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Spatial relationships among boreal riparian trees, litterfall and soil erosion potential with reference to buffer strip management and coldwater fisheries

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Litter cover is known to protect ground surfaces from raindrop impact and therefore reduces soil erosion. Significant differences were found to exist in the abundance, composition and size of trees, in their litter production rates, and in the resulting potential for soil erosion of the foreshore (0–20 m from shorelines) compared with the backshore (20–50 m upslope) regions of riparian zones around four boreal lakes located in northwestern Ontario, Canada. These findings support a global pattern wherein litter production adjacent to waterbodies is often considerably reduced compared with that characteristic of upland forests. This study therefore raises questions of the presumed effectiveness of existing forestry guidelines concerning widths of protective buffer strips around boreal, coldwater lakes in Ontario, which are presently based on an erroneous assumption of uniform tree cover and litterfall throughout riparian zones.

Key words: buffer strips, riparian litterfall, soil erosion

INTRODUCTION

Oligotrophic, boreal lakes, once envisioned as self-contained microcosms, are now recognized as being integrated components in a dynamic continuum of landscape processes through being dependent on terrestrial organic matter (e.g., del Giorgio & Peters 1993, del Giorgio *et al.* 1997) whose supply can be affected by the riparian clearcutting (France & Peters 1995, France *et al.* 1996). From this recognition comes awareness that "the maintenance of vegetation near waterbodies can mitigate many of the potential negative effects of [timber] harvesting … [such that] the presence of a vegetated area adjacent to waterbodies acts to buffer the waterbody from the effects of harvesting …" (Ont. Min. Nat. Res. 1988a). For Ontario, Canada, this awareness has led to the development of a series of Timber Management Guidelines to ensure protection of fish habitats from watershed clearcutting (Ont. Min. Nat. Res. 1988b, 1991).

However, concomitant with the increased scale of timber removal from boreal forests in Ontario, has been a decrease in the recommended widths for protective buffer strips (Ont. Min. Env. 1994) from 120–180 m (Flowers & Robinson 1976), to 133 m (Wainwright 1981), and finally to 30–90 m (Ont. Min. Nat. Res. 1988a) for "coldwater" lakes which contain various trout species. The protective function of buffer strips is most often accredited to their role as physical filters in removing sediment from transporting water (e.g., Heede 1990, Koski 1994). Despite the increased recognition of the importance of such areas, "relatively few data exist on the effects of riparian forests on aquatic ecosystems" (Adams 1994), such that there is a general "lack of information on forestry buffer zones" with respect to sediment transport (Neary *et al.* 1994).

Ontario's recommended buffer strip widths for boreal, coldwater lakes are based on an assumption of uniform tree cover throughout the designated riparian reserve, and dismiss vegetation composition as a factor in moderating riparian processes (Ont. Min. Nat. Res. 1988b, 1991). It seems reasonable to expect, however, that differences in the abundance, size, and type of riparian trees can exert a strong influence on preventing soil erosion and transport to receiving waters (Adams 1994).

Given that litterfall protects ground surfaces from the scouring actions of rainfall (Lowdermilk 1930, Johnson 1940, Rowe 1955, Helvey & Patric 1965, Gray 1973, Lattanzi *et al.* 1974, Singer & Blackard 1978), and as a result, reduces soil erosion (McClurkin *et al.* 1987, Naslas *et al.* 1994, France 1997), the possibility of lower rates of litter production in riparian compared with upland forests (Bell & Spence 1975, Bell *et al.* 1978, Thomas *et al.* 1992) raises questions about the presumed effectiveness of present day forestry guidelines concerning buffer strip widths that are based on characteristics of only upland forests.

The first purpose of this study was to provide the first estimates of the quantity, composition, and seasonality of nearshore riparian litterfall around Canadian boreal lakes as an initial step in examining the effectiveness of buffer strips in land–water management decisions. Such information is important because litter production measurements for boreal or hemiboreal forests in central North America are few (Foster 1974, Perala & Alban 1982, Van Cleve *et al.* 1983, Fyles *et al.* 1986), and only Grigal and McColl (1975) provide such data for riparian zones.

