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BRIDGES

Merging END concepts with protection of fish habitat and water quality in new direction for riparian forests in Ontario: a case study of science guiding policy and practice

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Abstract. The Crown Forest Sustainability Act stipulates that Ontario's public forests be managed to conserve biological diversity and long-term health by following an emulation of natural disturbance (END) paradigm. Upland forests have been managed following an evolving END approach since the mid-1990s, but operations have been largely excluded from riparian forests. The new Forest Management Guide for Conserving Biodiversity at the Stand and Site Scales attempted to integrate the protection of fish habitat and water quality with the desire to emulate natural disturbance patterns in riparian forests to create a diversity of habitats to support a broad range of riparian plants and animals. Where wildfire is the dominant agent of disturbance, it encourages thoughtfully planned and carefully implemented clearcutting within riparian forest. We provide some examples of how science-based knowledge was used to develop direction to achieve these objectives.

Key words: emulation of natural disturbance, forest management policy, riparian forests, Ontario.

The Crown Forest Sustainability Act (1994) stipulates that the public forests of Ontario be managed to conserve biological diversity and long-term health by following an emulation of natural disturbance (END) paradigm while minimizing adverse effects on a variety of ecosystem goods and services including fish and water. The END approach used in Ontario has been evolving since the mid-1990s. It focuses on providing a diversity of ecosystem conditions at a variety of spatial and temporal scales to meet the habitat needs of a broad range of plants and animals (e.g., OMNR 1998a, 2001a, 2010a). However, operations within riparian forests generally have been discouraged, ostensibly to protect fish habitat and

water quality (see OMNR 1988). This practice has created relatively unnatural ribbons and donuts of residual riparian forest adjacent to water features (Buttle 2002, Kreuzweiser et al. 2012).

Planning and implementation of forest management operations on public lands are directed by standards, guidelines, and best management practices (collectively referred to hereafter as *direction*) prescribed in a suite of forest management guides developed by the Ontario Ministry of Natural Resources (OMNR). All direction associated with biodiversity conservation was reviewed recently to ensure it reflected the latest science-based knowledge and would meet OMNR's objectives effectively and efficiently. The review (OMNR 2010b) suggested that direction for riparian areas was often more restrictive than necessary to protect water quality and fish habitat. Moreover, conservative application of past direction was not creating the diversity of ecosystem conditions that

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natural disturbances historically produced in riparian areas. A growing concern was that this failure might adversely affect plants or animals that use riparian forests, especially the American beaver (*Castor canadensis*), a keystone species (Quinn 2004).

Consequently, direction in the Forest Management Guide for Conserving Biodiversity at the Stand and Site Scales (Stand and Site Guide) (OMNR 2010a) was developed to integrate protection of fish habitat and water quality with the desire to emulate natural disturbance patterns in riparian forests to create a diversity of habitats that could support a broad range of riparian plants and animals. Direction was based on a thorough review of existing literature, and discussions with and review by ecological researchers, practitioners, policy makers, stakeholders, and members of the public to ensure that direction would be effective in meeting ecological objectives, while also being feasible to implement and socially palatable. The conclusion of the review was that riparian forests could be managed to achieve a range of ecological objectives without compromising fish habitat or water quality if operations were thoughtfully planned and carefully implemented.

Below we provide some examples of how science-based knowledge was used to develop direction to achieve these objectives. We acknowledge that riparian forests are subject to a variety of disturbance types (Moore and Richardson 2012). However, we focus here on emulation of wildfire because it is the dominant agent of disturbance across most of the province. Some of the discussion (e.g., that addressing careful implementation) applies equally to operations within riparian forests intended to emulate other types of disturbance.

We present this example as a case study that illustrates one approach to incorporating END concepts into riparian forest management. We hope that some components of our approach might be applicable in other jurisdictions in North America.

Thoughtfully Planned

Disturbance of riparian forests must be thoughtfully planned because some operations may be incompatible with other ecological, social, or cultural objectives (sensu Sibley et al. 2012). In Ontario, consideration of special wildlife habitats (OMNR 2010a), resource-based tourism (OMNR 2001b), and cultural heritage (OMNR 2007) normally limits opportunities for disturbance of riparian forest. Moreover, operations in riparian forests can be conducted only where fish habitat and water quality will not be adversely affected because the Fisheries Act (1985) prohibits harmful alteration, disruption, or destruction of fish habitat. All

standing and flowing waters contribute to the productive capacity of fish habitat and, thus, are addressed in the Stand and Site Guide. However, the guide adopted a risk-management approach that required us to identify the relative sensitivity of water features to forest management operations and when forest cover adjacent to water is necessary to maintain ecological functions of aquatic systems.

