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Interactive comment on "Measuring ecosystem nitrogen status: a comparison of proxies" *by* M. Almaraz and S. Porder

M. Almaraz and S. Porder

maya_almaraz@brown.edu

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Author's Response to Comments by Referee #2

We thank the reviewers for their thoughtful comments, which we think have led to substantial improvements in the manuscript. Below we provide a detailed list of responses.

Anonymous Referee #2 Received and published: 28 April 2016

Referee #2: BG review This paper poses an interesting and important question about whether different metrics used to characterize N availability (which represent different spatial and temporal scales) are correlated. This topic is of potential interest to a broad group of researchers who consider N availability in their studies. The paper attempts to evaluate some underlying assumptions that are included implicitly or explicitly in

interpreting ecosystem N dynamics. The scope of the analysis is not really clear from the paper. It is a little surprising that the authors did not include several large syntheses of similar data (Aber at al. 2003, BioScience, Pardo et al. 2006 Biogeochemistry, the CANIF study in Europe, Schulze 2000 Springer).

Response: Thank you for this comment and for the citations. We did our best to find all the literature available, however we are sure to have missed some. We did not include Aber et al. (2003) because they do not report the variables we are focused on, at least not in a manner that was useable in this analysis (i.e. they report NO3- but not NH4+ or DON, and they report percent nitrification rather than a nitrification rate in ug N/g/d). We did use Pardo et al. 2006 (which included CANIF sites) to find original papers, from which we extracted data. Any sites that seem to be excluded may have been done because we were unable to find multiple proxies from that site. We thank you for the Schulze 2000 reference and have added these data to our analysis.

Referee #2: The scope of the analysis is important, because it can be difficult to make assertions about different climatic zones or life forms unless enough variation is included among the samples to represent that observed

Response: We agree and have included the following text to strengthen that point.

Line 78-81: "This review assesses the correlation between common foliar, surface soil (i.e. δ15N, nitrification and mineralization), and nutrient loss (i.e. soil solution and stream N concentrations) metrics of N availability from unmanaged ecosystems globally."

Referee #2: Several issues should be addressed: Nitrate leaching is referred to as if it were the driver of the fractionation that would lead to 15N-enrichment of material remaining in the ecosystem (soil, foliage). In fact the elevated nitrification which leads to an increase d15N of the plant available (including the nitrate that leaches to the stream) is the driver. The authors are, no doubt, well aware of this, but it is worth taking the trouble to be more precise for the reader less familiar with these dynamics. This

should be addressed at several points in the paper.

Response: Thank you. We did not intend to give the impression that leaching is a key driver of isotopic enrichment in leaves and soil. To remedy this, we inserted: “primarily denitrification” in lines 63-64, and “during nitrification” in line 67.

Referee #2: The isotope literatures is not as current as it could be. I have given some examples of possible additional citations.

Response: Thank you for those. We have included the caveat that our literature search included only papers published prior to 2013 (line 86).

Referee #2: I assume that when the authors talk about long-term patterns and measures that are invariant temporally, that they mean in undisturbed systems. This should be stated explicitly, since over the long term, at many of these study sites, various disturbances have occurred which disrupt that N cycle and which would affect the values of these metrics.

Response: We added “in relatively undisturbed ecosystems” (line 34). However, one weakness of our approach for stream measurements is the nature of land use change upstream from a particular site described in the papers we searched. We have made that caveat clearer on lines 240-243, which now reads: “varied land-use (e.g. pasture, N fixing plant species, etc.) upstream of undisturbed sites is typically not reported in the literature, but is another possible explanation for the lack of correlation between terrestrial and water-based proxies.”

Referee #2: Need to define what is meant by N status.

Response: Agreed. We rephrased this to include “relative abundance of plant available N” (line 33-34).

Referee #2: More explanation about the differences between observed correlations in tropical versus temperate systems would be useful (why were foliar and soil d15N correlated in tropical, but not temperate?)

Response: We added lines 244-253: “While most observed correlations were consistent across latitudes, a few differed between the tropics and the temperate zone. The correlations of soil 15N with foliar 15N, foliar 15N with net nitrification, and net nitrification with N mineralization were consistent across both tropical and temperate regions. Net nitrification and N mineralization were correlated with stream DIN:DON only in temperate regions. These data suggest that while terrestrial proxies may be a useful across biomes, stream DIN:DON requires further research to understand the extent of its applicability across space. The correlation between foliar and soil δ15N also differs across latitudes, in that the correlation in the tropics was much tighter than in the temperate zone. Bias in the literature towards natural abundance isotopic data from the temperate zone may explain why previous research looking at this relationship has been noisy (Craine et al., 2009).”

Referee #2: Abstract: 10 if space permit, include the region considered in this study 19 is there a ‘that’ missing? i.e., given that both. . .

Response: We corrected these. Thank you.