The second purpose of this study was to determine: (a) if a shoreline–upland gradient in litterfall exists around boreal lakes as shown previously for lotic riparian zones (e.g. Bell 1974), and (b) whether variable amounts and compositions of the litterfall could be related to several easily observable features of riparian forests. Again, such information is important as existing investigations of lakeshore vegetation have been spatially very limited (Keddy 1983, 1984, Nilsson & Wilson 1991, Klosowski 1993, Holt *et al.* 1995), and therefore offer little insight toward issues concerning upslope basin management.

Finally, given that forest removal can increase the rate of soil erosion partially through a reduction in protective litter cover (McClorkin *et al.* 1987, Naslas *et al.* 1994, France 1997), the third purpose of this study was to determine if more subtle differences in amounts and compositions of litterfall (such as might occur within riparian zones) were substantial enough to affect soil erosion. These data are critical for developing an understanding of riparian boreal forest processes because "the effectiveness of the [Ontario] guidelines in mitigating potential negative effects of harvesting has not been determined" (Ont. Min. Nat. Res. 1988b), such that "more information … is necessary in order to determine if the guidelines are working" (Pike & Racy 1989).

MATERIALS AND METHODS

Study area

The study area is situated within the boreal forest of northwestern Ontario at the edge of the Great Lakes/St. Lawrence mixed forest region, located on the Canadian Shield 45 km northwest of Atikokan and about 150 km southeast of the Experimental Lakes Area (Fig. 1). Details concerning vegetative, topographic and soil properties of this area are presented or referenced in France (1995, 1997), France and Peters (1995) and France *et al.* (1996).

Field measurements

Litterfall traps were placed on the ground within the riparian zones of four oligotrophic, boreal lakes (Fig. 1; France

& Peters 1995). Each lake was divided into two or three sub-basins based on large-scale shoreline shape, and one site then randomly selected within each sub-basin for litterfall monitoring (France & Peters 1995). Three 0.9-m^2 wire mesh window screens were placed 5 to 15 m apart at distances from 3 to 10 m inshore as in France (1997). In total, 33 traps were used to estimate litter production at 11 locations within the four riparian zones. Traps were set during the last week of August and emptied at the end of September, the end of October just before snowfall, early the following June, and at the end of the following August to determine the annual cycle of litterfall. Litter was stored frozen until separated into coniferous, deciduous and wood categories, and then oven dried at 60°C before weighing. Density, height, and diameter at breast height of riparian trees were measured along transects (see below) near the set traps (France & Peters 1995) to characterize nearshore forests.

During early September, 20 plastic tubs (26.5 cm dia; France & Peters 1995) were set at 10-m distances from the shoreline to 90 m inshore along a randomly chosen transect location in each of two study lakes (Lake 039 and Lake 026). Litterfall was collected in late October, frozen, separated into coniferous, deciduous and wood components, and then weighed following drying at 60°C.

Vegetation around the four study lakes (L020, L026, L039 and L042) was surveyed during late autumn with 49 transects stratified by both lake size and shoreline topography. The locations of 33 of these transects (6 to 9 per lake) were selected in association with sites determined previously for a study of allochthonous litter input (France & Peters 1995). These sites were determined by first dividing each lake into two or three sub-basins based on large-scale shoreline shape as in France and Welbourn (1992). One site was then randomly selected within each sub-basin. Five additional transects were also randomly placed around each lake's perimeter regardless of sub-basin designations. All of these sampling locations were selected without consideration of riparian topographic features. After each transect was surveyed, it was then designated as either "bay", "straight", or "point" based on proximal shoreline shape as in France and Welbourn (1992). A further 16 transects (5 to 6 per lake) were then nonrandomly located to balance out the sampling effort with respect to both large-scale lake divisions and small-scale shoreline shapes.

Transects were 50 m long and were oriented upslope perpendicular from the water's edge. The number of both coniferous (black spruce = *Picea mariana* and jack pine = *Pinus banksiana*) and deciduous (white birch = *Betula papyrifera* and trembling aspen = *Populus tremuloides*) trees (> 2 m in height) located within a 2-m band on one side of the transect were enumerated within 10-m intervals. Shrubs and understory vegetation were not surveyed. At the shoreline, and at each 10-m location upslope, the diameter (DBH) of the five closest trees were measured to obtain a mean value. Tree canopy height was determined with a clinometer for each 10-m interval. In total, 245 tree heights and 1 470 DBHs were measured, and over 6 000 trees counted within 4 900 m^2 of surveyed riparian lakeshore.

