

Biogeosciences Discuss., author comment AC1
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Reply on RC1 (second revision)

Laura Anahí Macario-González et al.

Author comment on "Geodiversity influences limnological characteristics and freshwater ostracode species distributions across broad spatial scales in the northern Neotropics" by Laura Anahí Macario-González et al., Biogeosciences, <https://doi.org/10.5194/bg-2021-298-AC1>, 2022

Reviewer 1.- We deeply appreciate all your comments and suggestions to improve the manuscript. Below you will find answers to each of your comments and questions. In case we were unable to follow them, we provide an explanation.

General comments

Main text

Parts of the methods and most of the results are still written in present tense. Both sections are normally reported in the past tense. Two examples out of many:
187: The final data set includes 23 variables, of which 21 are numerical...
297: The PC1 accounts for 23.4%...

Answer: We carefully check the verb grammatical tense in the "Methodology" and "Result" sections. We additionally check grammatical time of verbs of other sections. Verbs were changed to their correct grammatical time.

204: I think the name of the R package that you used is "PCAmixdata"

Answer: PCAmixdata is the correct name of the package, this was changed throughout the manuscript.

288: "Limnological classification"; In the previous review, I commented "... the terms "limnological classification" and "limnological regions" are confusing as you also use the term "limnology" as hypernym for water chemical and physical properties of the aquatic ecosystems. The "limnological classification", however, is based next to limnological variables also on geological, sedimentological and mineralogical variables."; and you answered "...the term limnological classification was changed to geolimnological classification to be more precise and not to be confused with limnological variables.". I could not find these changes in the revised version of the manuscript.

Answer: We changed the term, but we decided not to use "geolimnology", as it may produce additional confusion. We stick with the term "limnological regions" used in other sections of the manuscript. The corrected text is as follows: "Limnological regions in the northern Neotropical region, with lakes main water physical, chemical, mineralogical, and geological properties"

305: ad figure 3 (a) and figure 4 (a): The two axes (component 1 and component 2) need to be on the same scale, otherwise arrows which rather follow the direction of component 1 seem more important.

Answer: figures were rescaled to the same extent to avoid graph misinterpretation.

436: Only species composition was included, not richness?

Answer: The analysis was performed on both species composition and richness, thus, we included richness to the text.

450: The explanations for CFI, RMSEA and SRMR need to appear when you first mention these metrics (line 436)

Answer: Following the suggestion of the reviewer, we provide the explanations for global metrics of fit CFI, RMSEA and SRMR in line 436.

600-601: It is not clear, what the values in the brackets mean " <0.1 ", " >2.0 ". Also consider a different word for "insignificant", because the paths are significant, however, of minor importance.

Answer: To avoid confusion, symbols $<$ and $>$ in the brackets were deleted and the significance value was used. Following the recommendation of the reviewer we exclude "insignificant" and used "significant with minor importance"

Supplement

I am not familiar with the output table of SEMs, however, it seems that conductivity and elevation/altitude are still part of the latent variables limnology and geodiversity, respectively, although they should be excluded from those latent variables in model 4 where the "individual influence of elevation and conductivity was tested on species composition and richness."

Answer: We re-run the SEM analysis excluding elevation and conductivity from geodiversity and limnology latent variables respectively. We update SEM output, global metrics of fit and resulting graph. Results and discussion were updated as well, but they are only slightly modified as no major changes were observed.

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Reply on RC2 (second revision)

Laura Anahí Macario-González et al.

Author comment on " Geodiversity influences limnological characteristics and freshwater ostracode species distributions across broad spatial scales in the northern Neotropics" by Laura Anahí Macario-González et al., Biogeosciences, <https://doi.org/10.5194/bg-2021-298-AC1>, 2022

Reviewer 2.- We appreciate all the comments and suggestions, they significantly improve the manuscript. Below we provide answers to all comments. We addressed most of the suggestions made by reviewer 2, but in case this was not possible, we provide a detailed explanation.

General comments

Geodiversity. I appreciate the defining of "geodiversity" at Line 38. It seems that the term "geodiversity" is synonymous with "local environmental conditions", a term that is more clear and is used nearly exclusively (at least in the multiple studies that I have seen). It's not clear why "geodiversity" is preferred, and in fact the term is misleading -- especially the "diversity" part of the word (which implies differences among sites, rather than denoting a fixed set of conditions). The authors should at least indicate this synonymy, e.g. near Line 38. Note that this is especially misleading at Line 618. I encourage the authors to consider replacing each "geodiversity" with "environmental conditions" (or a variation thereof) throughout, unless there's a convincing reason that "geodiversity" is indeed the better term.