How should potential sensitivity of water features be defined?

Past direction (OMNR 1988) recognized that warm- or cool-water systems usually were less sensitive to disturbance than were cold-water systems. The Stand and Site Guide adopted a framework (Table 1) similar to that proposed by Fisheries and Oceans Canada (DFO 2007). When inventory data are available for individual water features, potential sensitivity (high [HPS], moderate [MPS], or low [LPS]) is defined based largely on the criteria in DFO (2007).

When inventory data are not available, potential sensitivity is estimated using relatively simple measurable criteria based on factors influencing the spatial distribution of sensitive fish species (Table 1). For example, catchment area was used because it is easily modeled, tends to be correlated with stream size, and has a strong influence on fish assemblages (Zorn et al. 2002, Wang et al. 2003). A threshold of 3 km² was selected because brook trout (*Salvelinus fontinalis*) generally have a low likelihood of occupying streams (and associated beaver ponds) if up-stream catchment area is <3 km² (Parker 2006, R. Mackereth, OMNR, unpublished data). A 500-m distance criterion was used because brook trout can travel >500 m up small streams that are connected to water features that support brook trout (Curry et al. 1997, Borwick et al. 2006, R. Mackereth, OMNR, unpublished data). Information on brook trout was used to define thresholds because this species has high socioeconomic importance and generally is considered a sensitive indicator of changes in water temperature, water quality, and groundwater inputs.

When is forest cover adjacent to water necessary to maintain ecological functions?

Wildfires frequently burn to the edge of streams (Landstrom 2003, Lee and Smyth 2003, Nitschke 2005). However, removal of riparian forest may adversely affect thermal regime (see reviews in Steedman and Morash 2001, Steedman et al. 2004), inputs of fine organic matter (Webster and Waide 1982, Webster et al. 1990, Hartman et al. 1996), and recruitment of coarse woody material (Dolloff and

TABLE 1. Classification of water features based on potential sensitivity to forest management operations in Ontario. HPS = high potential sensitivity, MPS = moderate potential sensitivity, LPS = low potential sensitivity.

Sensitivity class	Water feature	Criteria
HPS	Lakes ^a Ponds ^b	<p>All</p> <p>When inventory data are available, HPS ponds are those with ≥ 1 of the following characteristics:</p> <ul style="list-style-type: none"> • Ponds known to contain fish species that are highly sensitive to perturbations (e.g., brook trout, <i>Salvelinus fontinalis</i>) • Ponds known to provide components of fish habitat for which there is a high degree of species' dependence • Ponds known to contain rare habitats or fish that are species at risk • Ponds with low habitat resiliency • Ponds identified as significant habitat by specific fisheries management plans <p>When inventory data are not available, HPS ponds are those with the following characteristics:</p> <ul style="list-style-type: none"> • Mapped or unmapped open water features ($\leq 25\%$ of surface area covered by emergent vegetation) encountered during operations that are ≥ 0.5 and < 8 ha in size and are connected to ≥ 1 HPS streams (see below)
	Rivers ^c Streams	<p>All</p> <p>When inventory data are available, HPS streams are those with ≥ 1 of the following characteristics:</p> <ul style="list-style-type: none"> • Stream segments known to contain fish species that are highly sensitive to perturbations (e.g., brook trout) • Stream segments known to provide components of fish habitat for which there is a high degree of species' dependence • Stream segments known to contain rare habitats or fish that are species at risk • Stream segments with low habitat resiliency • Stream segments identified as significant habitat by specific fisheries management plans <p>When inventory data are not available, HPS streams are those with 1 of the following characteristics:</p> <ul style="list-style-type: none"> • Mapped large permanent stream segments (catchment area ≥ 3 and < 50 km²) • Mapped small permanent stream segments (catchment area < 3 km²) < 500 m (stream distance) from lakes, rivers, mapped large permanent stream segments, or other water features identified as HPS based on inventory data • Recognizable unmapped permanent stream segments < 500 m from lakes, rivers, mapped large permanent stream segments, or other water features identified as HPS based on inventory data
MPS	Ponds	<p>When inventory data are available, MPS ponds are those with ≥ 1 of the following characteristics:</p> <ul style="list-style-type: none"> • Ponds known to contain fish species that are moderately resilient to perturbations (e.g., northern pike, <i>Esox lucius</i>) • Ponds known to provide components of fish habitat for which there is a moderate degree of species' dependence • Ponds known to contain habitats or fish that have a limited distribution • Ponds with moderate habitat resiliency <p>When inventory data are not available, MPS ponds are those with the following characteristics:</p> <ul style="list-style-type: none"> • Mapped or unmapped open water features ($\leq 25\%$ of surface area covered by emergent vegetation) encountered during operations that are ≥ 0.5 and < 8 ha in size and are connected to ≥ 1 MPS streams (see below)