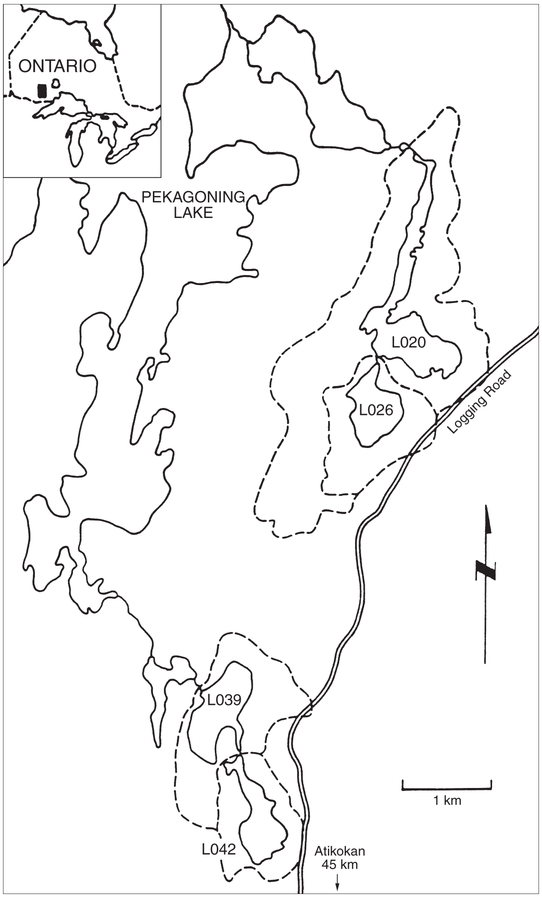

Fig. 1. Location of study area in northwestern Ontario, Canada. Dashed lines represent watershed boundaries around study lakes 042, 039, 026 and 020.

Experimental measurements

Simple experiments with a rainfall simulator as in France (1997) were used to assess the relative soil retention capability of riparian litterfall in relation to upslope distance. Sandy loam (220 g) collected from riparian zones was evenly placed in a thin (0.5 cm) and cohesive layer within a plastic paint-mixing tray (20 × 30 cm) in which a small hole had been drilled in the downslope end through which eroded material could be collected for drying (at 60°C) and subsequent weighing. In separate experiments, leaf litter (spruce, pine, birch and aspen) and wood litter were placed over the top of the soil in variable amounts and compositions representative of different inshore distances based on the previous litterfall transect data: 0–10 m (1.0 g coniferous needles and 1.0 g deciduous leaves; or 5.0 g wood), 10–20 m (1.5 g coniferous needles and 2.5 g deciduous leaves; or 10.0 g wood), 20–30 m (1.4 g coniferous needles and 5.6 g deciduous leaves; or 12.0 g wood), 30–40 m (1.7 g coniferous needles and 7.3 g deciduous leaves; or 18.0 g wood),

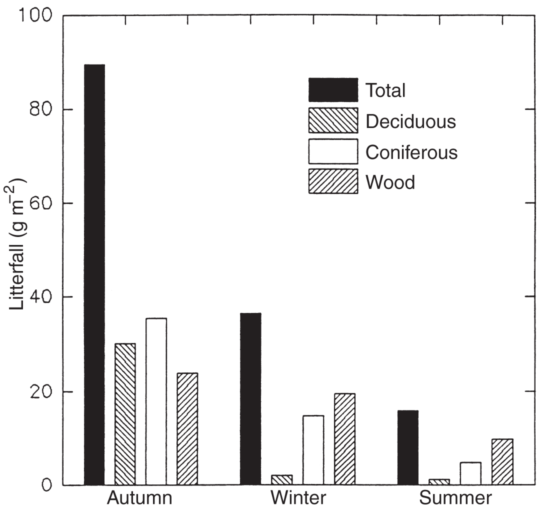

Fig. 2. Seasonal patterns of riparian litter production around boreal lakes in northwestern Ontario. "Autumn" = September–October, "Winter" = November–May, and "Summer" = June–August. Standard deviations averaged ± 24% of individual means.

