Biogeosciences Discuss., 6, C4834–C4841, 2010
www.biogeosciences-discuss.net/6/C4834/2010/

Biogeosciences Discussions

Interactive comment on "Microbiotic crusts on soil, rock and plants: neglected major players in the global cycles of carbon and nitrogen?" *by* W. Elbert et al.

W. Elbert et al.

w.elbert@mpic.de

Received and published: 12 May 2010

We thank the anonymous referee for reviewing our manuscript. The stimulating comments are very welcome, and the suggestions for improvement will be implemented upon revision as far as possible. Detailed responses to the individual comments are given below.

Referee Comment 1:

The authors have used median values, rather than averages, to gain more solid footing in their estimates, and also state that these estimates may be _2x off actual values. I would suggest that the error in the reported estimates is far higher than 2x, and that

more accurate values can be obtained.

Response:

Following up on the above comment and suggestion, we intend to clarify the approach and improve the uncertainty estimates in the methods section of the revised manuscript as follows.

For global upscaling we used median rather than arithmetic mean values in order to obtain conservative estimates. The median values were generally in fair agreement with the corresponding arithmetic mean values, and the relative standard errors of the mean values (relative standard deviation divided by the square root of the number of data points) ranged up to $\sim$80%. The 10th and 90th percentiles deviated from the median values by factors of 2-5 for carbon fixation by BSC and BRC, 3-20 for carbon fixation by EPC, and by factors of 3-4 for nitrogen fixation by BSC and EPC (Tables 1, 3, and 9). The percentile and standard error values indicate that the first global estimates presented here are uncertain by factors of 2-20. More long-term studies and detailed measurements of biological crust coverage, biomass, and uptake fluxes will be needed to reduce the uncertainties (Bader et al., 2010).

Referee Comment 2:

Values for C flux are more or less reliable. However, I would caution against using the median values here. The high values reported are for individual lichens, when in almost all settings, cyanobacteria dominate biocrust cover. Thus, the values reported need to somehow be weighted rather than averaged.

Response:

Following up on the above comment, we have further increased the data base and intend to add further information on the nature of the investigated crusts listed in Tables 1 and 3 (col. 2) of the revised manuscript. The available information suggests that the use of median values is not unrealistic, because there are no clear indications for

systematic deviations between different types of crusts, regions, climatic zones and ecosystems: high and low values are reported for all cyanobacteria-dominated crusts as well as chlorolichens, cyanolichens, and mosses, and they are scattered over arid, temperate, tropical, mid-latitude and high-latitude regions (Table 1).

Note that lichens and mosses are similarly widespread as cyanobacteria, and that CO2-fixing photobionts in lichens are cyanobacteria (cyanolichens), algae (chlorolichens), or mixtures of the two (tripartite lichens). With the currently available data it seems hardly possible to develop and apply a meaningful weighting scheme (lack of systematic data on ecosystem- and crust-dependent flux data).

Referee Comment 3:

N fixation values are especially problematic. This is especially true for nitrogen fixation values, as they are most often estimated using acetylene reduction assays (ARA). Conversion of ARA values to actual N fixed can vary from 0.1 to 56, a huge range. Looking at Table A9, I would start by not using the 37 g m2 a1 reported by Belnap et al. 2001, and perhaps not even the 10 g m2 a1 reported by Veluci (2003) and Evans and Lange (2006) as they are far higher than other values in the table. I would also not use the 42.3 g m2 a1 reported by Sheridan 1991a, for the same reason. In addition, the authors need to discuss the problems with N values obtained by the ARA method.

Response:

We agree that the conversion factors used with the ARA method span a wide range, but we do not feel called upon to discuss or discard data that were determined using the ARA method. This should be done by specialists. For our global exploratory study we see no other way than building on the data published in peer-reviewed scientific journals. Moreover, please note that several of the studies referenced in Table 9 used other methods instead of or in addition to the ARA method and obtained comparable results; e.g., “natural 15N abundance method” (Horne, 1972; Green et al., 1980; Russow et al., 2008; Holst et al., 2009), ARA and 15N method (Pike, 1978), and growth

measurements (Denison, 1979)). Furthermore, some investigators argued that higher rates are probably more accurate (Liengen, 1999; Belnap et al., 2001).

