harvesting in riparian areas is clearly established. For example, is the purpose of harvesting in a riparian area to create disturbance with the goal of enhancing habitat and species diversity, to increase access by the forest industry to the high quality wood that may occur there, or both? If the primary goal is to create disturbance and increase diversity, which, under the premise of emulating natural disturbance regimes is one of the objectives of the Ontario SSGs, it is possible that forest companies could be required to conduct harvesting in riparian areas regardless of the economic benefit to them. If the goal is to extract additional wood, the companies would have to determine the quality of that wood, its merchantability, and the cost of extracting it before deciding to harvest. In most cases, the decision to harvest will be a combination of a desire to create disturbance and extract wood, with the relative net economic benefit to the forest company being decided by the amount and quality of the wood based on the constraints imposed by the SSG or the topography of the landscape (affecting access to the wood).

Special Values

The second function of the first tier is to consider all special values, features and landscape attributes that might preclude or restrict harvesting in riparian areas (Figure 6 & 7). In forest planning, it is at this stage that the forest manager typically identifies the major socio-cultural, ecological, and economic exclusions that will either prevent or restrict harvesting in the riparian area. There are many potential critical values that would preclude or restrict harvesting in a riparian area. Socio-cultural values might include the presence of rare/endangered habitat and/or species, important heritage sites, traditional hunting/fishing/trapping areas for Aboriginal peoples, tourism, or the preservation of water bodies used as a source of drinking water. Decisions on socio-cultural values are not addressed directly in the decision support system and are referred instead to regional socio-cultural values guides (OMNR 2001b; 2007) that provide specific guidance on these important values. If such guides do not exist in other jurisdictions, the decision process should include an alternate mechanism.

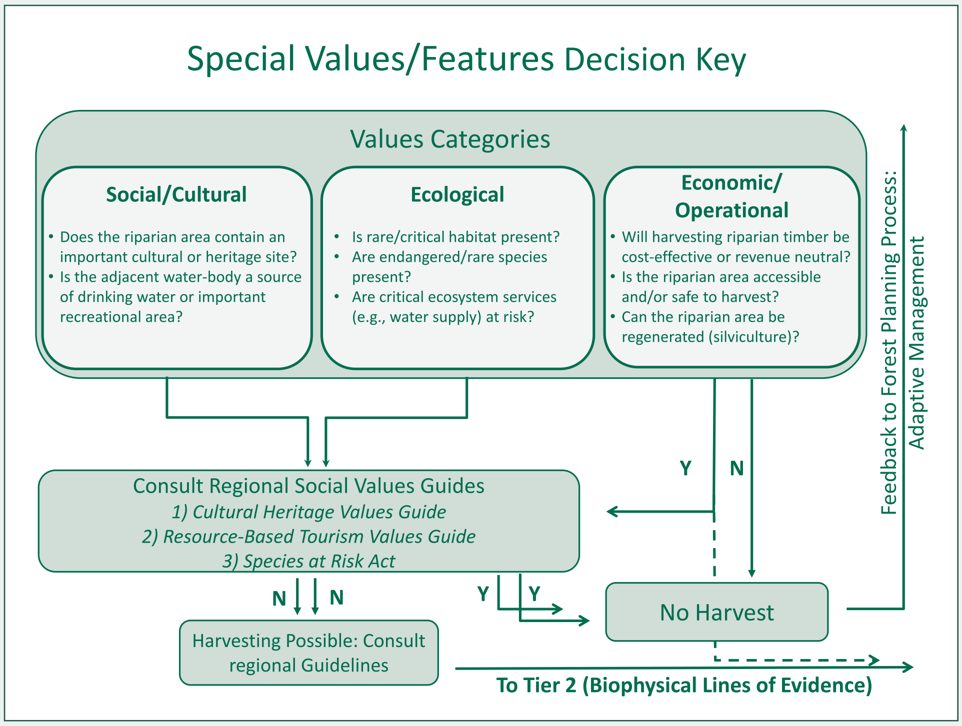


Figure 7. Tier 1 of the decision support system: Special socio-cultural, ecological, and economic/operational values and/or features that should be addressed at the beginning of the decision-making process when considering harvesting in riparian areas.

In some cases, the presence of important socio-cultural values may preclude any harvesting in a riparian area. This might be the case around small water bodies in which a high proportion of the riparian area is occupied by a potential socio-cultural exclusion. In other cases, the presence of important socio-cultural values may not preclude but might restrict riparian harvesting activity. This may occur

around larger water bodies in which the socio-cultural value occupies only a portion of the riparian area and would not be affected by operational activities in adjacent area(s). For example, a recognized Aboriginal heritage site may occur on one side of a lake or stream but not on the other. In this case, it might be possible to consider harvesting activity on the unaffected side pending additional assessments according to the considerations of the second tier of the decision support system.

Special hydroecological values/features are also identified in the first Tier (Figure 7). Here, the decision support system focuses on aspects such as critical or endangered habitat and wildlife populations. Thus, the presence of rare or endangered species and/or their habitat, as stipulated by the Species at Risk Act (2002), is considered as part of this early stage of the decision-making process. In the absence of such exclusions, or where these exclusions are spatially restricted and thus only eliminate a portion of the riparian area from harvesting, the user may proceed to the next tier of the decision support system to consider additional hydroecological LOE (see next section).

Economic factors that could influence harvesting decisions may also need to be considered during early tiers of the decision-making process (Figure 7). Key economic and safety factors to be considered are the amount and merchantability of timber in the riparian area, the cost of extracting and transporting the wood to the mill, and whether it can be harvested in a safe manner. In Ontario, under the SSG, forest companies are encouraged to harvest timber from riparian areas in order to meet the objective of creating ecological disturbance. In most cases, it will be most cost-effective for a forest company to harvest the riparian timber at the same time, and as part of, harvesting in adjacent upland areas of a cut-block. Returning to a riparian area after harvesting a main cutblock is not cost-effective. While most forest companies are willing to cooperate in meeting these disturbance objectives, depending on the amount of wood that is available in a riparian area once the various exclusions have been considered, it may be determined that harvesting is not cost-effective even when conducted in conjunction with planned harvesting in upland areas. In such cases, harvesting may not be conducted. However, if harvesting is feasible, both economically and in terms of accessibility and safety, forest companies should be encouraged to harvest within the riparian area.

