A Review of the Use of Buffer Strips for the Maintenance and Enhancement of Riparian Ecosystems

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INTRODUCTION

Over the past few decades, pollution associated with agricultural and forestry activities have increasingly been recognized as a serious threat to the quality of surface and ground water throughout North America (Garcia and Carignan 2000, Sovell *et al*. 2000, Castelle *et al*. 1994, Lynch *et al*. 1985, Owens *et al*. 1983, Omernik *et al*. 1981). Certain agricultural and forestry practices can degrade surface water quality by increasing stream bank erosion, increasing the loading of contaminants, nutrients and bacteria and increasing stream temperatures (Garcia and Carignan 2000, Sovell *et al*. 2000, Muscutt *et al.* 1993, Peterjohn and Correll 1984, Younge *et al*. 1980). The growing concern about non-point source pollution has resulted in the development of forestry and farming practices, often called "Best Management Practices" (BMPs) that minimise the impact of these activities (Aubertine and Patric 1974). Best Management Practices are part of the non-point source pollution control strategies of environmental groups and government (state, provincial and federal) agencies throughout the US and Canada (Peterson 1993, Walker and Graczyk 1993, Lowrance *et al.*1985, Haugen 1983).

Buffer strips along water bodies are a central component of most non-point source pollution programs in North America. Vegetated buffer strips can mitigate the effects of agricultural and forestry activities by acting as a physical barrier to sediment, nutrients and pesticides being carried into streams (Barling and Moore 1994, Cooper 1990). Buffer strips may also reduce the flux of soluble nutrients by uptake into growing plants or by supporting environmental conditions that favour chemical transformations such as denitrification (Haycock and Pinay 1993, Cooper and Gilliam 1987). Forested buffer strips that are sufficiently dense may also improve water quality by restricting the access of live stock to streams, thereby reducing inputs of nutrients and bacteria associated with livestock faeces and reducing erosion resulting from stream bank trampling (Barling and Moore 1994, Muscutt *et al.* 1993).

Although the potential benefits of buffer strips are intuitively appealing, the criteria for the establishment of buffer strips are often subjective and detailed monitoring after buffer zones are established is often lacking (Briggs *et al.* 1994). Often these criteria are set based on the discretion of individual biologists or restoration technicians. In many cases the widths of buffer strips are set based on what is politically acceptable or what landowners can reasonably be expected to "give up". Removing land from active production and converting it to riparian buffers can be expensive for farmers with extensive stream systems bisecting their farms, therefore an accurate understanding of the real benefits of buffer zones is required if landowners are to be convinced to maintain vegetative zones.

In discussing the effectiveness of riparian buffers with professionals working to implement non-point source agricultural pollution control programs in eastern Ontario, it became apparent that few were aware of well documented examples of cases where the efficacy of riparian buffers have been measured. This, despite hundreds of papers being published on the subject over the last few decades.

One of the reasons that much of the research related to riparian buffer strip design and function does not make its way to the individuals implementing restoration activities in the field, is that the literature is widely spread over a vast range of scientific disciplines. Riparian buffers can have impacts on sedimentation rates, erosion, nutrient input, stream temperature, and movement of wildlife populations. As a consequence of this wide range of ecological functions, the literature about the riparian buffers is found in journals representing a wide range disciplines (e.g., ecology, geomorphology, population genetics, soil science, limnology, and fisheries science). Thus, making it difficult for those who are busy implementing projects to keep track of this growing body of literature.

The purpose of this paper was to review and synthesise the available literature about the effectiveness of buffer strips. Our goal was to provide a succinct synthesis of the available information about riparian buffers that could be used by non-point source project managers, to prioritise projects, develop biologically appropriate criteria for buffer strips widths, and identify situations where buffer strips will be most effective.

We have organised the review according to the following ecological functions: removal of sediment and nutrients, stream bank stabilisation, effects on water temperature, and importance as habitat corridors.

A large body of literature is developing about the use of buffer strips to improve or protect water quality. We surveyed more that 100 papers and our review was not exhaustive. Since the purpose of this review is to produce a succinct document that can be used by those undertaking non-point source pollution control projects, we have not attempted to summarize each study we reviewed. Instead, we have selected specific studies to illustrate the range of results obtained by authors studying the efficacy of riparian buffers strips. A complete list of the papers we reviewed is available from the authors.