Note that the upper and lower limit values of the ranges listed in brackets at the bottom of Table 9 (including the values of 37 g m-2 a-1 and 10 g m-2 a-1 pointed out above) were never included in the determination of the median value. This shall be clarified in the methods section of the revised manuscript: Ranges shown in brackets at the end of some tables were not used for calculations but may serve for comparison.

With regard to the high value of nitrogen fixation by EPC reported by Sheridan (1991, 1992), we found no good reason for exclusion. In any case, it had little influence on the median value reported in the discussion paper, and it will have even less influence on the median value of the revised manuscript, for which we found and included additional data and references. The additional data confirm the robustness of the median value, as they lead to a small increase relative to the discussion paper.

Referee Comment 4:

One suggestion for estimating the values for C, biomass, and N: assume lichens represent 10% cover (a generous value) and cyanobacteria 50% cover. Delete the very high values obtained for individual lichen species and obtain the median values for those. Use the median value for cyanobacteria. Then weight these values by this “average” cover. I suspect the values obtained will be far lower than those currently reported, but more accurate.

Response:

Following up on the above comment and suggestions, we performed test calculations on net carbon uptake by BSC excluding the two highest values of Table 1a of our original manuscript, and arranging the remaining data into subsets. In the first approach we determined median flux values for lichens (21 g m-2 a-1) and for pure cyanobacterial BSC (5.8 g m-2 a-1) as suggested by the referee. In an alternative approach we deter-

mined median values for lichens with algal photobionts (chlorolichens, 20.8 g m-2 a-1) and for BSC with cyanobacterial photobionts (cyanobacteria plus cyanolichens, 9.2 g m-2 a-1), which appears more systematic than the first approach. By multiplication of the median flux values with the global (semi)arid area and with the fractional coverage values suggested by the referee (10% and 50%), we obtained estimates of 0.32 Pg a-1 (approach 1) and 0.43 Pg a-1 (approach 2). These values are somewhat but not much lower than the estimate and uncertainty presented in our original manuscript ($\sim$1 Pg a-1 with an uncertainty factor of $\sim$2). In any case they are well within the estimated range of uncertainty presented in our revised manuscript ($\sim$1.1 Pg a-1 with uncertainty factors of 2-20 as specified above).

Still we think that the approach of arbitrarily fixing the lichen and cyanobacteria coverages to 10% and 50%, respectively, is not superior to the scaling approach and calculations presented in our original manuscript, because biological crusts are usually mixed communities including varying proportions of lichens, cyanobacteria, algae etc. Moreover, it seems not necessarily appropriate to arbitrarily exclude the highest values but not the lowest values from the calculation of median values from a wide range of published data. Last but not least, the above test calculations do not include fixation rates measured for mixed communities and for BSC other than lichens and cyanobacteria (algae, mosses, etc.).

We did not perform similar test calculations for biomass and nitrogen fixation because all data as tabulated, referenced and used in our estimations were directly taken from studies that had already accounted for partial surface coverage. Likewise, test calculations were not performed for carbon uptake by EPC because all reported data were for lichens (no data available for pure cyanobacterial crusts).

Referee Comment 5:

... May I also suggest not using “microbiotic” in the title? “Biological crusts” is more in vogue these days ...

Response:

Following the suggestion of the referee, we will adjust the title and use the term “biological crust” throughout the revised manuscript. For clarification we intend to add the following footnote in the introduction.

For clear distinction from vascular plants, these communities are also called microbiotic crusts (Evans and Johansen, 1999). Various other terms used in the literature include cryptobiotic, cryptogamic, microfloral, or microphytic crusts (Evans and Johansen, 1999) and endolithic or epiphytic biofilms (Currin and Pearl, 1998; Hoppert et al., 2002; Pohl and Schneider, 2002). In this manuscript we use the most general and popular term biological crusts.

