Referee 3:

General Comments

This MS presents a review of the current knowledge of biocrust distribution, and although the authors have cited the appropriate papers and have accurately identified the current state of the research, the MS requires reorganization and a cohesive synthesis of the current state of knowledge. I have addressed potential ways of doing this in the specific comments below. Also, as the third referee, I read the responses of the others and agreed with their comments. I hope that my comments, in addition to theirs, are helpful during the revision of this MS.

Response: Thank you for acknowledging the potential and give the helpful feedback on this work. In the revised manuscript, we have reorganized the manuscript to give a clearer picture of the underlying knowledge framework. As responded above, we have adjusted the section 3.3 to a separate section, i.e., new section 4, to introduce influencing factors of biocrust, which was previously integrated into the section 3 where was used to introduce current knowledge of biocrust distribution. Meanwhile, the new section 4 had been totally rewritten to make it clearer. Furthermore, a new conclusions section, i.e., section 6, was added in the revised manuscript to summarize the main ideas given by this work, to make it smoother for readers to follow up. In addition, we have added a few figures (Fig. 2 and 4) to quantitatively summarize current understanding of biocrust distribution.

Specific Comments

Section 3, titled "what have we known", should be rephrased to a statement rather than a question. I suggest "Current State of Knowledge" or something similar.

Response: Thank you for giving this suggestion. In the revised manuscript, we replaced the title with "Current State of Knowledge" as suggested (line 158).

In the first paragraph of section 3, citations should reference the work of the authors you mentioned so the reader can find previous studies on biocrust distribution. In this section, it would also be helpful to have a map of all the places where biocrust distribution has been measured. Most studies provide lat and long values, which can easily be mapped and is a good way to show the gaps in our knowledge. It should also be mentioned that although biocrust distribution has been heavily focused on arid and semi-arid regions, several arid and semi-arid regions have received very little attention (especially the Global South). With a map, this can easily be explained in the text.

Additionally, Figure 2 (the author framework) does not provide much new scientific information other than demonstrating which authors are the primary experts in the field. It would be more informational to show a schematic with hubs at the most researched locations (I expect China and Utah would dominate), again this would highlight the gaps in the research that need to be filled.

In section 3.1, this information may also be displayed on the map I mentioned previously, or in a table. It is difficult, as the reader, to understand how all the values relate to each other and to place them in a geographic context. Also, within the table, it would be good to specify the scale of the data for each study to provide greater context when comparing it against other studies.

Response: We are grateful to the reviewer for these valuable suggestions, which are very important to improve this manuscript. In the revised manuscript, we mainly made the following

modifications:

1) In the first paragraph of section 3, the references of several authors mentioned in this paragraph have been cited in text (lines 159-163);

2) Fig. 2 has been updated by adding a figure of co-occurrence network of researchers (Fig. 2(a)), maps of research hotspot countries (Fig. 2(b)) and biocrust distribution data under different drought gradients (Fig. 2(c)), so as to clearly show readers the most important information from a spatial perspective;

3) In the revised manuscript, we added interpretation of Figure 2(b) and (c) "The topic has gradually received attention from all over the world, particularly the countries with extensive dryland areas such as China, United States, Spain, United Kingdom, Germany, Australia, and Israel (Fig. 2(b)). However, some other dryland countries and regions, such as central and southern Africa, where biocrust distribution has been reported still there is a paucity of studies and the amount of data on biocrusts is far from adequate (Fig. 2(c)). These areas may be potential areas of widespread distribution of biocrusts in the future." (lines 163-169)