Definitions and terminology

Different authors have used a variety of definitions and terminology related to riparian buffer strips. For the purpose of this review, we define a buffer strip any strip of vegetation between a river, stream or creek and an adjacent upland land use activity, that is maintained for the purposes of protecting or improving water quality, or enhancing the movement of wildlife among habitat patches. Buffer strips may be composed of native vegetation (e.g., pre-existing native forest) that is intentionally left intact when land is cleared for other land uses (forest harvesting, agriculture or urban development) as well as vegetative buffers that are re-established where original vegetation has previously been removed. The latter may include forested or herbaceous buffer zones. We use the terms buffer strips, riparian buffers and vegetative buffer strips interchangeably.

RESULTS AND DISCUSSIOIN

Sediment and Nutrient removal

Degradation of surface water quality in areas where native forest has been replaced by intensive agriculture has been well documented (Barling and Moore 1994, Muscutt *et al.* 1993), but whether vegetative buffer strips along stream banks can mitigate these effects is less clear. The results of some studies clearly show nutrient removal in buffer strips (Cooper 1990, Lowrance *et al*. 1984), and in some cases removal approaches 90-100%. Others studies show poor removal efficiencies of some nutrients (Groffman *et al*. 1991, Magette *et al.* 1989; Table 1).

Omernik *et al*. (1981) compared water quality in watersheds with similar degrees of conversion from forest to intensive agriculture. In some of the watersheds, the deforestation and land conversion to agriculture was predominantly in riparian areas. In other watersheds, the extent of the deforestation was similar, but the agricultural activity was located away from riparian areas. Their results indicated that the proximity of agricultural activity to riparian areas did not influence water quality in the streams they studied (Omernik *et al*. 1981). Instead, they found that the total proportion of land converted to agriculture was a better predictor of water quality than proximity of agricultural activity to riparian areas (Omernik *et al*. 1981).

The conflicting results of these studies (Groffman *et al*. 1991, Cooper 1990, Lowrence *et al*. 1983, Omernik *et al*. 1981) clearly illustrate that the functions of riparian buffer strips are complex. The efficacy of buffer strips as nutrient filters may depend on the specific characteristics of the buffer strip (soil chemistry, type of vegetation, successional stage) as well as the nutrients involved.

Nitrogen:

Much of the nitrogen that moves from agricultural land into rivers and streams is in the form of nitrate. Processes within riparian zones, wetlands and streams are capable of nitrate removal under appropriate conditions but the relative importance of these processes is highly variable (Cooper 1990).

Riparian buffers can remove nitrogen via a variety of mechanisms. Nitrogen can be removed by uptake into growing plants or by conversion of nitrate to nitrogen gasses (NO or NO_2) by denitrifying micro-organisms. Sediment-bound nitrogen can also be removed when riparian vegetation physically slows the movement of water allowing increased sedimentation rates. Atmospheric nitrogen (N_2) can also be converted back to nitrate by nitrogen fixing micro-organisms associated with the roots of some plants (e.g., Leguminosae), further complicating the situation for nitrogen (Haycock *et al*. 1993, Lowrance 1992, Groffman *et al.* 1991, Cooper 1990, Magette *et al*. 1989, Jacobs and Gilliam 1985).

Reported nitrate removal efficiencies are highly variable and much of the variation may be related to the many different mechanisms involved in nitrogen removal as well as

Table 1: Comparison of nutrient and sediment removal efficiencies in selected works.

Author	**Parameter measured**	**Buffer width**	**Percent reduction**
Cooper *et al*. 1987	Sediments	Variable (woodlots)	84% - 90%
Groffman *et al*. 1991	Denitrification	Plots (3 m x 5 m)	1% – 29%
Haycock *et al*. 1993	Nitrogen	Approx. 20 m–25 m	84% - 99%
Lowrance *et al*. 1984	Nitrogen	No set values	68%
Magette *et al*. 1989	Total Suspended Solids, Total Phosphorus, Total Nitrogen	4.6 m & 9.2 m	0% - 66%
Young *et al*. 1980	Nitrogen, Phosphorus	0 m – 25 m	67% - 83%

variation in the balance between nitrogen fixation and denitrification rates (Philips 1989a, b, Warwick and Hill 1988). Magette *et al.* (1989) found that experimental buffer strips (4.6 m and 9.2 m in width) were ineffective in removing nitrogen. They found that nitrogen losses from experimental plots with buffer strips varied from 45% to 184% compared to losses from plots without buffers.