A potentially useful area for future research would be to model the relationship between the relative size of a riparian area (defined as the area that would have been left on the landscape as a buffer using previous planning guidelines), the amount of merchantable wood, and the cost of harvesting the resource under various scenarios of imposed constraints (e.g., exclusions) and harvest designs. This might provide valuable information to forest companies with respect to possible economic thresholds below which harvesting in a riparian area would not be cost-effective.

Other questions, as dictated by regional or provincial planning processes, might also be pertinent during Tier 1 of the decision-making process in each of the values categories (the questions shown in Figure 7 should be considered as examples only). Within Tier 1, and indeed at all stages of the riparian decision support system, the forest planner should periodically review the management plan to ensure riparian strategies align with the established goals and objectives (the adaptive management feed-back loop in Figure 7). If there are no factors from Tier 1 that lead to a "no harvest" decision, or that identify areas that cannot be harvested after the exclusions are fully considered, the decision-making process proceeds to the second tier.

In instances where riparian harvest is constrained by various values, or wood that may be otherwise harvestable is not accessible, it may be useful to consider the riparian planning process in the context of the landscape-level planning process. For example, assuming wood volumes for riparian areas are included in a company's annual allowable cut, wood that is not accessible in the riparian area could be offset by increased wood taken from elsewhere in the cutblock. Conversely, it may be appropriate to consider leaving additional wood in upland areas to meet wildlife tree retention requirements, for instance, and harvest in the riparian area to contribute to allowable cut volumes.

5.2 Tier 2: Developing the Lines of Evidence

5.2.1 Establishing Areas of Concern (AOCs)

In Tier 2 of the decision support system, hydroecological indicators, based on various criteria, are used to develop lines of evidence (LOE) as the basis for decision-making and compiling weight-of-evidence (third tier of the decision support system) to evaluate the potential susceptibility of riparian areas to harvesting activity (Figure 8). Typically, LOE are derived from physical (e.g., slope/soil characteristics, size of lake basin, stream order, etc.) and biological indicators (e.g., type of fish habitat, type and extent of wetlands, etc.) but does not preclude consideration of biogeochemical indicators (e.g., potential export of solutes, elemental cycling).

In the decision support system, specific indicators are incorporated into a series of decision trees, each corresponding to a particular criterion. The user answers a series of yes/no or direct answer questions until a decision is reached (Figure 9). In practice, populating the framework with appropriate, prioritized LOE can be challenging due to insufficient information for some indicators. Effort should be made to develop a robust framework that is not "over-populated" as this may lead to an unwieldy and poorly functioning decision support system. In part, this may be addressed by prioritizing criteria and their indicators according to their perceived or known hydroecological significance.

Specific indicators are incorporated into a series of decision trees, each corresponding to a particular criterion. The user answers a series of yes/no or direct answer questions until a decision is reached.

Prioritization may be facilitated if it is known that protecting one value protects another by virtue of their interconnectedness (surrogate). An example of this surrogate function is slope, which is often used as a key indicator of the potential for impacts to aquatic systems due to erosion caused by harvesting activity. Decisions based on slope by default protect soil from erosion and may reduce the export of nutrients. In this case, it would not be necessary to measure an indicator such as nitrogen export (or other assessments of biogeochemical cycles) because it is assumed that these cycles would be maintained by ensuring the slope indicator is applied to the decision making process.

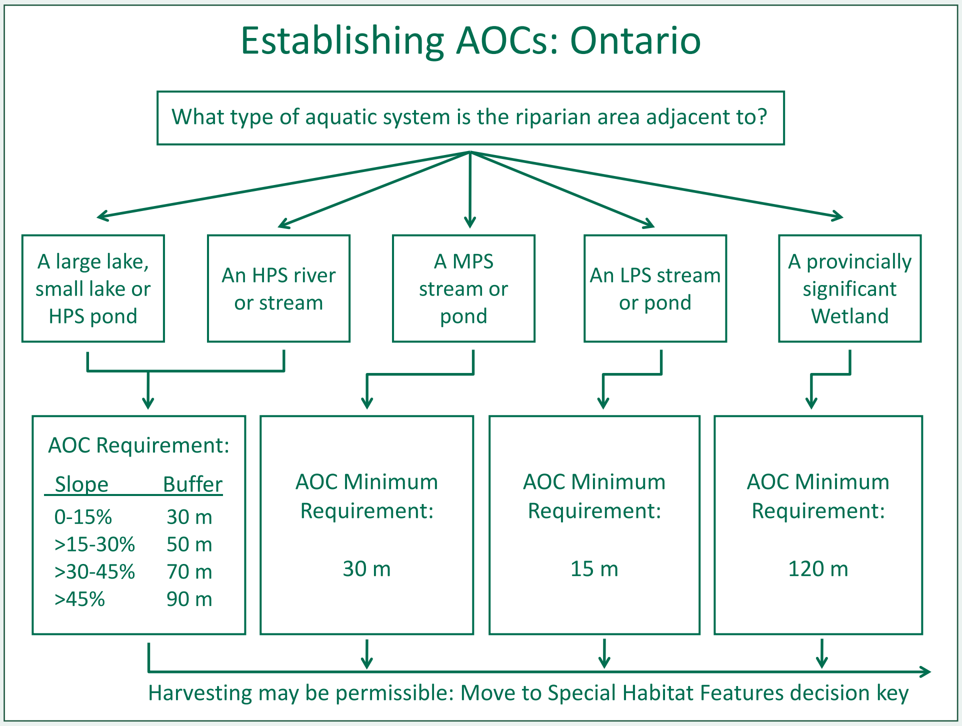


Figure 8. Tier 2: Developing lines of evidence. Decision key used in Ontario to establish areas of concern (AOCs) around water bodies using the concept of relative sensitivity (HPS/MPS/LPS = high/medium/low potential sensitivity, respectively).