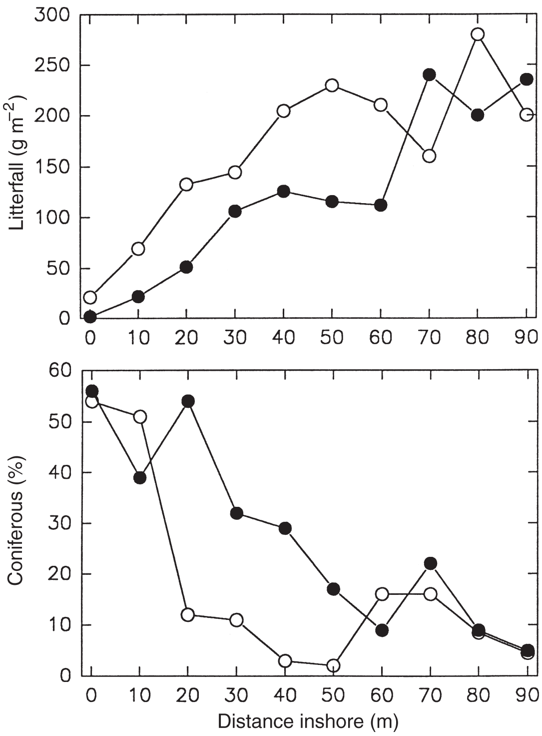

Fig. 3. Autumnal litterfall amount and composition along two 90-m inshore transects in the riparian zones of watersheds L039 (closed circles) and L026 (open circles).

and 40–50 m (1.3 g coniferous needles and 8.7 g deciduous leaves; or 32.0 g wood). Water (1.5 litres) was deposited on the litter–soil trays during a simulated rainfall of an intensity and energy representative of the most extreme storm observed in the area during three decades of measurement (France 1997). The experiment was replicated four times at a surface slope of 15° for leaf litter and 22° for wood litter.

RESULTS

Deciduous foliage was found to represent as little as 5% of the total annual riparian litter production around Lake 042 and as much as 39% of the total around Lake 020. Seasonally, 63% of the total annual litterfall occurred during the two months of September and October, with almost all the deciduous litter being produced at this time (Fig. 2). During the 7-month winter period, a further 26% of the total litterfall occurred of which wood (bark, branches and twigs) accounted for over half the amount. The quantity of riparian litterfall was significantly related to average tree density ($r = 0.65$, $p = 0.03$) but to neither average tree height nor average DBH across all 11 sampling-sites. Total annual litter production (± SD) averaged 135 ± 46 g m^{-2} around Lake 020, 139 ± 41 g m^{-2} around Lake 039, 198 ± 42 g m^{-2} around Lake 042, and 208 ± 35 g m^{-2} around Lake 026, for an overall average of 170 g m^{-2} for riparian forests in the study region.

Although no differences were found in autumnal litterfall amounts and compositions between 50 and 90 m inshore (Fig. 3), average litter production from the two transects were significantly related ($r = 0.94$, $p = 0.008$) to distance from 0 to 50 m. The amount of litterfall occurring within 10 m of the shoreline was on average less than 15% of that deposited between 40 and 50 m inshore. Whereas less than 20% of the leaffall between 40 and 50 m was coniferous, about half of that deposited within 10 m of the shoreline was coniferous (Fig. 3).

The nearest that riparian trees grew to lakes varied between 1 to 17 m with an average distance of 4 m (Fig. 4). Significant differences (t-tests, $p < 0.05$) existed between the "foreshore" (0–20 m) and the "backshore" (20–50 m) regions for tree density, percent coniferous composition, and tree size (both height and DBH) in these riparian forests (Fig. 3).