Referee #2: 27 why ‘Nevertheless”? what follows doesn’t not seem to contrast with what was said in the first sentence. 31 don’t really need ‘such’ on this line 32 I would suggest adding ‘rates’ after mineralization and nitrification, to make the comparison to another flux clearer. Also, the verb needs to agree with the subject is→are

Response: We corrected these. Thank you.

Referee #2: 33-4 This is an important point (basing annual budgets on short-term measures) and one that is often ignored.

Response: Agreed.

Referee #2: 34-6 There seems to be a word missing or a punctuation problem. Is ‘are relevant’ associated with scales or N status?

Response: We changed this to “While N status measured over longer temporal and

larger spatial scales is relevant to many ecosystem properties and their response to global change, it is more difficult to measure." (lines 37-39)

Referee #2: 87-90 Is this level of detail necessary?

Response: See our response to Reviewer 1 (and our response now in lines 92-96), who had a query about why we chose these metrics and not others. We thought it best to present our thinking as fully as possible.

Referee #2: 90 What is meant by 'intact'? does this mean 'not fragmented'? Or is it intended to include disturbance as well? And if so, only anthropogenic disturbance (e.g., harvesting) or also natural (fire, wind, ice or pest events, etc.)?

Response: We agree "intact" was unclear. We changed this to: "We limited our search criteria to studies that took place in forest or grassland ecosystems that had not incurred any large disturbances that might impair their function." (lines 100-102).

Referee #2: 92 Is there a list of the sites in supplemental information? (cite supplemental material here)

Response: The list is available in the supplemental. We have now noted this on line 106. Thank you.

Referee #2: 101 Is it appropriate to lump net nitrification potential measures with measures of nitrification? This should be justified.

Response: We agree that this is a point worth clarifying in the text. We limited our nitrification methods to intact soil core, buried bag, and lab incubations in order to avoid any methodological differences (as state in lines 112-114). In the literature net nitrification and nitrification potential are terms that are sometimes (but not always) used interchangeably (Ross et al. 2012, Journal of Geophysical Research: Biogeosciences, 117(G1); Bohlen et al. 2001, Ecology, 82(4), 965-978). Some authors define a buried bag incubation as "potential" because it is not what is actually happening in intact soils. However others define nitrification "potential" as how much nitrification happens

when soils are amended to overcome potential substrate limitations to nitrification. We did not include any nitrification assays where the soils were amended and have thus revised the text to reflect this (lines 112-114): "In order to control for methodological differences, we limited our net nitrification and N mineralization methods to those which used intact soil core, buried bag, and laboratory incubations of unamended soils".

Referee #2: 105-6 This level of detail is unnecessary.

Response: We thought that including this level of detail might help field reader questions regarding the analyses we chose to run and have chosen to leave the text as is unless the editor prefers we remove it.

Referee #2: 107 Are these five watersheds identified somewhere? Supplemental material?

Response: Yes, the supplemental data lists full citations for each watershed, and there we state where we "collected soil".

Referee #2: 137 How is foliar d15N on the same timescale as bulk soil d15N? The plant available portion of the soil pool is very small and is not what is measured by bulk soil. Foliar %N and d15N can vary on very short time scales. Bulk soil d15N may vary in response to disturbance, but the soil N pool is many orders of magnitude larger than the foliar N pool.

Response: We agree that foliar δ15N can differ among species, and that N in leaves turns over much more quickly than N in soil. However, our understanding is that average foliar δ15N for a site is relatively stable in time, absent large changes in species composition. If the reviewer can point us to literature that suggests otherwise we would be happy to incorporate it in our discussion.

Referee #2: 141 What does 'that' refer to in this sentence (that of water-based proxies)

Response: We changed this to read "with water-based proxies" (line 168).

Referee #2: 144 Does the absence of a correlation between soil solution and stream DIN:DON suggest that stream DIN:DON does not reflect what is available in the terrestrial ecosystem?

Response: We think so, at least for the dataset here. We discuss this in lines 212-227, which read: "Another surprise from our dataset is that soil solution DIN:DON was not significantly correlated with any other metric, not even with stream DIN:DON, despite $\sim$40% of papers in our dataset reporting both soil solution and stream DIN:DON in the same watershed. While the correlation between soil solution DIN:DON below the rooting zone and N availability has been documented across gradients in soil age and fertility (Hedin et al., 1995), this correlation was not found across the range of sites examined here. We found a no relationship between soil solution DIN:DON and lysimeter depth, suggesting that the majority of N transformations responsible for the discontinuity between soil solution DIN:DON and that of terrestrial metrics are likely occurring either within the rooting zone or in riparian zones. Neither soil solution or stream DIN:DON was sensitive to environmental variability (i.e. elevation, temperature, precipitation, N deposition), suggesting that processing along flowpaths may be responsible for the disconnect between soil solution and stream N concentrations. From these data, at least, it does not seem that soil solution DIN:DON can be used to infer terrestrial N status across this suite of unmanaged sites. These data also do not support the idea that soil solution DIN:DON is representative of N forms that leach into streams (Binkley et al., 1992; Pregitzer et al., 2004; Fang et al., 2008)."