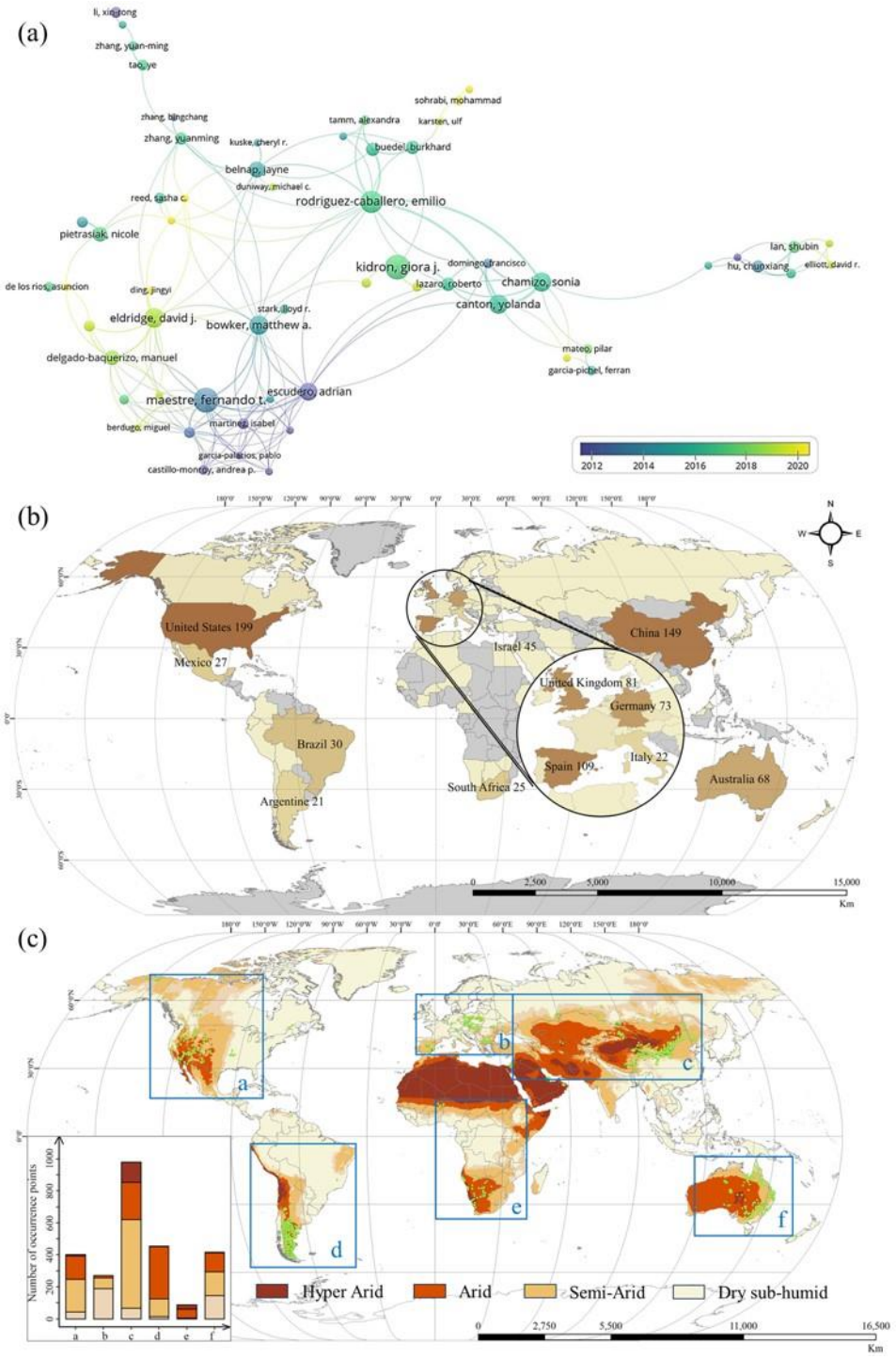

Fig. 2 Literature review of biocrust distribution studies. (a) Representative authors associated frameworks for biocrusts distribution studies (1990 to 2022). The time series is the average time of the year of publication, e.g., if the number of articles is 2 in 2004 and 8 in 2019, the node in this figure shows the year as (2004 x 2 + 2019 x 8)/10 = 2016. (b) Map of hotspot countries for biocrust distribution research, with the top 12 countries in terms of number of publications shown; The database is Web of Science, TS = ("biogenic crust*" OR "biological crust*" OR "biological soil crust*" OR "biocrust*" OR "microphytic crust*" OR "microbiotic crust*" OR "cyanobacterial*" OR "algal*" OR "lichen*" OR "moss*" OR "biotic crust*") AND ("mapping*" OR "distribution*" OR "spatial pattern*") AND (“dryland” OR “hyper*arid*” OR