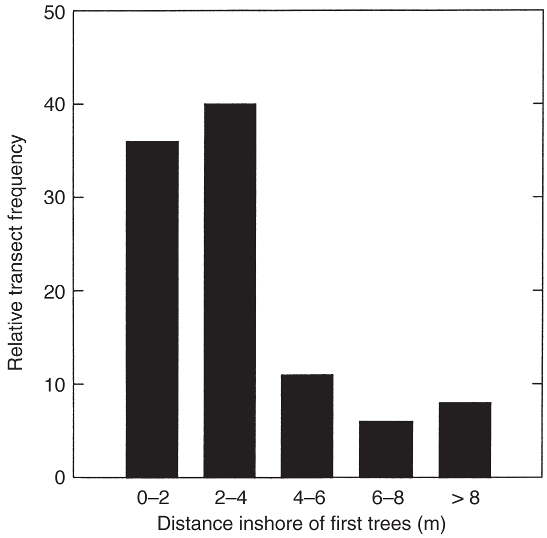

Fig. 4. Percentage frequency distribution of the proximity of the closest riparian trees to lakeshores.

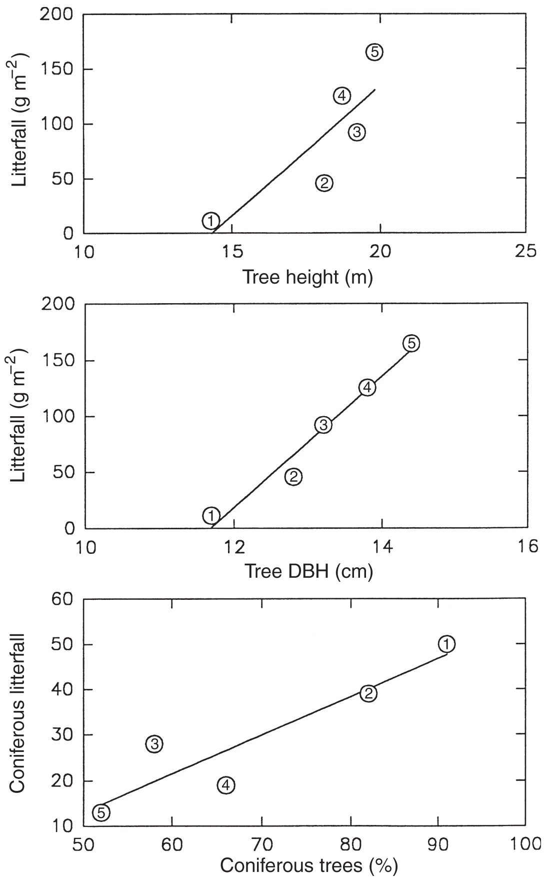

Fig. 5. Relationships between litterfall production and average tree height and girth (DBH), and between percentage coniferous leaffall and average percentage coniferous trees, for riparian zones around the study lakes. Numerals 1 to 5 denote 10-m distance intervals along transects from the shoreline to 50 m upslope.

Upslope spatial differences ($n = 5$) in litterfall abundance averaged across the four study lakes were related (Fig. 5) to both tree height ($r = 0.84$, $p = 0.07$) and DBH ($r = 0.97$, $p = 0.009$) but not tree density. The percent of leaffall composed of coniferous needles within each averaged upslope region closely matched the proportion of coniferous trees in these riparian forests ($r = 0.93$, $p = 0.03$).

The rainfall simulation experiment showed that soil erosion was dependent on the differing amounts and compositions of litterfall as related to riparian inshore distances. Soil loss from the treatments with litterfall characteristic of that within 10 m of the shoreline was over two times greater than that from treatments with litterfall representative of 40 to 50 m inshore from the lake (Fig. 6). Leaf/needle litter was much more effective in retaining soil than wood litter.

DISCUSSION

The phenology of litterfall determined for riparian boreal forests in northwestern Ontario, Canada is similar to patterns found in other north-temperate forests located in regions which are exposed to snow accumulation (e.g. Gosz *et al.* 1972). Average litterfall rates for riparian forests in northwestern Ontario are substantially below (Fig. 7) averages recorded for all same-latitude forests (Van Cleve *et al.* 1983), other temperate coniferous forests (Bray & Gorham 1964, Cole & Rapp 1981), as well as other Great Lakes/St. Lawrence coniferous-mixed forests (e.g. Alway & Zon 1930, Foster 1974, Tappeiner & Alm 1975, Perala & Alban 1982, Weber 1987). Litterfall estimates for more northern boreal forests (Van Cleve *et al.* 1983, Fyles *et al.* 1986) and other Great Lakes/St. Lawrence riparian zones (Grigal & McColl 1975) are comparable to those found in the present study (Fig. 7). These results for riparian zones around boreal lakes are not unique but represent a global pattern wherein litter production adjacent to water-

