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Comment

Comment on 'Kane *et al*. 2008. Precipitation control over inorganic nitrogen import-export budgets across watersheds: a synthesis of long-term ecological research. *Ecohydrology* 1(2): 105–117'

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A recent paper in Ecohydrology (Kane *et al*., vol. 1, pp. 105–117) made a first attempt to synthesize and compare a large body of watershed biogeochemical data from diverse Long-Term Ecological Research (LTER) sites, which is certainly an impressive exercise. These authors correctly point out that while there is large body of work exploring the ways that disturbance and elevated N influence the relationships between N deposition and watershed dissolved inorganic N (DIN) retention, there have been a few studies exploring climate and precipitation effects on N losses from watersheds using a cross-site approach.

However, there appear to be some flaws in the logic and data analysis that we would like to point out, not as a critique of this exercise *per se*, but to raise further avenues for research and to raise new questions that perhaps could be answered by different analyses or more focused research.

Our main concerns are over inferences made from the graphs in the paper. The problem, of course, with a cross-site, observational data set is that it is not experimental. In other words, no factors could be held constant while variables in question could be varied, so the sample may not be representative of the full range of variation in presumed causal factors, and may even coincide with other, underlying factors not included in the analysis. In this case, simple geographical patterns in N deposition unfortunately confound most of the interesting climatological inferences that were made. The issues of interpretation arise from the fact that much higher N deposition occurs in the eastern compared with the western United States or Puerto Rico. Also, N retention calculated as the difference between inputs and outputs creates a bias for eastern sites with high N inputs to appear to have a high capacity for retention, simply because there is much more N entering the system to be retained than there is in the western sites.

While one might predict that strongly N-limited forests with low inputs of N might be highly retentive of N, this is generally not the case, and this seeming paradox has been the focus of numerous analyses (e.g. Vitousek *et al*., 1998; Cairns and Lajtha, 2005). Not only are significant quantities of dissolved organic N (DON) lost in many temperate forests with low anthropogenic N inputs (Sollins and McCorison, 1981; Hedin *et al*., 1995; Lajtha *et al*., 1995; Vanderbilt *et al*., 2003) but also a certain baseline of DIN is lost due to small and/or large scale disturbance, preferential flow past roots, and from precipitation that leaches through soil during dormant seasons. Thus with very low N inputs, pristine forests can appear to have low retention simply because any stream output loss at all will appear to be significant compared to their small deposition input value. Conversely, forests with high levels of N in deposition can appear to have high 'retention' in part because N losses due to riparian zone/stream denitrification and stream N uptake are counted as retention when using stream output as a measure of loss from the terrestrial ecosystem (Cairns *et al*., 2009). A lack of understanding of this problem led to an error in the interpretation of Figure 3. The authors conclude that 'In general, temperate deciduous watersheds [Hubbard Brook (HBR), Coweeta (CWT), and Walker Branch (WBR)] had higher net DIN retention than did old-growth, coniferous [H.J. Andrews (AND)], boreal [Bonanza Creek (BNZ)], and tropical [Luquillo (LUQ)] watersheds (Figure 3).'

In fact, the correct statement to describe Figure 3 should be that 'the temperate deciduous watersheds measured [Hubbard Brook (HBR), Coweeta (CWT), and Walker Branch (WBR)] have significantly higher N

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inputs than the pristine sites used in the study, and, not surprisingly, higher DIN retention measured as a difference between inputs and outputs.'

The spatial pattern of N deposition (higher in the eastern than the western United States) also coincides with the spatial pattern of seasonality of precipitation, leading to a spurious correlation between seasonal precipitation and N deposition (Figure 6 in Kane *et al.*). The western sites (AND, BNZ, Gila) all have low N deposition and dry summers (high seasonal variation in precipitation); while the eastern sites have high N deposition and low seasonal variation in precipitation. The LUQ site in Puerto Rico, however, has both low N deposition and low seasonal variability. The fact that LUQ appears as an outlier in a plot of precipitation seasonality versus N retention demonstrates that the correlation with seasonality is purely spurious and that DIN retention as calculated is highly related to DIN inputs.

Issues of inconsistent interpretation of outliers plague both Figures 6 and 5, illustrating the challenges of drawing general inferences in an observational study from a sample of sites that was not selected to represent all possible combinations of causal factors. Thus, in Figure 5, where possible 'outliers' were included in the model fitting, they may produce a marginally significant trend. In contrast, in Figure 6, the point representing LUQ is treated as an outlier relative to the overall trend. In both cases, it is not clear whether these single points represent a large number of actual cases inadequately represented in the sample, or whether they should be treated as aberrations. This problem is demonstrated by the spurious correlations that emerge, above, from samples that happen to coincide with an underlying trend such as N deposition or seasonality of precipitation. The solution to this problem is to (1) map the locations of sample points in the geographic space of the causal factors as noted here; (2) make a decision whether they represent a large (but underrepresented, hence necessary to include) or small (hence over-represented, and perhaps necessary to exclude) contribution to the inferences drawn from the statistical model, and (3) apply this decision consistently across various statistical analyses.

Kane *et al.* represent a valuable first step for an intersite comparison of N budgets. The point of this note is to commend this cross-site comparison, and to urge the authors to rethink some of the analyses they used, and perhaps to find creative ways to extract statistically significant trends in spite of the strong covariance between geographic trends in N deposition and seasonal climatic variability. This covariance likely confounds many cross-site comparisons within LTER and other data, and a creative solution to this would be welcome.

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