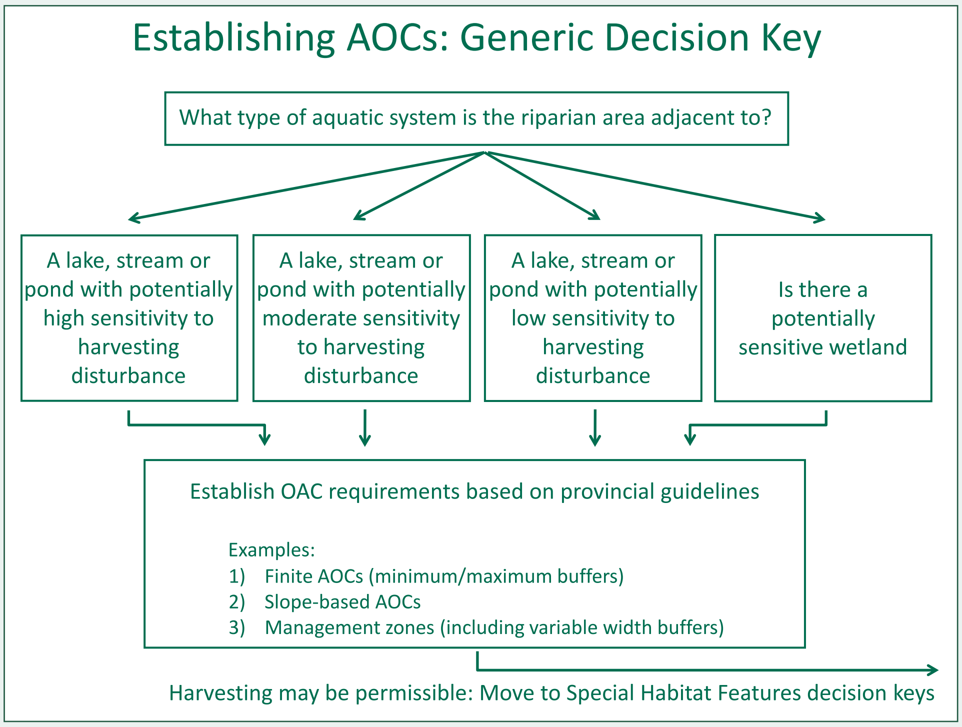


Figure 9. Generic decision key for establishing areas of concern (AOCs) around water bodies that could be applied in other provinces.

Ideally, information derived from traditional ecological knowledge (TEK) from Aboriginal people or others, would also be incorporated as one of the important LOE in the decision-making process; however, for various reasons (Stevenson 2009), this ostensibly collaborative approach has often failed. For this reason, no attempt has been made to incorporate TEK into the decision support system at this time. With growing recognition of the ethical imperative to include First Nations not as subjects but as partners in research and decision-making in forestry, it is hoped that this situation will change. In this context, the decision support system presented here is designed to be flexible and subject to change as the needs or demands of the forest industry grow with respect to riparian management.

Functionally, Tier 2 is comprised of a series of water bodies, habitat and species keys that follow the stipulations of the Ontario SSG (OMNR 2010). The SSG assumes that all water bodies represent important components of fish habitat; those that are deemed to have high or moderate potential sensitivity (see below) must be considered in the planning process through the establishment of AOCs. Thus, in the riparian decision support system, the initial decision key in Tier 2 allows the user to establish the type and size of an AOC around a water body based on the stipulations of the SSG. Ontario-based and generic decision keys for the process of selecting an AOC are presented in Figures 8 and 9, respectively. In Ontario, the establishment of AOCs is based on several criteria linked to the maintenance of suitable aquatic habitat and productivity (OMNR 2010) including:

- minimizing the risk of sedimentation,
- mitigating the effects of forest harvest on water temperature, circulation, and inputs of organic matter,
- ensuring future inputs of coarse woody debris,
- mitigating the effects of forest management operations on aquatic-terrestrial hydrological linkages,
- retention of shoreline forests as residual habitat and dispersal corridors, and
- the creation of some early succession riparian habitat.

The type and size of an AOC around a water body depends on the type and size of water body and its associated sensitivity. There are essentially three designations. Water bodies that have an open area >8 ha and which are >2 m in depth are classified as **lakes** (large lakes have an open area > 100 ha; small lakes have an open area >8<100 ha). Water bodies that have an open area that is >0.5 ha and <8 ha, which are <2m in depth, and have ≤25% of their surface area covered by emergent vegetation are classified as **ponds**. Water bodies that are <0.5 ha are classified as either streams or wetlands depending on the system with which they are associated. Flowing systems are similarly categorized according to size. **Rivers** are defined as any permanent flowing water body that drains a catchment area >50 km^2. **Streams** are defined as either permanent or temporary flowing water bodies that drain catchment areas <50 km^2.

The type and size of the Area of Concern around a water body depends on the type and size of water body and its associated sensitivity.

Figures 8 and 9, the specific and generic keys, respectively, present an approach to establish AOCs. Both pose the initial question "what type of aquatic system is adjacent to the riparian area?" Figure 8 illustrates the approach used in Ontario for establishing AOCs and the approach used in the decision support system. Here, water bodies are designated as having high, moderate or low potential sensitivity to disturbance. All lakes and rivers are considered to have high potential sensitivity (HPS) under the Ontario SSG. Ponds and streams can be classified as having high, moderate (MPS) or low potential sensitivity (LPS) depending on the known characteristics of the water body (Table 1), with the size and characteristics of the AOC commensurate with the designation (Figure 8).

Wetlands are not classified in terms of their relative sensitivity but, rather, as:

1) provincially significant wetlands, as determined by the Ontario wetland evaluation system (http://www.mnr.gov.on.ca);

2) rich lowland hardwood-dominated forest, characterized by mapped stand of rich lowland forest (e.g., black ash, green ash, silver maple, white elm, etc) or pockets of such forest that are ≥0.5 ha in size that are encountered during operations;

3) mapped, permanent non-forested wetlands such as open wetlands, treed wetlands, and brush and alder wetlands where the boundary between forested wetlands and forest is defined as the canopy cover of trees ≥10 cm diameter at breast height is ≥25% or the canopy cover of trees ≥1.5m tall is ≥30%; and

4) woodland ponds, which are recognized temporary bodies of open water encountered during operations that have surface areas of ≥500 m2, are not ponds, and are not connected to a stream or associated with a mapped non-forest wetland.