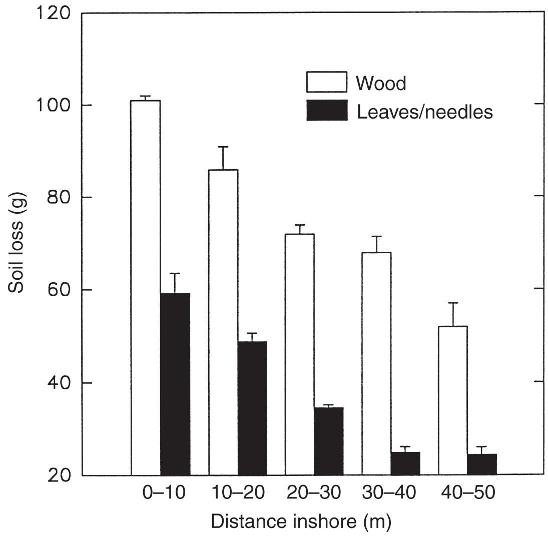

Fig. 6. Experimental soil loss (± SE) in relation to variable litterfall representative of inshore distances within riparian boreal forests (see text).

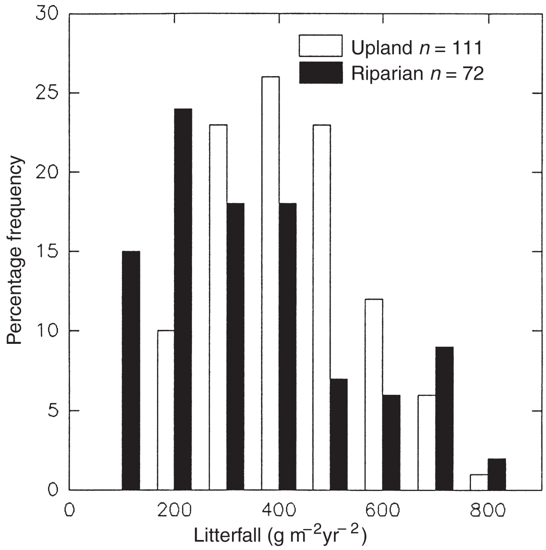

Fig. 8. Comparison of the distribution of annual rates of litter production for upland forests (compiled by Van Cleve *et al.* 1983) with that for riparian zones around lakes and streams (obtained from the literature) in the limited latitudinal range 30 to 60°N or S. Frequency distributions were significantly different (χ^2 test, $p < 0.05$).

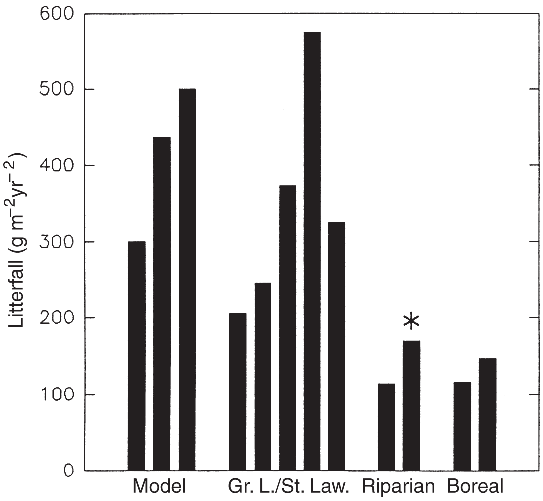

Fig. 7. Comparison between the average litter production rates for the present surveyed riparian zones (denoted by ✳) and those recorded for other north-temperate forests. Studies from left to right are Bray and Gorham (1962), Cole and Rapp (1981) and Van Cleve *et al.* (1983) for Model estimates, Tappeiner and Alm (1972), Alway and Zon (1930), Foster (1974), Perala and Alban (1982) and Weber (1987) for Great Lakes/St. Lawrence forests, Grigal and McColl (1975) and this study for riparian forests, and Van Cleve *et al.* (1983) and Fyles *et al.* (1986) for boreal forests.

bodies is more frequently lower (Fig. 8), often by 200–300 g m^{-2} yr^{-1} (Fig. 9), compared with that characteristic of upland forests.

