Analytical methods for defining stand–clearcut edge effects demonstrated for N mineralization

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Abstract: Edge effects are becoming an important forest management consideration, but information regarding the in-

(Franklin and Forman 1987). Edge effects such as soil tem-perature and moisture (Saunders et al. 1999; Gray et al. 2002; Redding et al. 2003). It has been proposed that these variables may influence the spatial patterns of soil nitrogen (N) mineralization across edges (Chen et al. 1995; Edmonds et al. 2000).

The detection and quantification of edges and their functions may require the application of a range of techniques (Fagan et al. 2003), depending on the form of the boundary and the type of data available (Strayer et al. 2003). Recently, wavelet analysis has been used as an edge detection technique to allow comparison of the position of the structural edge (location of trees) and the position of the functional edge (location of transition between forest and clearcut for the variable of interest) for structure and composition of forest vegetation (Harper and Macdonald 2001) and soil tem-BC V2C 2T7, Canada.

perature and moisture (Redding et al. 2003). Wavelet analysis is well suited for studying spatial patterns across forest edges, as it does not require data normality or stationarity, unlike many other spatial analysis methods used in soil and forest ecology research (Lark and Webster 1999; Csillag and Kabos 2002; Lark and McBratney 2002). To complement the wavelet analysis, the depth-of-edge influence (DEI) method (Chen et al. 1995; Saunders et al. 1999) may be employed to provide the range (functional extent of the edge effects) over which the transition between forest and clearcut occurs for different variables. In addition, variance partitioning methods (Borcard et al. 1992) may be employed to investigate the influence of the edge on selected response variables relative to the influence of various environmental and spatial variables.

At the Sicamous Creek silvicultural systems trial (Vyse 1999), edge effects have been well documented for a number of biotic and abiotic variables (Huggard and Vyse 2002), including soil temperature and moisture (Redding et al. 2003). Concurrent research at the Sicamous Creek site has also measured elevated nitrate concentrations in forest floor and

N mineralization

The buried bag method (Hart et al. 1994) was used for determining net nitrification and net ammonification at all sampling locations. Two sets of samples were collected: fresh samples for analysis of initial (preincubation) NO_3-N and NH_4-N concentrations; and field-incubated samples for analysis of postincubation NO_3-N and NH_4-N. Both initial and incubated samples were composites of three subsamples collected within 20 cm of every sampling point. Samples were incubated for 40 days (July 6 – August 14, 2000). Samples were stored at 4 °C until processed within 1 week of field collection. In the laboratory, samples were sieved (4.7-mm mesh) to remove pieces of wood and rocks. A 5-g subsample (dry mass equivalent) was extracted in 1 mol/L KCl and filtered through Whatman No. 42 equivalent Gelman glass-fibre syringe filters. Extracts were analyzed for NO_3-N and NH_4-N concentrations with the use of a Lachat QuikChem® AE autoanalyzer (Lachat Instruments, Madison, Wis.). Net nitrification and net ammonification were calculated as the difference between postincubation and unexplained (Borcard et al. 1992). The spatially structured environmental variation is determined by environmental variables that covary with spatial variables (Borcard et al. 1992). Variance partitioning was performed with partial RDA in CANOCO™ (ter Braak 1998).

Forest floor net nitrification and net ammonification were used as separate sets of response variables in the variance partitioning. All variables were assessed for normality and transformed, as required, with square root or logarithmic transformations to most closely approximate a normal distribution. The net nitrification and net ammonification data sets were each split into three subsets: all samples, forest samples (not for net nitrification, as most locations had values below the analytical detection limits), and clear-cut samples. The inclusion of each additional insignificant explanatory variable is likely to increase the amount of variation explained by chance alone (Borcard et al. 1992; Okland and Eilertsen 1994). Therefore, the number of environmental and spatial variables measured was reduced for the analysis by removing variables with high inflation values or low explanatory power in a forward selection procedure (ter Braak 1998). For all data sets, the number of environmental variables retained was less than 10, and the maximum number of spatial variables was 4.

Results

Initial NO_3-N and NH_4-N contents and net nitrification rates all increased markedly from the forest into the opening; net ammonification changed only little across the edges (Fig. 1). Clear edge-related influences (single dominant peaks) were found by wavelet analysis for initial NO_3-N and NH_4-N and net nitrification (Fig. 1) at both the 1- and 5-m spatial resolutions (Table 1). These edges were within 3–7 m of both north and south edges (Table 1). The functional extent of the edge effects (DEI range) was small (<4 m) for ni

Variable	South edge Range (m)	South edge Width (m)	North edge Range (m)	North edge Width (m)
Initial NO_3-N	50–53	3	146–150	4
Net nitrification	51–53	2	146–150	4
Initial NH_4-N	40–44	4	146–153	7
Net ammonification	N.D.	N.D.	N.D.	N.D.

Note: Obtained from depth-of-edge influence analysis for north

analysis. For net nitrification in the clearcut and for all variance partitioning analyses conducted on the three net ammonification data sets, environmental factors were the predominant sources of variability and spatial influences were small.