Once the type of aquatic system has been identified, and its relative sensitivity determined, the decision key guides the user to the type of prescription that is appropriate given the classification of the water body (Figure 8). For example, for high potential sensitivity lakes, ponds, and streams, the size of the AOC is based on the slope of the adjacent hill slopes, with prescriptions ranging from 30 m for slopes of 0-15% and 90 m for slopes >45%. In general, the size of the AOC declines with decreasing sensitivity of the water body. For example, the minimum AOC for a moderate potential sensitivity pond is 30 m while the minimum AOC for a low potential sensitivity pond is 15 m. The minimum AOC for a provincially recognized wetland is 120 m; for wetlands that are not deemed to be provincially significant, harvesting direction defaults to conditions stipulated by regular operations as stated in the SSG. AOCs may also be designated for groundwater recharge areas if they are associated with brook trout spawning sites. In such cases, regular operations, as stipulated in the SSG, are followed. It must be kept in mind that these are minimum prescriptions and larger AOCs can be established.

Figure 9 is a modified, generic decision key for establishing AOCs that could be adapted for use in other regions of Canada. In this generic version, the user is asked the same initial questions regarding the type of aquatic system that is adjacent to the riparian area and its known or perceived relative sensitivity. The actions that are taken thereafter will depend on the provincial guidelines and policies that are stipulated as part of the forest planning process. In most cases, the establishment of AOCs for the protection of aquatic systems will include one or more of absolute buffers (minimum buffer independent of slope), slope-based buffers, or management zones that allow limited harvesting outside a minimum "no disturbance" buffer or limited and directed harvesting within the AOC as in Ontario. The specific details used in Ontario need not necessarily be applied in other regions (other criteria/indicators may be more relevant). The idea of classifying systems according to their potential sensitivity to disturbance can be rationalized in the context of ecological principles (e.g., intermediate disturbance regimes) and is, therefore, a reasonable approach when the appropriate information is available.

5.2.2 Habitat and Species Feature Key

Once the AOCs have been established for the riparian areas under consideration in the forest management unit, the decision-making process is then directed toward special habitat and species features (Figure 10). Because the decision support system focuses on riparian areas, the special habitat features decision key similarly focuses on species that inhabit riparian areas and which directly depend on the adjacent aquatic system resources. However, species that do not depend directly on the aquatic systems but which may inhabit riparian areas (e.g., stick-nesting raptors such as owls and hawks) must also be considered during the riparian management planning process.

The special habitat features decision key focuses on species that inhabit riparian areas and which directly depend on the adjacent aquatic system resources.

In the special habitat features key, the initial question is posed: "Are there defined species habitat requirement areas in the riparian area?" If the answer to this question is "no," then the planning process can move on to the next decision key. If the answer to this question is "yes," the user is then directed to a series of "species boxes" which identify the key species that inhabit riparian areas that exhibit direct dependence on the adjacent aquatic system and the sections in the Ontario SSG that provide management guidance for those species. Here, the minimum size of buffer or main operational constraints are provided for each species within each organism class. Specific and detailed guidance on operational constraints are provided in the various sections of the SSG as shown in the boxes. At any point in the planning process, it may be useful to consider decisions in the context of the broader planning process. In Ontario, for example, a fine (stand-level) and coarse (landscape-level) filter approach is used in the forest planning process; consideration of any decision at the stand level should be made with due consideration of landscape level special habitat/features (and other) objectives.

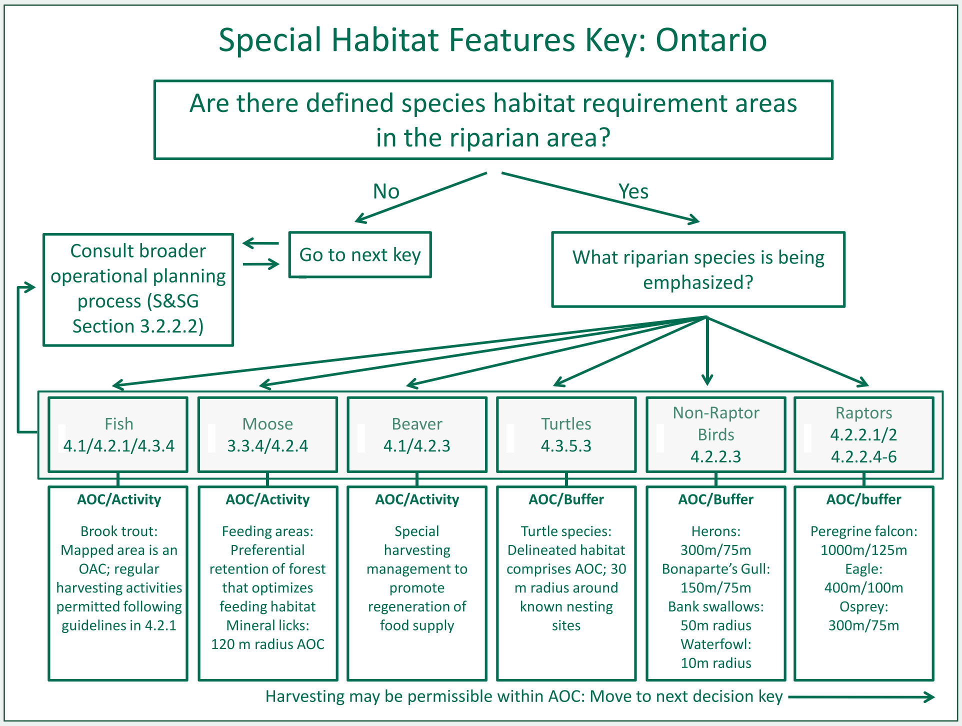


Figure 10. Special habitat features key depicting the decision process and associated guidance used to determine protection for riparian species dependent on aquatic habitats. Adapted from the Ontario Ministry of Natural Resources *Forest management guide for the conservation of biodiversity at the stand and site scales* (OMNR 2010).

The special habitat features key identifies six classes of organisms for which guidance is provided under the SSG for Ontario: fish, moose, beaver, turtles, non-raptorial birds, and raptors (Figure 10). The SSG also provides direction for many other species and their habitat but they are not considered here as part of the riparian decision support system because they are not directly associated with riparian habitat or their adjacent aquatic systems.