The present finding that nearshore riparian litter production in northwestern Ontario is comparable to that characteristic of more northern boreal forests suggests that the soil entrapment capability of these riparian zones may be much lower than once thought. Therefore, the setting of buffer strip guidelines for Great Lakes/St. Lawrence forest regions based on an assumed litter production of 300 to 500 g m^{-2} yr^{-1} from empirical models, or of 200 to 600 g m^{-2} yr^{-1} determined from upland forests, should be reexamined. Instead, litter production for riparian zones in these regions (100 to 200 g m^{-2} yr^{-1}) are more similar to those expected in more northern boreal locations where much larger buffer strip guidelines (90 to 100m) are currently in effect (Alb. For. Land. Wild. 1990, Sask. Parks Recreat. Cult. 1992).

Ontario's Timber Management Guidelines (Ont. Min. Nat. Res. 1988b) state that buffer strips "should be measured from the high water mark". In the present study area, riparian trees are on

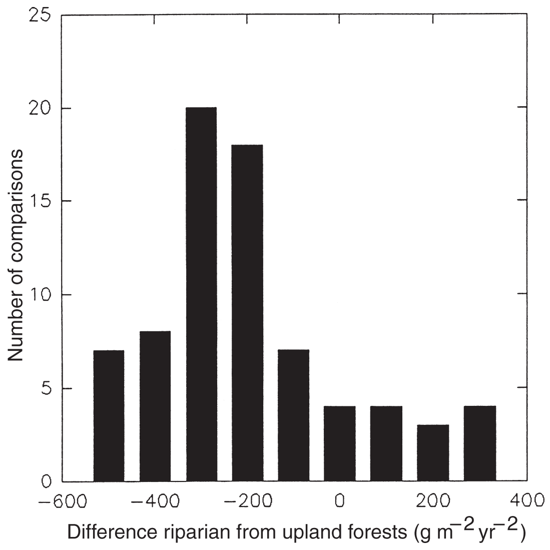

Fig. 9. Latitude-specific residual differences between rates of litter production for riparian zones and the empirical equation determined for upland forests by Lonsdale (1988) from 2 to 67°N or S.

average set back 4 m from the shoreline. The interlying distance between lake and first trees was most often composed of bare bedrock and boulders. Consequently, the very low rates of litter production in these nearshore regions indicates that surfaces will remain impervious and will obviously not serve buffer strip functions of sediment interception, and should therefore not be included when calculating effective buffer strip widths (Nieswand *et al.* 1990).

The present results are in agreement with those of Brusnyk and Gilbert (1983) and Euler (1983) in demonstrating that a "coniferous fringe" is a characteristic feature of riparian zones around many Ontario lakes. This finding, together with the present demonstration of decreased tree size near the shorelines, could have important implications for runoff and sediment transport. The rainfall simulation experiment suggested that due to the greatly reduced litterfall occurring within the foreshore region, riparian zones around boreal lakes in northwestern Ontario have the potential to be less able to "buffer" receiving waters from watershed clearcutting then was once believed. Whether that potential becomes realized, however, depends on complicated drainage patterns within individual riparian zones (Adams 1991, Daugharty & Douglas 1994). Until detailed studies are undertaken of such riparian erosion dynamics, guidelines for buffer strip widths may have to be reexamined in relation to these results in association with other information about the relative decomposition rates of coniferous and deciduous litter.

In their review written after the Ontario Timber Management Guidelines had been drafted, Pike and Racy (1989) stated that "reserve widths should be related to canopy height and density". The present results suggest that the sediment entrapment capability of the foreshore region around northwestern Ontario lakes may be much lower than that for the backshore region due to the presence of smaller trees, dominance of coniferous species, and bare exposed bedrock. Because of this, Pike and Racy's (1989) advice concerning the design of riparian buffer strips in relation to forest characteristics should be heeded.

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