Discussion

The application of three complementary analytical methods (wavelet analysis, DEI, and variance partitioning) indicated that initial NO_3-N content and net nitrification rate increased abruptly within the clearcut close to the edge. This does not agree with the hypothesis that N mineralization would change gradually across the edge following the patterns of soil temperature and moisture. Wavelet analysis indicated soil temperature and moisture data boundaries at 57–62 m for the south edge and 160–168 m for the north edge, depending on the variable and weather conditions (Redding et al. 2003). The DEI analysis indicated the functional zones of edge influence were 50–62 m and 150–160 m for soil temperature and moisture, depending on the variable and weather conditions (Redding 2001). Although changes in initial NO_3-N content and net nitrification occur within the temperature and moisture transition zones for the south edge, they do not at the north edge, where changes in temperature and moisture occur within the forest. These results are confirmed by the variance partitioning of net nitrification, which shows that the difference between forest and clearcut overwhelms any more gradual edge gradients, such as those for temperature and moisture.

The spatial pattern in net nitrification may be related to differences in substrate. In a concurrent study at Sicamous Creek, Prescott et al. (2003) examined the relative influences of soil temperature and substrate quality on net nitrification in buried bags. They found evidence that differences between forest and clearcut substrates, rather than differences in soil temperature, were driving the difference in net nitrification. The abrupt changes in initial NO_3-N content and net nitrification correspond spatially to the boundary of the canopy drip line approximately 2 m into the opening from the tree stems (G. Hope, B.C. Ministry of Forests, unpublished data), a decrease in recent conifer litter within 4 m of the edge (Redding 2001), a large decrease in fine root abundance (Welke et al. 2003), and a decrease in fungal diversity and abundance (Hagerman et al. 1999). The absence of litter, conifer fine roots, and hyphae may indicate a loss of labile carbon sources (Stark 1994) and reduced fungal immobilization (Stark and Hart 1997), resulting in greater accumulation of NO_3-N in the forest floor during incubation. Our results for net ammonification, although not explainable by substrate differences, agree with those of Prescott et al. (2003), who found no difference between postincubation NH_4-N concentration in 1-ha clearcuts and that in forests 5 years after harvest at Sicamous Creek.

Wavelet analysis allowed comparison of the position of the forest edge (50 and 150 m) with the location of the transition between forest and clearcut for N mineralization and comparison between different variables. Wavelet analysis provides a robust tool for quantifying edge effects, as it does not require data normality or stationarity, unlike many other spatial analysis methods commonly used in ecology and soil science (Bradshaw and Spies 1992; Lark and Webster 1999; Csillag and Kabos 2002). However, wavelet analysis, as with most other edge detection methods, works best for well-defined boundaries (Fagan et al. 2003). When patterns in the data are not clear, the interpretation of what is and what is not a boundary is subjective. As a boundary detection method, the usefulness of wavelet analysis is only as clear as the data series on which it is performed. For some data sets, it might be possible to increase the maximum scale (kernel size) of the wavelet to provide a smoothing effect and a larger scale interpretation of the spatial pattern; however, long data series are required so that boundaries are not obscured by distortion at the ends of the series (end effects) (Lark and McBratney 2002).

Although the DEI results confirmed, for the most part, the results of the wavelet analysis, this method also requires subjectivity in application and interpretation. A problem with all edge detection methods is that when boundaries are not clearly defined, they can produce results that might be misinterpreted as a well-defined boundary (Fagan et al. 2003). We have shown that for our data set, the interpolation of the data to 1-m spacing did not introduce artefacts into the results of the wavelet analysis. This might be due to the fact that the original sample spacing was only 1–2 m within the zone in which all edge influences occurred in the N mineralization data, and therefore potential distortions due to interpolation for this data set were likely minor. The use of the 1-m interpolated data provided greater resolution in delineation of edge effects relative to the results of the 5-m data. However, on the basis of our experience, we recommend that wherever possible, a regular sampling interval be used when wavelet analysis (or most other edge-detection methods) is to be applied, to avoid any potential complications introduced by interpolation to a regular interval.

The variance partitioning provided a useful tool for examining the role of multiple spatial and environmental influences on net nitrification and net ammonification. For net nitrification, the primary source of explained variability was related to differences between forest and clearcut and not the more gradual edge effects measured for soil temperature and moisture (Redding et al. 2003). As net ammonification did not show a strong forest–clearcut contrast, the primary source of explained variation was from environmental variables, rather than spatial influences. Although the unexplained variance component was large, this is consistent with most other applications of this technique (Borcard et al. 1992; Okland and Eilertsen 1994).

From this examination of boundary detection and quantification, it is clear that a careful visual inspection of the data is necessary to confirm that wavelet peaks and DEI-determined zones are related to edge effects. However, the advantage of these techniques over purely visual inspection is that they provide a boundary location or extent of edge effects that can be compared consistently between variables or