"arid*" OR "semi*arid*" OR "dry subhumid*"), with research interests in Environmental Sciences/Ecology and a total of 700 papers. (c) Global biocrust data distribution, based on field surveys and literature compilation. Data have been collected and expanded from the published database (Chen et al., 2020; Rodriguez-Caballero et al., 2018) to 3848 items.

In section 3.3, there should be a connection between the importance of precipitation with the previously mentioned studies of biocrust distribution. This can be done again, by using a map. The authors can make a map, using publicly available data, showing the global precipitation patterns next to the models of the global biocrust distribution. The same can be done with temperature.

Response: In the revised manuscript, we have added a new Figure 4 as you suggested, to show biocrust distribution map with environmental maps (with precipitation and soil texture as examples, Fig. 4), and cited the figure in the corresponding places (lines 244, 279, 361).

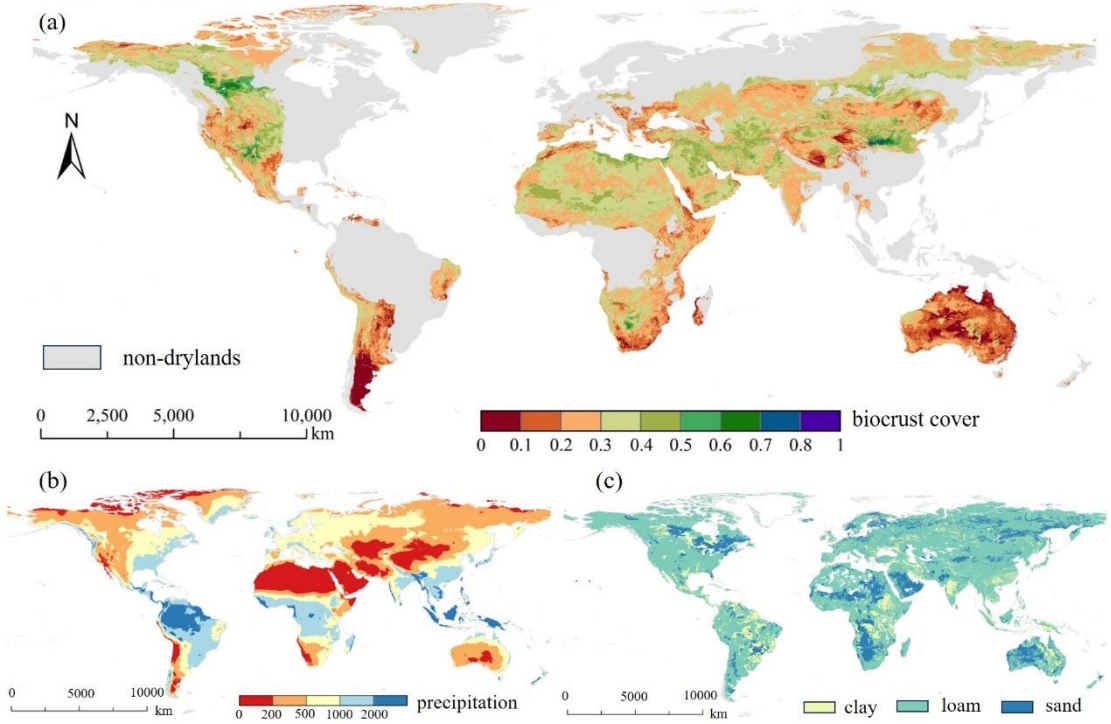

Fig. 4 Biocrust distribution and its critical influencing factors. (a) Biocrust cover map and its influencing factors. (a) Global biocrust distribution, by random forest modelling. Based on a global biocrust database constructed by Chen et al., we expanded the biocrust data to 3848 entries through literature compilation and field surveys and fitted them with four types of remotely sensed environmental data, including climate, land use, soil properties, and elevation, to finally predict the suitable areas for the biocrust distribution and quantify the biocrust cover. (b) Global average annual precipitation (1970-2020), data from the WorldClim database (version 2.1). (c) Global soil texture distribution, data from HWSD (Harmonized World Soil Database, version 1.2). Precipitation and soil texture were taken as examples of environmental factors.

L262: there is an abrupt shift from soil variables to fire which does impact biocrust distribution, but this should be a separate section, perhaps with other anthropogenic impacts on biocrust distribution. I think section 3 would work better if it just included a review of local scale and global scale studies. Then there should be an additional section 4 which reviews the climatic, abiotic (i.e. soil texture), and disturbance (natural and anthropogenic) effects on biocrust distribution.

Response: Thanks for pointing out this issue and giving this wonderful suggestion. In the revised manuscript, we have totally reorganized section 3.3, where this issue is located at, to be a new section 4, to discuss the effects of precipitation, temperature, soil variables, fire, disturbance and other factors on biocrust distribution in separate paragraphs, for a smoother logical flow. (lines 244-320)

I enjoyed section 4 and like your proposed methods of solving some of the issues with measuring biocrust distribution. This information would also be helpful to have in a table like you did with Table 1, highlighting the advantages and disadvantages. However, in agreement with the other referees, there should be a concluding paragraph summarizing the goals and results of this paper.