Referee #2: 155 Foliar 15N is not an integrator on the time scale of decades to centuries

Response: The fact that foliar N is derived from soil N and that foliar δ15N correlates with soil δ15N across broad spatial scales suggests that these two values are dependent on one another. While we agree that average foliar δ15N may change faster than soil δ15N in perturbed sites that have experienced a turnover in species composition or large scale disturbances, we argue that foliar δ15N in relatively undisturbed ecosys-

tems (such as the sites that we analyzed) change on a similar timescale as soil δ15N.

Referee #2: 160 It seems a fairly broad interpretation to say that these data suggest that correlations between categories 1 and 2 are robust some of them may be, but not all of them. To what extent is it reasonable to extrapolate this finding?

Response: We agree that it was not well written. We have changed this line to read "Our data suggest that category 1 and 2 metrics are correlated" (lines 193-194).

Since these data incorporate as much of the available data that we could find across a broad geographic and climatic range, we would imagine these findings can be extrapolated, but when we look at differences within biomes it becomes apparent that these relationships may vary geographically, and for that reason we call for more research examining these relationships at smaller spatial scales in lines 257-260: "Explicit comparisons of these proxies to each other, with a focus on how they are influenced by hotspots, hot-moments, biological diversity, and N transformation between the soil-stream interface, will enhance their utility for understanding N availability at the ecosystem scale."

Referee #2: 171 I don't see why one would expect DIN:DON to be correlated with soil 15N, they are measuring very different things.

Response: We agree. However, in the literature both are used as an indication of N status within watersheds. We hope that these data highlight that they are measuring different things, and that interpretations of terrestrial N status based on these metrics is not straightforward. This is a key point we hope this paper makes.

Referee #2: 178 Is DIN:DON more sensitive to N deposition than DIN?

Response: We would presume that DIN is more sensitive than DIN:DON, because N can be deposited in both forms, but the majority is deposited as DIN. As we suggest in lines 207-208, because most N deposition comes in the form of DIN, DIN:DON is lower in pristine settings than in polluted ones.

Lines 207-208: “We note that stream DIN:DON is sensitive to N deposition, and that relatively pristine settings have a lower DIN:DON than polluted ones (Perakis and Hedin, 2001).”

Referee #2: 183 What does it tell you if soil solution DIN:DON is not correlated with stream DIN:DON?

Response: We propose several explanations for this in the text (lines 228-243). One of which is that N is removed along hydrologic flowpaths, and another is that stream N is potentially affected by upstream land-use/inputs that overshadow local inputs.

Referee #2: 198 Hydrologic flowpath and flowrate are also probably important. 2002-4 Work by K. Lohse et al. addresses these issues.

Response: Agreed. Thank you for the citation. We touch on this in lines 228-243: “While nitrate (NO3-) removal along flow paths can reduce stream NO3- (Vidon et al., 2010), with higher percent removal in forested watersheds (Sudduth et al., 2013), DON has been shown to be relatively resistant to removal by decomposition and biologic uptake along subsurface flowpaths (Carreiro et al., 2000, Neff et al. 2003). We found no correlation between stream and soil solution DIN:DON, and suggest that variation in NO3- removal (relative to DON) along flowpaths below the rooting zone of undisturbed ecosystems may explain this lack of correlation. The extent to which riparian zones influence nutrients varies spatially with geomorphology, soil texture, vegetation, and riparian zone development (McDowell et al., 1992, Mayer et al., 2007); and soils with high rates of leaching to ground water may bypass riparian processing. As nutrients leach down the soil profile, denitrification, biologic uptake, and storage are all potential mechanisms that could alter soil solution and stream N species concentrations. Investigation of soil profile processes and riparian zone spatial variability may help determine where and when watershed-scale N status can be inferred from these proxies. Alternatively, varied land-use (e.g. pasture, N fixing plant species, etc.) upstream of undisturbed sites is typically not reported in the literature, but is another possible ex-

planation for the break down between terrestrial and water-based proxies.”

Referee #2: Figures and tables Fig 2 there is a lot of useful information in Figure 2, but the graphs are too small and are illegible. The format, in the end, is more clever than useful. It would be better to enlarge the graphs a bit so that it is easier to resolve the patterns. (The quality of the figure in the paper I downloaded is fair, but I assume there is a high resolution version). The size of the statistical info is fine and legible. It might be easier to follow if it were presented in the same triangle configuration as the figures (as opposed to flipped) or else in a table.

Response: Thanks. Since there are 16 graphs, we chose this format to conserve space. However, we have attempted to make the panels bigger so that they can be seen more easily. We hope that the editor will inform us of any further issues with legibility/resolution.

Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/bg-2016-43/bg-2016-43-AC2-supplement.zip

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