In contrast, several studies have shown that buffer strips can be effective in the removal of nitrates from surface run-off (Cooper 1990, Lowrance *et al*. 1983). Cooper (1990) observed nitrate removal efficiencies varying from 88% to 97% for riparian organic soils at his study site. Removal efficiencies of mineral soils were less spectacular and in some months these sites served as net exporters of nitrate (Cooper 1990). Organic soils accumulate in low-lying areas that receive disproportionately large volumes of runoff, therefore these organic soil deposits can still be important sites of nitrate removal even if they occupy only a small area of the riparian zone. For example, Cooper (1990) found that between 56% and 100% of denitrification occurred in organic soils even though organic soils covered only 12% of the study area.

One key difference between the experiments of Magette *et al.* (1989), and those of Cooper (1990) and Lowrance *et al*.(1983), is that Magette *et al.* (1989) measured nitrate removal in small herbaceous riparian buffer strips established in agricultural fields. In contrast, the studies by Cooper (1990) and Lowrance *et al*. (1983) were conducted in intact riparian ecosystems. Although the latter two studies were conducted in buffer strips that were much wider that those used by Margette *et al.* (1983), buffer width alone is not sufficient to explain the difference between these studies since denitrification often occurs within the first 10 m of riparian forest (Lowrance 1992).

Both forested and herbaceous buffer strips can be effective sites of nitrogen removal but whether herbaceous or forested buffers are more effective in removing nitrogen varies.

Haycock and Pinay (1993) found that forested buffers were more effective in promoting nitrogen removal in winter months compared to grass buffers. In contrast, Groffman *et al.* (1991) found higher nitrate removal rates in grass buffers compared to forested buffers.

Taken together, these studies illustrate the importance of maintaining the ecological integrity of riparian buffers. Some studies have shown that buffers consisting of herbaceous vegetation or forests in early successional stages can increase the efficiency of nitrate removal (Lowrance *et al*. 1984). This may be effective when plant uptake is primary route of nitrate removal but nitrate removal by plant uptake is only a short-term effect since the nitrogen becomes available again when plants senesce. Denitrification by microbial communities in soil on the other hand results in long-term nitrogen removal from riparian zones. Removing vegetation to maintain buffers in an early successional stage may promote sustained nutrient remove via plant uptake, but may also remove carbon that is essential for denitrification.

Phosphorus:

In contrast to the situation for nitrogen, there is no mechanism to remove phosphorous to the atmosphere (Cooper and Gilliam 1987). Phosphorous in agricultural run-off can be removed by sorption onto soil particles, by sedimentation, or through uptake by plants (Cooper and Gillian 1987). In contrast to nitrogen, the capacity for phosphorous removal is finite (Cooper and Gilliam 1987) and the capacity for riparian areas and wetlands to remove phosphorous may become saturated (Omernik *et al*. 1981). Whether riparian buffers serve only as short-term sinks for phosphorous is unclear. Most studies follow phosphorous removal over too short a time span to draw conclusions about the long term potential for phosphorous removal. Nonetheless, several studies have shown that buffer strips can remove phosphorous from both surface and shallow ground water (Osborn and Kovacic 1993, Cooper and Gilliam 1987). Osborn and Kovacic (1993) found that grass buffers removed more phosphorous that forested buffers.

Many of the studies demonstrating long- or short-term phosphorous removal involved buffer widths that were much greater than what can be expected in agricultural areas. Magette et al. (1989) measured phosphorous removal by 4.6 m and 9.2 m buffers. Their results were highly variable but phosphorous removal was generally poor compared to other studies involving wider buffers.

Sediment:

A number of studies have shown that buffer strips can assist in the retention of sediments thereby reducing sediment loads to rivers and streams (Heede 1990, Cooper *et al.* 1987, Lowrance *et al*. 1986). Large heavy particles are most efficiently removed by buffer strip vegetation. Reducing sediment transport may also reduce nutrient export from riparian zones because nutrients are often bound to sediment particles. Unfortunately, fine particles such as clay that bind a disproportionate amount of the sediment-bound nutrients are less effectively removed compared to larger heavier particles.

Sediment retention alone (i.e., even without significant quantities of bound nutrients) is desirable because increased sedimentation can degrade spawning sites for fish and other aquatic animals. Riparian vegetation can also reduce sediment loads by stabilising stream banks and minimising stream bank erosion (Kemper *et al*. 1992, Schloseer *et al*. 1981).