Specific provisions for fish habitat under the SSG are given for several rare or endangered species and for brook trout. For the latter, the AOC is the delineated (mapped) area that comprises the groundwater recharge area. While regular harvest, regeneration and silviculture operations are permitted within the AOC, guidance focuses on mitigating operational activities that may disrupt groundwater flow patterns associated with the spawning habitat.

The SSG contains specific coarse and fine filter provisions for moose habitat. Moose are frequently associated with aquatic habitats and associated riparian areas. Aquatic habitats (such as shallow lakes, ponds, and slow-moving streams that contain submerged and floating vegetation) are commonly used by moose as feeding areas. Riparian areas are used as a place to obtain browse, especially during winter, but also as a place to ruminate, thermoregulate during the summer, escape pestiferous insects, seek shelter, and to calve (Lohman 2004). Protective direction under the SSG focuses on moose aquatic feeding habitat including mineral licks, which occur as mineral-rich springs (Risenhover and Peterson 1986). For moose aquatic feedings areas, guidance focuses on the preferential retention of residual forest that optimizes feeding habitat as described above. Areas known to contain mineral licks are buffered by a 120 m radius AOC in which no forest operations are allowed.

Specific provisions for beaver habitat are provided in the SSG. Among mammals, few species have a greater influence on riparian and aquatic habitat structure and function than beaver (Lohman 2004). In this context, they represent a keystone species and are considered to be ecosystem engineers to the extent that their disturbance activities can lead to increased biodiversity among both plants and animals. Beavers require and feed on a wide range of herbaceous and woody vegetation and much of this is often associated with the early stages of vegetation succession following some form of disturbance. Perhaps more than any other species associated with riparian habitats, beaver typically benefit from periodic disturbance that promotes growth of the food stock required to fuel summer activities and for winter storage. Direction in the SSG therefore focuses on riparian harvest practices that promote and maximize regeneration of beaver food supply, most notably early succession aspen, as long as these objectives are consistent with other ecological objectives.

Specific provisions for turtle habitat are provided in the SSG and focus on several species that are either rare or endangered. In general, these species only occur in the Great Lakes St. Lawrence Lowlands region and therefore may not be relevant in terms of boreal riparian forest management. Direction under the SSG varies somewhat between species but in general requires that the delineated habitat comprises the AOC and that a 30 m radius be established around known nesting sites in which no harvesting is allowed.

Specific provisions for non-raptor birds (e.g., herons, waterfowl, Bonaparte's gull, bank swallows, and black tern) associated with riparian areas and wetlands are also given in the SSG. Direction varies according to species requirements. For herons, an AOC of 300 m must be established around nesting sites (rookeries) and no harvesting is permitted within 75 m of the nesting sites. Harvesting is permitted in the remainder of the AOC according to the directions stipulated in the guide. For Bonaparte's gull nests, an AOC of 150 m radius must be established and no harvesting activity is permitted within 75 m of the nest site. Harvesting is permitted in the remainder of the AOC according to the directions stipulated in the guide. For bank swallow colonies, an AOC of 50 m, measured from peripheral nests of colonies occupied by $\geq$100 pairs, must be established and harvesting is permitted within 10, 25 or 50 m depending on whether there is low, moderate, or high potential for impact and only during periods that do not coincide with the critical breeding period. For waterfowl, active nests (e.g., those containing eggs or young) that are encountered during operations will receive a 10 m AOC in which no harvesting can take place.

Table 1. Characteristics of lakes, ponds, and streams associated with riparian areas that are used to determine their relative sensitivity under the Ontario Stand and Site Guide (OMNR 2010).

Type of Water Body	Sensitivity Designation		
	High Potential Sensitivity (HPS)	Moderate Potential Sensitivity (MPS)	Low Potential Sensitivity (LPS)
Lakes	• All lakes are designated as HPS		
Ponds	• Containing fish species that are highly sensitive to perturbations (e.g., brook trout) • Providing components of fish habitat for which there is a high degree of species dependence • Containing rare habitats of fish species at risk • That have low habitat resiliency • Identified as having significant habitat by fisheries management zone advisory councils or specific management plans	• Containing fish species that are moderately resilient to perturbations (e.g., pike, walleye) • Providing components of fish habitat for which there is a moderate degree of species dependence • Containing habitats or fish that have limited distribution • Possessing moderate habitat resiliency	• Any pond that does not meet the HPS or MPS criteria
Rivers	• All rivers are designated as HPS		
Streams	• With segments containing fish species that are highly sensitive to perturbations (e.g., brook trout) • With segment known to provide components of fish habitat for which there is a high degree of species dependence • With segments with low habitat resiliency • Identified as having significant habitat by fisheries management zone advisory councils or specific management plans	• With segments that contain fish species that are moderately resilient to perturbations (e.g., pike, walleye) • With segments that provide components of fish habitat for which there is a moderate degree of species dependence • With segments containing habitats or fish that have limited distribution • With segments that contain moderate habitat resiliency	• Any stream that does not meet the HPS or MPS criteria

Specific provisions for raptors (e.g., bald eagles, ospreys, peregrine falcons) associated with riparian areas are provided in the SSG. For peregrine falcons, nest sites are typically established on cliffs and this species shows high site fidelity. For this species, an AOC of 1000 m must be established, centered on the ledge that is or has previously been occupied. Harvesting is not permitted within 125 m of the front or back of the cliff ledge; regular harvest is permitted within the remainder of the AOC only during periods that do not coincide with the critical breeding period. For bald eagles, an AOC of 400 m must be established around primary nests that are occupied or have been occupied during the past five years. Harvesting is not permitted within 100 m of the nest; harvesting in the remainder of the AOC is subject to a series of constraints related to canopy closure and residual stand structure. No harvesting is allowed within 400 m during the critical breeding period. For osprey, an AOC of 300 m must be established around primary nests that are occupied or have been occupied during the past five years and no harvesting is permitted within 75 m of the nest. Harvesting in the remainder of the AOC is subject to a series of constraints related to canopy closure and residual stand structure. No harvesting is permitted in the 300 m AOC during the critical breeding period.