TABLE 1. Continued.

Sensitivity class	Water feature	Criteria
	Streams	<p>When inventory data are available, MPS streams are those with ≥ 1 of the following characteristics:</p> <ul style="list-style-type: none"> • Stream segments known to contain fish species that are moderately resilient to perturbations (e.g., northern pike) • Stream segments known to provide components of fish habitat for which there is a moderate degree of species' dependence • Stream segments known to contain habitats or fish that have a limited distribution • Stream segments with moderate habitat resiliency <p>When inventory data are not available, MPS streams are those with 1 of the following characteristics:</p> <ul style="list-style-type: none"> • Mapped small permanent stream segments that are ≥ 500 m (stream distance) from lakes, rivers, mapped large permanent stream segments, and other water features identified as HPS based on inventory data • Recognizable unmapped permanent stream segments that are ≥ 500 m from lakes, rivers, mapped large permanent stream segments, and other water features identified as HPS based on inventory data • Mapped or recognizable unmapped intermittent stream segments < 500 m from water features known to support brook trout
LPS	Ponds Streams	<ul style="list-style-type: none"> • Any pond that does not meet the criteria for an HPS or MPS pond • Any stream segment that does not meet the criteria for an HPS or MPS stream

^a Water features ≥ 8 ha in surface area

^b Water features ≥ 0.5 but < 8 ha in surface area

^c Streams segments with catchment area ≥ 50 km²

Webster 2000, Meleason et al. 2003, Jones and Daniels 2008). Stream temperature typically is influenced by forest within 10 to 30 m of shorelines depending on tree height and canopy density (Barton et al. 1985, Castelle et al. 1994, Sridhar et al. 2004, Wilkerson et al. 2006). More than 80% of allochthonous inputs typically come from vegetation within $\sim 1/2$ tree height of shorelines (Reeves et al. 2006). Thus, the Stand and Site Guide requires retention of mature forest with high canopy closure within 15 m of both sides of HPS or MPS streams (Table 2). Partial harvest within this forest is permitted because moderate levels of canopy removal may emulate small-scale disturbances and increase light availability with minimal effects on water temperature (Zwieniecki and Newton 1999, Mellina et al. 2002, Wilkerson et al. 2006, Kreutzweiser et al. 2009) but with resultant increases in productivity of aquatic systems (Newton and Cole 2005, Wilzbach et al. 2005, Nislow and Lowe 2006). Moreover, partial harvesting may create sufficiently large canopy gaps to attract some wildlife species typically found in young riparian forests (Darveau et al. 1995).

To emulate the conditions created when wildfire burns to the edge of streams, retention of mature riparian forest is not required along HPS or MPS streams when the treed edge is > 15 m from the edge of the active channel. Moreover, retention of mature

riparian forest is not required along LPS streams (Table 2) because they are typically very narrow, and understory vegetation generally will provide adequate shade (see Blann et al. 2002).

Wildfires also frequently burn to the edge of lakes (see below). Removal of riparian forest appears to have limited effect on littoral water temperature or thermal regime in lakes (Steedman et al. 1998, 2001, Steedman and Kushneriuk 2000). Moreover, allochthonous inputs may be reduced after removal of riparian forest (France 1997), but biological effects appear to be transitory because of rapid regrowth of riparian vegetation (France 1998). However, harvesting of riparian forest may influence future recruitment of coarse woody material into the littoral zones of lakes (Guyette and Cole 1999, Bolgrien and Kratz 2000). Thus, the Stand and Site Guide permits some clearcutting of riparian forest adjacent to standing water (see below) but requires retention of some trees along these shorelines to provide future inputs of coarse woody material (Table 2).

How many riparian trees are necessary to maintain ecological functions?