References

Bader, M. Y., Zotz, G. and Lange, O. L.: How to minimize the sampling effort for obtaining reliable estimates of diel and annual CO2 budgets in lichens, Lichenologist, 42, 97-111, 2010.

Belnap, J., Kaltenecker, J. H., Rosentreter, R., Williams, J., Leonard, S. and Eldridge, D.: Biological soil crusts: ecology and management. Technical reference 1730-2, US Departement of the Interior, Denver, 1-118, 2001.

Currin, C. A. and Pearl, H. W.: Epiphytic nitrogen fixation associated with standing dead shoots of smooth cordgrass, Spartina alterniflora, Estuaries, 21, 108-117, 1998.

Denison, W. C.: Lobaria oregana, a nitrogen-fixing lichen in old-growth Douglas fir forests, In: Symbiotic Nitrogen Fixation in the Management of Temperate Forests, Gordon, J. C., Wheeler, C. T. and Perry, D. A. (eds.), Corvallis: Oregon State University Press, 266-275, 1979.

Evans, R. D. and Johansen, J. R.: Microbiotic crusts and ecosystem processes, Critical Reviews in Plant Sciences, 18, 183-225, 1999.

Green, T. G. A., Horstmann, J., Bonnett, H., Wilkins, A. and Silvester, W. B.: Nitrogen fixation by members of the Stictaceae (Lichenes) of New Zealand, New Phytologist, 84, 339-348, 1980.

Holst, J., Butterbach-Bahl, K., Liu, C. Y., Zheng, X. H., Kaiser, A. J., Schnitzler, J. P., Zechmeister-Boltenstern, S. and Bruggemann, N.: Dinitrogen fixation by biological soil crusts in an Inner Mongolian steppe, Biology and Fertility of Soils, 45, 679-690, 2009.

Hoppert, M., Berker, R., Flies, C., Kamper, M., Pohl, W., Schneider, J. and Strobel, S.: Biofilms and their extracellular environment on geomaterials: methods for investigation down to nanometre scale, In: Natural Stone, Weathering Phenomena, Conservation Strategies and Case Studies, Siegesmund, S., Weiss, T. and Vollbrecht, A. (eds.), Geological Society of London, London, 207-215, 2002.

Horne, A. J.: The ecology of nitrogen fixation on Signy Island South Orkney Islands, Br. Antarct. Surv. Bull., 27, 1-18, 1972.

Liengen, T.: Conversion factor between acetylene reduction and nitrogen fixation in free-living cyanobacteria from high arctic habitats, Canadian Journal of Microbiology, 45, 223-229, 1999.

Pike, L. H.: The importance of epiphytic lichens in mineral cycling, The Bryologist, 81, 247-257, 1978.

Pohl, W. and Schneider, J.: Impact of endolithic biofilms on carbonate rock surfaces, Natural Stone, Weathering Phenomena, Conservation Strategies and Case Studies, 177-194, 2002.

Russow, R., Veste, M., Breckle, S.-W., Littmann, T. and Böhme, F.: Nitrogen input pathways into sand dunes: biological fixation and atmospheric nitrogen deposition, In: Arid Dune Ecosystems. The Nizzana Sands in the Negev Desert, Breckle, S.-W., Yair, A. and Veste, M. (eds.), Springer-Verlag, Berlin, 319-336, 2008.

Sheridan, R. P.: Epicaulous, nitrogen-fixing microepiphytes in a tropical mangal com-

munity, Guadeloupe, French West-Indies, Biotropica, 23, 530-541, 1991.

Sheridan, R. P.: Nitrogen fixation by epicaulous cyanobacteria in the Pointe de la Saline mangrove community, Guadeloupe, French West Indies, Biotropica, 24, 571-574, 1992.

Interactive comment on Biogeosciences Discuss., 6, 6983, 2009.