It is important to note that the stipulations described above for each species group are not exhaustive and additional guidance is provided in the SSG. It must also be kept in mind that the special habitat features key presented in Figure 10 is specific to Ontario. However, a similar approach and structure could be readily adapted to other provinces. While some of the species of interest shown in Figure 10 would be relevant to other regions of Canada, others species, unique to those regions, would need to be considered and the appropriate guidance developed. Whether the species are the same or different, specific provisions for harvest restrictions in the AOCs would undoubtedly need to be considered in light of the different biogeophysical characteristics and stakeholder interests within a given region.

The key presented in Figure 10 is readily adaptable to other provinces and we present a generic version of the special habitat features key in for this purpose (Figure 11). In this key, the user is asked the same initial question as shown in Figure 10, with the same decision option outcome. In the event that there are no species-specific habitat features that need to be addressed, the user is directed to the next step in the decision support system (either a key or the next tier, depending on how the decision support system is modified for use in a particular region). If important species-specific habitats exist in an area, the user then follows the series of species-specific boxes (presented as generic organism groups in Figure 11) that will lead to the appropriate guidance, if available, for that species.

It will be necessary to include keys that provide guidance on specific regional attributes of concern, or which reflect different provincial/regional philosophies on riparian forest management. In the decision support system presented here, we have opted not to include specific soil or water quality keys since the SSG for Ontario protects these entities through the establishment of AOCs and detailed direction regarding both ecological requirements (e.g., retention of wood as a source of coarse woody debris, percent canopy closure, vegetative species

It will be necessary to include keys that provide guidance on specific regional attributes of concern, or which reflect different provincial/ regional philosophies on riparian forest management.

composition, etc.) and operational requirements (e.g., guidance on rutting, road construction, river crossings, etc.) within the AOCs. The province of Manitoba recently introduced a framework for managing forest operations in riparian areas that included specific decision keys for soil and water quality (Manitoba Conservation 2008). Manitoba also incorporated several wildlife keys based on provincially recognized ecozones that serve the same function as the single wildlife key in the decision support system presented here.

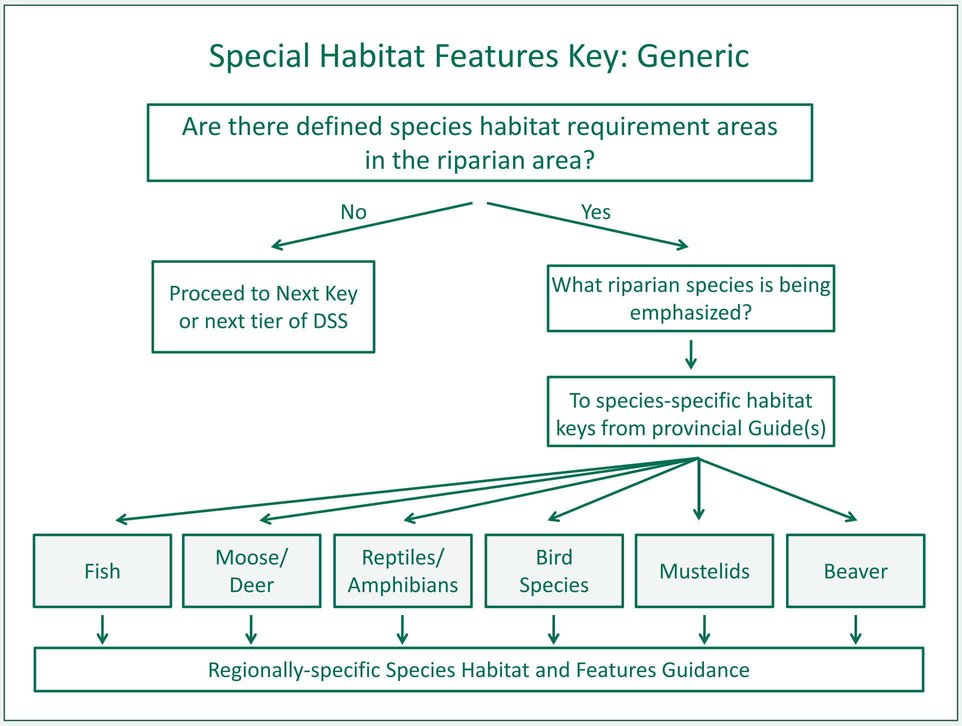


Figure 11. Generic decision key for special habitat features. The species-specific composition of the key will depend on provincially designated species of interest or those known to be rare or endangered. An example key is provided in Figure 10 for Ontario.

5.3 Tier 3: Developing a Weight-of-Evidence

In Tier 3 all lines of evidence are integrated to characterize the overall risk that management may pose to a riparian area.

Once all available LOE have been collected, the decision support system proceeds to the weight-of-evidence stage where risk is characterized (Figure 12). In this stage, all LOE are integrated to characterize the overall risk that harvesting may pose to a riparian area. It is also the first stage in which decisions about where and when harvesting could occur in the riparian area and how much wood can be removed are made. At this critical tier of the decision-making process the forest planner, ideally in consultation with all parties potentially affected by the decisions (e.g., government, Aboriginal peoples, industry, NGO's), must determine the susceptibility of the riparian area and advocate an appropriate course of action with respect to potential harvesting (e.g., develop a harvest plan). In Tier 3 sources of uncertainty are evaluated by examining all information from the previous tiers of the decision support system along with any information that may not have been available in developing the LOE. All of the questions posed to this point, along with the guidance offered in the harvesting limits key (Figure 13), should be considered in the context of the broader forest planning process (shown as the feedback loop in Figure 12).