The Stand and Site Guide requires retention of 10 dominant or codominant trees/100 m of clearcut shoreline to provide future inputs of coarse woody

TABLE 2. Summary of direction designed to emulate natural (wildfire) disturbances in riparian forests while protecting fish habitat and water quality on crown lands in Ontario (see OMNR 2010a for more detailed direction). HPS = high potential sensitivity, MPS = moderate potential sensitivity, LPS = low potential sensitivity.

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

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

material. This number was based on: 1) estimates of the supply of coarse wood in the littoral zone of individual lightly developed lakes in Ontario, Michigan, and Wisconsin (Christensen et al. 1996, Jennings et al. 1999, Mallory et al. 2000, Steedman et al. 2004, Marburg et al. 2006, Sass et al. 2006, B. Cole, OMNR, unpublished data), 2) estimates of the annual input of coarse wood required to balance losses to decay based on mean residence time of coarse wood (Tyrrell and Crow 1994, Guyette et al. 2002), and 3) estimates of the volume of wood that may actually fall into water from trees retained along shorelines based on distance from shore and the likelihood that trees fall toward the water (Robison and Beschta 1990, Bragg et al. 2000, Welty et al. 2002).

The Stand and Site Guide specifies that, ideally, retained trees should be within $\frac{1}{2}$ tree height of water and leaning toward the water. Conifers are preferred because coniferous logs have a longer residence time in water than do hardwood logs (Cole et al. 2003). Moreover, conifers typically have a more complex branching structure that provides better cover for schooling fish (Newbrey 2002) and more complex bark that supports a higher diversity of invertebrates (Bowen et al. 1998).

How much riparian forest would be altered by natural disturbances?

Following an END paradigm suggests that the amount of riparian forest disturbed by forest management operations should be similar to that altered by natural disturbances, such as wildfire. Considerable empirical evidence exists to indicate that fire can play an important role in the dynamics of riparian forests (Russell and McBride 2001, Dwire and Kauffman 2003, Pettit and Naiman 2007), but only a few studies provide detailed quantitative information on the amount of shoreline burned during disturbances. For example, Landstrom (2003) studied 23 large fires in northwestern Ontario and found that fire burned $\sim 60\%$ of the riparian forest adjacent to lakes and streams.

The pattern of riparian disturbance around >1800 lakes within 42 wildfires in the boreal and transition forests of Ontario was examined to provide more empirical information to support direction in the guide (OMNR 2010b). Overall, the median percent of riparian area burned around lakes averaged $\sim 50\%$. However, variation was quite large and values for

individual lakes ranged from <10 to >90%. Thus, up to 50% of the shoreline of HPS or MPS ponds and small lakes may potentially be clearcut to reflect the average amount of riparian disturbance observed in our analysis and the literature (Table 2). The actual amount of riparian forest that can be clearcut around individual water features will vary considerably given constraints imposed by other direction (e.g., special wildlife habitats, cultural features), operability or marketability considerations, and land ownership. More of the shoreline of LPS ponds and less of the shoreline of larger lakes may potentially be clearcut to capture some of the variation inherent in the natural pattern (Table 2). This approach largely reflects our observation that the median percent of riparian area burned tended to be inversely related to the size of water features (OMNR 2010b).

Carefully Implemented

The Fisheries Act (1985) prohibits the deposition of deleterious substances, including sediment, into water. In this regard, the most significant concern is that forest management operations may expose mineral soil and facilitate transport of sediment in runoff and subsequent deposition in water (see reviews in Steedman and Morash 2001, Steedman et al. 2004, Croke and Hairsine 2006). Most jurisdictions prescribe riparian buffers within which forest management operations are prohibited or restricted to minimize the risk of sediment entering water (Lee et al. 2004, Richardson et al. 2012).

Roads, landings, and water crossings are the major potential sources of sediment in forest management operations (see reviews in Stafford et al. 1996, Steedman and Morash 2001, Steedman et al. 2004). Smaller amounts of mineral soil exposed by mechanical site preparation (Steedman and Morash 2001) or skidding (Stafford et al. 1996) are also a potential (but minor) source of sediment.

What restrictions are necessary for major potential sources of sediment?