Answer: The term geodiversity is defined by various authors as follows:

1. The "Encyclopedia of Geomorphology (edited by A. Goudie) Zwolinski states for the term "geodiversity" (p. 417): The most popular definition of geodiversity was put forward by the Australian Natural Heritage Charter (AHC 2002): Geodiversity means the natural range (diversity) of geological (bedrock), geomorphological (landform) and soil features, assemblages, systems and processes. Geodiversity includes evidence of the past life, ecosystems and environments in the history of the earth as well as a range of atmospheric, hydrological and biological processes currently acting on rocks, landforms and soils."
2. Gray, M. (2004: Geodiversity: Valuing and Conserving Abiotic Nature. John Wiley & Sons Ltd., Chichester) presents different definitions of the term geodiversity (see Table 1 on page 10). Often the definitions include materials (similar to our study) such as minerals, rocks, sediments, fossils, soils and water.
3. Schrodtt et al. (2018 Journal of Biogeosciences) defines geodiversity as the variety of geological, geomorphological, pedological and hydrological features and processes, although some definitions include atmospheric aspects, too.

We are convinced that in our study the use of the term “geodiversity” is justified, as we integrate at least 5 aspects of the term such as geology (bedrock), mineralogy, sediments, landform (elevation), and hydrological features of landscape. In studies of macro-ecology and biogeography using species distribution, diversity, and richness, a holistic view of the historic causality and current drivers of observed patterns is gained by using aspects of geodiversity (using the term as it). The term geodiversity is therefore, commonly used together with the term biodiversity, and such integration is strongly recommended by several authors to comprehensively evaluate linkages between them for biogeography, conservation, and climate change studies. “Environmental conditions” may refer to broader aspects of the landscape including atmospheric, soil and water variables and even human disturbances. Below please find attached references of the applied use of the term geodiversity for biodiversity analysis.

Alahuhta, J., Ala-Hulkko, T., Tukiainen, H., Purola, L., Akujärvi, A., Lampinen, R., & Hjort, J. (2018). The role of geodiversity in providing ecosystem services at broad scales. *Ecological Indicators*, 91, 47– 56. <https://doi.org/10.1016/j.ecolind.2018.03.068>

Bailey, J. J., Boyd, D. S., & Field, R. (2018). Models of upland species’ distributions are improved by accounting for geodiversity. *Landscape Ecology*, 33(12), 2071–2087. <https://doi.org/10.1007/s10980-018-0723-z>

Bailey, J. J., Boyd, D. S., Hjort, J., Lavers, C. P., & Field, R. (2017). Modelling native and alien vascular plant species richness: At which scales is geodiversity most relevant? *Global Ecology and Biogeography*, 26(7), 763–776. <https://doi.org/10.1111/geb.12574>

Hjort, J., Heikkinen, R. K., & Luoto, M. (2012). Inclusion of explicit measures of geodiversity improve biodiversity models in a boreal landscape. *Biodiversity and Conservation*, 21(13), 3487–3506. <https://doi.org/10.1007/s10531-012-0376-1>

Räsänen, A., Kuitunen, M., Hjort, J., Vaso, A., Kuitunen, T., & Lensu, A. (2016). The role of landscape, topography, and geodiversity in explaining vascular plant species richness in a fragmented landscape. *Boreal Environment Research*, 21, 53–70.

Tukiainen, H., Bailey, J. J., Field, R., Kangas, K., & Hjort, J. (2017). Combining geodiversity with climate and topography to account for threatened species richness. *Conservation Biology*, 3, 1–37. <https://doi.org/10.1111/cobi.12799>

All authors again agreed to use the term “geodiversity”, as it reflects best the content of our paper and thus fits perfectly – moreover this makes our study even more attractive to a much larger number of scientists from different disciplines.

Sample sizes. Apparently only six individuals (or three?) were identified at some sites, but as many as 60 were at other sites. A better mention of the numbers identified is essential, for example at Line 217. This creates the potential for a substantial error due to sampling effort. For sites with six identified individuals, the percentages are coarse approximations at best. This study is still useful – we all deal with compromised or limited data sets -- but this potential limitation must be addressed in the Discussion.

Answer: We realized that our text is not clear enough to explain our sampling procedure. Sampling was standardized for all lakes to avoid differences in sampling effort. In most lakes, 5 littoral water samples and 5 sediment samples were collected (a total of ten samples). In five large lakes such as Lake Nicaragua, Lake Atitlán, which exceed 100 km², we collected seven water and seven sediment samples (14 samples). Out of these samples, we sorted individuals and separated them based on their external morphology. The identification of the morphological groups was conducted by dissecting and evaluating taxonomic attributes in at least three individuals. Based on this, we consider that our sampling effort did not bias our diversity index calculations. Now, we clearly explained the sampling procedure in the manuscript.

Specific comments

Comments: Line 156: Please give the reader an idea of how many samples were *typically* collected. If most lakes were represented by two samples (i.e. 6 individuals) but some were represented by ten samples (i.e. 30 individuals), this may affect the apparent distribution of species as well as the calculated richness and Shannon-Weiner diversity indices.

Answer: sampling size was standardized in all lakes to reduce bias related to total and relative abundance, richness and diversity. In almost all lakes five littoral and five sediment samples were collected and analyzed. As lake size matters and may produce over- or underestimation of diversity because of sampling effort. For six large lakes from Central America, seven littoral and seven sediment samples were evaluated. This is explained in detail in lines 156-162.

Line 215: Change "was" to "were".

Answer: done

Line 216: Either transpose "stereomicroscope" and "Leica MZ75", or place "Leica MZ75" in parentheses.