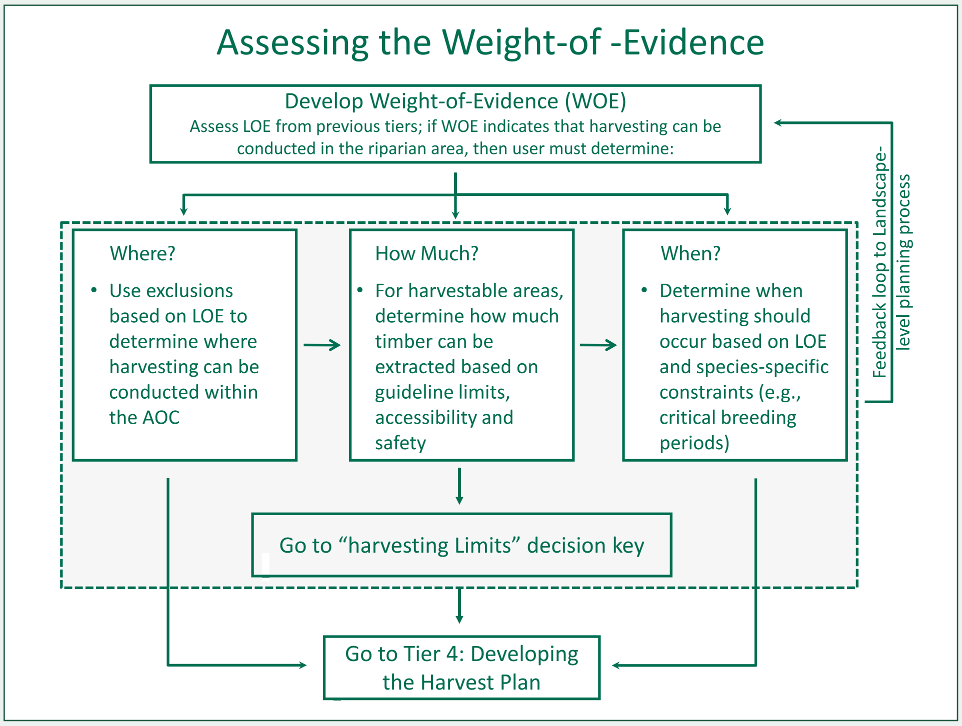


Figure 12. Decision key for determining where and how much harvesting should take place and when harvesting should occur. Additional guidance on how much timber to harvest is provided in the "harvesting limits" key (Figure 13).

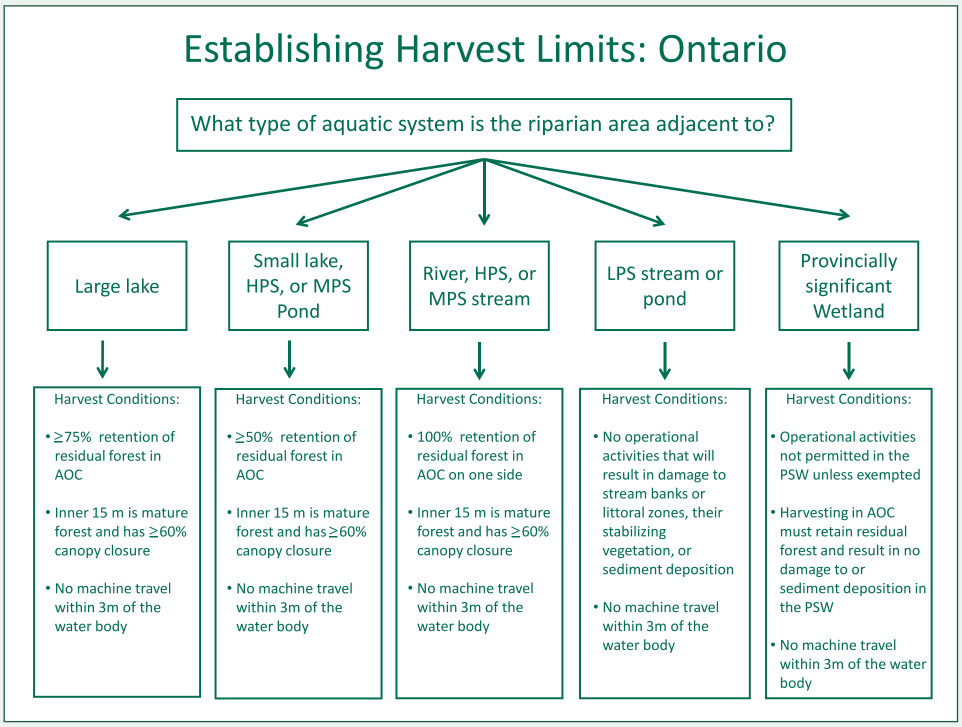


Figure 13. Harvesting limits within AOCs associated with various types of aquatic systems as stipulated under the Ontario Stand and Site Guide (OMNR 2008).

Decisions about where harvesting can occur in the riparian area will be based on those areas that were not excluded in the first two tiers of the decision support system. Once the harvestable areas within a riparian forest have been identified, the user is then asked to determine how much wood can be extracted from those areas. In part, this will be constrained by the maximum limits of allowable harvest set out in the harvest limits key (Figure 13).

The harvest limits key specifies the maximum allowable harvest that can occur within a riparian AOC based on the type of water body with which it is associated.

The harvest limits key specifies the maximum allowable harvest that can occur within a riparian AOC based on the type of water body with which it is associated. Areas around higher sensitivity water bodies contain a lower total proportion of riparian forest within an AOC that can be harvested. Based on the Ontario SSG, for large lakes there must be >75% retention of residual forest in the AOC. For rivers and streams with high or moderate potential sensitivity, there must be 100% retention of timber in the AOC on one side of the water body. For small lakes, ponds with high or moderate potential sensitivity, >50% of residual riparian timber must be retained. For streams and ponds with low potential sensitivity, no operational activity is allowed that will result in damage to stream banks or littoral zones, or their stabilizing vegetation. For large/small lakes, high or moderate potential sensitivity ponds, and rivers and high or moderate potential sensitivity streams, the inner 15 m of the AOC must retain sufficient mature forest to provide >60% canopy closure. In all cases, no machine travel is allowed within 3 m of the water body.

The timing of harvest may also need to be addressed. Considerations in this context include:

- critical breeding periods for feature species that may be present;
- operational considerations (such as machine access during certain times of the year); and
- socio-cultural events (such as spiritual ceremonies, rafting seasons).