Whether sediment removal is effective over the long term is a matter of debate. Cooper *et al*. (1987) used Cesium dating to examine sediment deposition over a 20-year period. They found that the riparian zone was a sediment sink over the 20-year period they studied. Lowrance *et al.* (1986) reached a similar conclusion (using different methods) examining sediment deposition over a 100-year period. Both of these studies were conducted in watershed that were characterised by > 50% forest cover. Whether narrow buffers are able to retain sediments over the long-term is not clear. Most studies have been too short in duration to detect remobilization of sediments during infrequent intense floods.

In addition to trapping sediment and nutrients moving into the stream from upland areas, riparian buffers may also reduce sedimentation that results from the erosion of the stream bank itself (Bowie 1995, Kemper *et al*. 1992).

Effects of tile drainage:

Nutrient removal requires contact between runoff water and soil containing micro-organisms (denitrification) or the roots of plants (plant up-take). Much of the agricultural land in Eastern Ontario is tile drained, therefore, much of the nutrient load can bypass the plant root zone and denitrifying soils. Buffer zones therefore, may be most effective in preventing the deterioration of water quality in areas where the natural drainage patterns are intact.

Stream temperature

Several studies have documented increases stream temperatures associated with removing riparian forest (Hotlby 1988, Barton *et al.* 1985, Rishel *et al*. 1982). Rishel *et al*. (1982) found that average temperatures increased by 4.4 ^{o}C following the removal of riparian forest. The increase in maximum temperature was even more dramatic: 32 ^{o}C in the clearcut stream compared to 22 ^{o}C on a nearby reference site. Lee and Samuel (1976) observed similar increases in stream temperature associated with timber harvesting.

Stream temperature is a critical factor for some fish, especially salmonids which are important sport fish. Barton *et al*. (1985) found that temperature was the most important factor distinguishing between trout and non-trout streams.

Even narrow riparian buffers are sufficient to reduce stream temperatures. The proportion of the stream bank that is buffered by vegetation is more important than buffer width in determining effects on stream temperature (Barton *et al*. 1985). Vegetation height is also important since the buffer vegetation must be sufficiently high to shade the water surface. Although buffer width is not critical for regulating stream temperature, narrow buffers may be more susceptible to wind damage that may compromise the long term integrity of the riparian buffer.

Habitat Corridors

Numerous studies have demonstrated the use of riparian forest as wildlife habitat (Skagen *et al.* 1998, Crompton *et al*. 1988). Riparian buffers may serve as corridors for dispersal among larger patches of forest habitat (Rich *et al*. 1994). Although many studies have reported the use of corridors by forest dwelling species (Skagen *et al*. 1998, Crompton *et al*. 1988), it is less clear whether these corridors provide for sufficient movement of animals to significantly influence the dynamics of the populations of animals living in these forest patches (Beier and Noss 1998). For example, knowing that a particular species that is found two isolated patches also occurs in a corridor connecting the two patches, is not conclusive evidence that the presence of the connecting corridor will reduce the probability of local extinction of that species in one or both patches.

While it is theoretically possible that riparian buffers may provide corridors to facilitate movement of wildlife among forest patches, there is little evidence to indicate that buffers in the size range typically found in agricultural areas are effective at promoting gene flow among populations or reducing local extinction probabilities. Narrow corridors may allow the movement of some small mammals (insectivores and rodents) but most species require larger corridors.

The presence or riparian corridors between two isolated forest patches will increase the proportion of edge habitat, potentially exposing nesting birds increased predation and nest parasitism. Keyser *et al*. (1997) found that predation on artificial bird nests increased as forest fragmentation increased. Haegen and DeGraaf (1996) compared the frequency of predation on artificial nests located in riparian buffer strips to those located in intact forest patches. In their experiment, the frequency of nest predation was twice as high in riparian buffers compared to nests in intact riparian forest. These studies clearly demonstrate that riparian buffers may not always be beneficial and that their efficacy may vary among sites.

For many area sensitive species, buffers widths of at 100m are required to maintain breeding populations. For example, Lambert and Hannon (2000) found that Oven birds (*Seiurus aurocapillus*) were absent from 20m buffers following a clear cut. Larger buffers (100 and 200m) were sufficient to maintain ovenbird populations (Lambert and Hannon 2000). Pearson and Manuwal (2001) found that buffers 30 m wide on each side of a third order stream in the Pacific Northwest was sufficient to maintain pre-logging bird communities.