Answer: Following the suggestion of the reviewer we added "Leica MZ75 stereomicroscope"

Line 217: It seems that only 3 individuals were identified in each sample, and up to 10 samples were collected at each lake (Line 156); please report the average number of samples per lake. Multiple sampling is appropriate and should be repeated here at Line 217. I'm not familiar with ostracod procedures, but three is a very small number. If this is a reasonable number, please indicate and include references. For example, add "Although a sample size of three is very small, this is consistent with ostracod studies in general (reference, year) in part due to low ostracod abundances in most sediments worldwide (reference, year)." In addition, see comment for Line 379.

Answer: For species identification, we first sorted ostracodes in all samples (mostly 10 samples per lake) and then, individuals were separated based on their external morphology (morphospecies). For each morphospecies a minimum of three individuals were dissected to identify them taxonomically at species level. Please consider that at each lake we recognize between 2-7 morphospecies. We describe this procedure in detail in the lines 219-225 in the methodology section.

Line 244: Delete "the" and transpose "software" and "Canoco version 5".

Answer: done

Line 248: Please specify the software that includes SEM. It may be part of R, but this isn't mentioned until Line 264, so a mention is needed early in this section.

Answer: We report in line 248 the R package used and then deleted it from line 264.

Line 379: Please report the total number of species.

Answer: We found 70 species, with species richness ranging from 1-9 species and 4 species average per lake. This information is described in line 385.

Line 421: I see the groups of ostracods from NMDS is Figure 5(a), but I would very much like to see the eigenvectors from CCA. A figure similar to Figure 4(a), but based on CCA, is important.

Answer: Following the suggestion of the reviewer, we include CCA eigen vectors and explained variation for the first and second axis to the NMDS graph.

Line 423: We're told that local geology is the ultimate driver, and I accept this as true. I think its effect is delivered through evaporative concentration (PCA shows that ionic concentration varies strongly among these systems). In other words, ionic concentration is the immediate cause; what matters *directly* to ostracods is water conditions, so local geology is an *indirect* factor. A figure with NMDS eigenvectors would be very, very useful for this.

Answer: The PCA shows that ionic concentration is highly variable between lakes and regions in our study area. In highlands, the variability of ionic concentration was mainly associated to evaporation and volcanic influence. This same trend is observed in highlands in Central Mexico and Central America. At regional scale, considering lowlands lakes, the role of evaporation in ionic composition is less evident and the role of bedrock seem to be more relevant. This latter patter is recovered in SEM analysis and therefore discussed in the manuscript, in lines 510-530.

Line 447: Insert comma after "limnology".

Answer: done

Line 460 (Figure 6): I like this figure very much; it's clear yet detailed. I'm somewhat confused, however: doesn't "geodiversity" *include* limnology, conductivity, and elevation? I'm not sure that "NMDS" is needed in the "Species composition" box; please verify and/or put "NMDS" in parentheses.

Answer: As previously suggested, geodiversity now is more precisely defined and used in the manuscript. For SEM, geodiversity was defined based on bedrock type and age and elevation. Limnology was used as an independent variable and considered to be integrated by conductivity ionic composition, pH. Please see supplementary material S1 section. This discrimination was done to test the individual influence of geodiversity and limnology in ostracode composition and richness. In one of the models evaluated, we tested the individual influence of elevation and conductivity, as they were recognized as most influential for ostracode distribution in CCA. This model more clearly explains the relationships between species and geological and limnological variables.

The NMDS term included in the box of species composition was put in parenthesis.

Line 467: Replace "drives" with "defines".

Answer: done

Line 506: It's not clear that volcanism created most Central American lakes; in my experience, at least as many were formed by mass movement (in higher elevations). At best, the authors could say that "Volcanism is a common mode of formation".

Answer: we agree with the comment of the reviewer and changed the text accordingly.

Line 547: Line 217 reports that three ostracods were identified per sample, yet Line 547 reports up to nine species per lake.

Answer: We address this issue in the methodology section to avoid confusion. Three individuals make reference to the number of specimens dissected for identification of morphotypes observed in the lakes. We usually observed 1-9 morphotypes per lake.

Line 551: Collection effort can make a huge difference here. If ten samples were collected from one lake but only two from another, we'd expect greater richness in the 10-sample lake. In addition, two samples may be enough to characterize small lakes (*if* sufficient numbers of ostracods are identified in each sample), but this is less true for larger lakes. At least this should be acknowledged here: "While the number of samples per lake varied from X to Y"....

Answer: following the comment of the reviewer, we included the number of samples per lake. Please see general comments.

Line 618: transpose "abundant aquatic systems" and "high geodiversity". If "geodiversity" = "environmental conditions", then this phrase should be "high diversity of environmental conditions" rather than "geodiversity". This is where the "diversity" in "geodiversity" becomes confusing.

Answer: We modified the text as follows "The northern Neotropics is a region characterized by diverse environmental conditions, abundant aquatic systems, and high biodiversity". This is a general statement, and environmental conditions is preferred over geodiversity, because it makes reference of to the set of atmospheric, soil and water variables.