Past direction (OMNR 1988) restricted major potential sources of sediment within 30 to 90 m of water based on the slope-dependent distance required to attenuate sediment movement in a small study conducted in New Hampshire (Trimble and Sartz 1957). More recent literature suggests that smaller buffers (15–60 m wide) generally may be adequate to slow surface water flow and trap suspended sediment from major sources of exposed mineral soil (see reviews in Clinnick 1985, Castelle et al. 1994, Croke and Hairsine 2006). The relationship between the

length of sediment tracks originating from forest access roads and slope was modeled, pooling data available from the literature, to evaluate whether past direction was still appropriate (see OMNR 2010b). Slope was a highly significant predictor of the length of sediment tracks. Buffers of 30, 40, and 50 m were generally predicted to attenuate ~95% of sediment tracks when slope was 15, 30 and 45%, respectively. This result suggested that the 30- to 90-m model proposed by Trimble and Sartz (1957) probably is effective but somewhat conservative. The 30- to 90-m slope-based buffer has been used for >20 y in Ontario and appears to be effective, so it was prescribed for HPS water features. However, narrower buffers were prescribed for MPS and LPS features because the 30- to 90-m buffer probably is conservative.

What restrictions are necessary for minor potential sources of sediment?

Numerous studies suggest that effects of skid trails can be mitigated by applying careful operating practices (e.g., Martin and Hornbeck 1994, Martin et al. 2000, Macdonald et al. 2003). For example, Kreutzweiser and Capell (2001) found no significant input of sediment when machine travel was >3 m from streams and harvesting equipment did not create channeled flow paths. Plamondon (1982) suggested that effects of skidding could be mitigated by retaining 10 to 15 m of undisturbed forest floor adjacent to water features. Therefore, past direction (OMNR 1998b) that prohibited disturbance of the forest floor within 3 m of water features was retained. Moreover, the literature and discussions with experts suggested that additional restrictions on site disturbance would further minimize the risk of sediment transport and deposition associated with machine travel (Table 2).

Ephemeral streams that channel runoff from snow-melt or rainfall events directly into water features can be significant conduits for movement of sediment (Haupt and Kidd 1965, Kreutzweiser and Capell 2001, Maine Forest Service 2004). Moreover, when springs, seeps, and other areas of shallow groundwater discharge enter water features they can create important habitat for cold-water fish, such as brook trout (Biro 1998, Ridgway and Blanchfield 1998, Borwick et al. 2006). Thus, the Stand and Site Guide prohibits disruption of water movement within these features when associated with other water features.

Looking Ahead

Growing recognition that riparian disturbance may contribute to biodiversity conservation is encouraging

various jurisdictions to incorporate riparian disturbance into their forest management practices (e.g., Manitoba Conservation 2008, OMNR 2010a). Recently, Sibley and Gordon (2010) developed a decision-support system to help forest managers plan disturbance thoughtfully in riparian areas. We hope that some components of the approach described in our case study may be applicable to other jurisdictions that have similar natural disturbance regimes, planning and operational frameworks, types of aquatic and terrestrial values, and social receptivity (Sibley et al. 2012).

Looking ahead, Ontario faces 3 main challenges to incorporating END concepts into riparian forest management. First, although the Stand and Site Guide incorporates the best science-based information available at the time of development, uncertainties still exist about the effects of emulating natural disturbance in riparian forests on aquatic systems and the effectiveness of mitigative direction (Sibley et al. 2012). Thus, OMNR continues to promote, conduct, support, or monitor hypothesis-driven studies examining the effects of forest management operations on ecological functions within aquatic systems as part of an adaptive management approach. Knowledge gained from these studies will be used to inform future versions of the Stand and Site Guide, which is reviewed and potentially revised every 5 y.

Second, the Stand and Site Guide defines the maximum amount of riparian forest that can be clearcut within individual harvest areas. The frequency with which this direction is applied ultimately determines the mosaic of young and old riparian forest across landscapes. However, OMNR currently does not provide END-based guidance for riparian management at the landscape scale (see Moore and Richardson 2012 for a discussion of END-related landscape-scale considerations).

Last, despite the new direction, some forest managers have been reluctant to clearcut to the shore of water features. This reluctance reflects a number of factors including stakeholder resistance. Stakeholder resistance largely reflects the perception that riparian management is driven by economic considerations and that operations in riparian areas cannot be conducted carefully. Perceptions are changing as messages about the ecological benefits of riparian disturbance are being shared with stakeholder groups. In our experience, the best way to influence perception is to combine messaging with tours of harvest areas that include riparian management so stakeholders can see the results for themselves. We anticipate that END-based management of riparian forests will become more common across the province as forest managers

and stakeholders become more comfortable planning and implementing operations in riparian areas.

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