RELEVANCE TO THE EASTERN ONTARIO MODEL FOREST

The literature we reviewed yielded mixed conclusions about the efficacy of buffer strips. In some situations buffers were clearly effective in improving water quality and promoting the movement of wildlife along stream corridors. The results of these studies are sufficiently compelling for us to recommend the use of riparian buffers as an indicator of forest ecosystem health. The results of this review indicated that targets for minimum buffer widths along steams should be at least 30 m. This goal should be achievable in heavily forested parts of the Eastern Ontario Model Forest's jurisdiction but may be unrealistic in agricultural areas. In heavily agricultural parts of eastern Ontario, especially in areas with extensive tile drainage, buffer zones should be considered just one part of a comprehensive approach to protect water quality.

Despite several initiatives to promote the use of buffer zones in eastern Ontario there are few data about the efficacy of these programs. The studies we reviewed came from a wide range of geographic locations, but because many of the biological processes that operate in riparian zones are probably universal ecological processes, these studies likely apply to eastern Ontario. The Eastern Ontario Model Forest should develop partnerships with other groups involved in buffer programs to obtain local data on buffer strip efficacy.

FURTHER RESEARCH REQUIREMENTS

The one outstanding feature of most of the papers we reviewed is the large degree of variation both within and among studies. This variation was a conspicuous feature of most of the parameters we considered (e.g., N, P, sediments, habitat corridors etc.). Much of this variation probably reflects the wide range of conditions under which studies were conducted. For example, some authors examined forested buffer strips whereas others focussed their attention on herbaceous buffer strips. Forested buffers ranged from remaining native riparian forest to forest plantations established specifically for the purpose of reducing nutrient and sediment export to adjacent watercourses. The studies we reviewed included buffers ranging from vegetative strips less than 10 m wide surrounded by agricultural land to 100 m buffers in landscapes dominated by forest.

The wide range of approaches and conditions makes it difficult to make site-specific conclusions about how vegetative buffer strips will perform in a given location. Many of the papers we reviewed suffered from one of more serious methodological deficiencies. Because of the difficulties associated with undertaking large landscape level studies, most studies lacked sufficient replication. Few studies have adopted an experimental approach, once again, reflecting the challenges of working at landscape level.

A more serious limitation is the lack of research involving buffer widths within the size range typically found in eastern Ontario. In areas dominated by agriculture buffer strips are often less than 5m. When farmers in the Raisin Region Conservation Authority (RRCA) watershed are required to establish buffer zones in return for subsidies for fencing or the establishment of alternate water sources, the buffer widths are typically mush less than 10m (C. Chritoph RRCA, personal communication). Only a few studies examined buffers in this size range and the results of those studies were highly variable.

Much more research needs to be focussed on buffers in the 1-10m range since this is the size of buffer strip typically encountered in many agricultural settings. Where possible, carefully controlled field experiments should be conducted. The experimental approach of Magette *et al* (1989) offers a useful model. They compared buffers of three different widths under simulated rainfall events where they could control and manipulate nutrient content in the runoff. Their study also included adequate replication but unfortunately their statistical analysis was insufficient to draw conclusions.

CONCLUSIONS

Despite the enormous variability that characterized most of the literature we reviewed, it is possible to draw some general conclusions:

1. Numerous studies have demonstrated that vegetative buffer strips can reduce non-point source pollution to streams.

2. Results, both within and among studies are highly variable making site-specific predictions difficult.

3. Wide buffer strips (30-100 m) provide the best protection from non-point source pollution.

4. Few studies have focussed on buffer strips within the size range typically encountered in areas dominated by agriculture.

5. Even narrow buffers may reduce non-point source pollution in some situations.

6. Narrow buffer strips are sufficient to provide other benefits such as shading streams and thereby reducing water temperature (which is critical for some fish species including salmonids).

RECOMMENDATIONS

1. Since vegetative buffers strips have the potential to protect streams and rivers from the detrimental effects of agricultural and forestry activities, the establishment of buffers should be actively promoted by the Eastern Ontario Model Forest.

2. The best available evidence suggests that buffers >30m wide are most likely to provide a wide range of benefits, therefore this threshold should be the minimum target buffer width.

3. When maintaining buffers that are >30m is not possible, narrower buffers should be promoted since they provide some benefits (e.g., maintaining cooler stream temperatures).

4. Maintenance of buffers composed of wide tracts of intact riparian forest, which are more likely to retain the ecological attributes necessary to sustain denitrification should be encouraged.

5. Since the efficacy of riparian buffers in highly variable, riparian buffers should represent one part of an overall mitigation strategy to protect aquatic ecosystems from degradation resulting from upland land use practices.

6. The Eastern Ontario Model Forest should encourage and promote research and monitoring associated with buffer strip projects.

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