At all times during the planning process, it is important to review decisions made in relation to riparian forest management in the context of the decision-making process at the landscape level. One aspect that a forest planner may need to consider is how best to distribute wood on the landscape (the "woodshed"). In the context of the riparian area, harvesting will be limited to those areas identified based on the above constraints. In cases where maximum allowable cuts in a cutblock can be achieved, and harvesting is permissible in riparian areas, it may be necessary to develop a harvest plan that considers riparian wood as part of the total allowable cut. Given that historical forest management plans were based on developing total allowable cuts from wood available outside of riparian areas, this may mean that wood extracted from a riparian area may have to be off-set by increased wood left elsewhere on the landscape. Regardless of the allocation of wood across the landscape, it is likely that the relative importance of the different

LOE will vary in accordance with the unique characteristics of a region (or specific riparian area). In this respect, the decision making process in Tier 3 might be facilitated by prioritizing different LOE by ranking or weighting, an approach that should ideally be completed through consultation with stakeholders.

5.4 Tier 4: Harvesting Plan Development

In Tier 4 the focus is on operational considerations and riparian management options, commensurate with the characterized state of the riparian area and consensus among participating parties.

Once Tier 3 has been completed and decisions have been made with respect to when, where, and how much harvesting is allowed in a riparian area, the decision support system moves to the final tier which focuses on the development of a harvesting plan (Figure 14). At this point in the decision-making process, the focus is largely on operational considerations and riparian management options, commensurate with the characterized state of the riparian area and consensus among participating parties. The combination of where the exclusions occur in the riparian area and the physiography of the landscape (which may dictate accessibility), will ultimately determine where harvesting can occur within a riparian area.

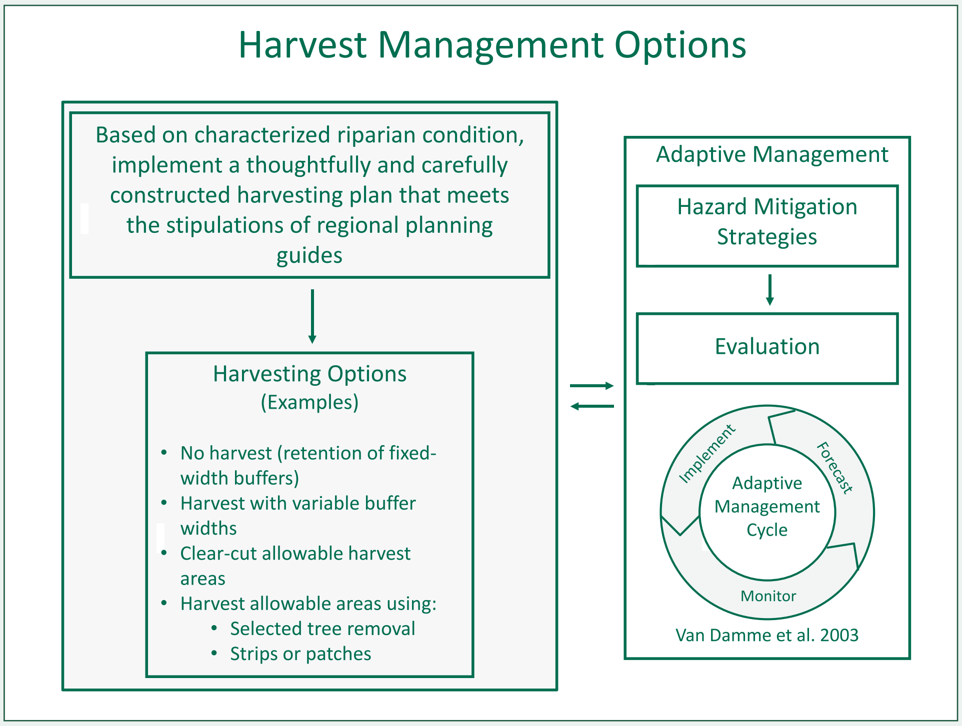


Figure 14. Schematic illustrating various harvesting management options (not inclusive) that may be incorporated into a harvest plan. The harvest plan should be developed using an adaptive management approach in which hazard mitigation strategies are delineated, decions are periodically re-evaluated based on monitoring, and changes implemented as required for future harvest scenarios.

In Tier 4 the user determines the type of harvest to be implemented. Numerous potential harvesting options could be employed. For example, in some jurisdictions, application of the standard approach of a fixed-width buffer may be viewed as the simplest and best mitigation option. However, if the objective is to create disturbance for the purpose of enhancing biodiversity, the standard buffer approach may not be sufficient. Other options might include:

- the use of variable-width buffers, with greater buffer widths around potentially sensitive areas;
- selective, patch or strip harvesting in machine-accessible areas; or
- “reach and grab” harvesting in areas that are not accessible by machine.

Guidance is needed to ensure that operational practices minimize soil and site disturbance in riparian areas where harvesting is permitted. However, minimizing the degree of legislated prescriptiveness in terms of how harvesting is conducted would leave greater decision-making power in the hands of operators. This could encourage a greater degree of creativity on the ground that would acheive the goal of creating ecological disturbance while minimizing the level of mechanical disturbance. Detailed guidance for Ontario is provided in the SSG (OMNR 2010) and other documents (e.g., Mattson *et al.* 2000).

Plans should be periodically evaluated based on information generated through monitoring so that changes can be implemented as required for future riparian harvest scenarios.

Ideally, the harvest plan will be developed and implemented using an adaptive management approach. From an operations standpoint, it is important to identify all potential hazards so they can be avoided or mitigated through the implementation of hazard mitigation strategies. Decisions should be periodically evaluated based on information generated through monitoring so that changes can be implemented as required for future riparian harvest scenarios.

6.0 Conclusions

With increased understanding of the importance of, and relationships between, the multiple values of riparian areas, and the greater emphasis being placed on landscape-level approaches, there has been growing interest in developing integrative approaches to forest management. In this report, we have discussed the importance of riparian areas on the landscape from a socio-cultural, ecological, and economic perspective; provided some perspective on the relative importance and applicability of various criteria and indicators (lines of evidence) for each of the values categories as part of the forest planning process; and, finally, presented a preliminary decision support system for riparian forests. The decision support system can serve as a basis for decision making that will allow forest managers and planners to determine when, where and how much to harvest. The decision support system was developed within an Ontario forest management context, but it is flexible and can be adapted as appropriate to other regions of Canada.

Future areas of riparian (and general forest) research include:

1. Enhance our understanding of riparian processes,
2. Further our understanding of appropriate criteria and indicators (including surrogates),
3. Increase our ability to integrate traditional ecological knowledge into the various decision keys, and
4. Increase our ability to compare different values.

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