Response: We are pleased with your endorsement of section 4 of the article. We would like to agree with you on giving a table to summarize the advantages and disadvantages of the proposed approaches and measure to advance studies on biocrust distribution. Whereas we decided to not add such a table, because the contents and major points of each methods/measures differ dramatically. For example, new section 5.1 (original section 4.1) is about database; new section 5.2 (original section 4.2) discusses modelling approaches; new section 5.3 touches equipment – improving biocrust-specific remote sensing products; section 5.4 goes to algorithms and statistics; section 5.5 talks about social aspect. Therefore, it may be distracting to combine so different aspects in one table. Even this table is given, readers still need to go back to main text to get detailed information as the table is unable to convey so contrasting information. In this sense, this table differs from the present Table 1, which is about available methods to study biocrust distribution. More importantly, section 5 is to inform readers about challenges and ways to go ahead, and it should focus on promising side relative to negative side. We hope you can agree with us.

In the revised version, we have added the conclusion section as follows "This work aims to advance global knowledge of biocrust distribution for better ecosystem management and sustainable development in drylands. We firstly compared the advantages, disadvantages, and applicability among three methods, spectral characterization index, dynamic global vegetation models and geospatial models, in order to provide the most appropriate methodological suggestions for biocrust distribution studies at different scales and needs. Then, we systematically sorted out the regional-global biocrust distribution cases, and drew a map of global biocrust distribution hotspots and a map of spatial distribution of data points. Further, we tried to clarify the causes of biocrust distribution from several aspects, such as precipitation, temperature, soil, fire, and other anthropogenic factors. Finally, from a personal point of view, we would like to focus more on the following points in the future: database construction, model performance enhancement, big data processing, and synergistic progress of potential distribution area studies.". (lines 455-466)

Technical Corrections

L49: typo in the citation "(KrÖPfl et al., 2022)"
Response: Done. (line 52)

L174-178: check the phrasing of this sentence, it should be two separate sentences
Response: This sentence has been rewritten as two separate sentences "In the Mojave Desert, biocrusts distribution was closely related to geological age, surface stability, topography, and dust

transport (Miller et al., 2004).” and “Lichen, moss, and dark algal crusts patchily distributed on the desert, averaging 8% cover, though in some bar and shrub zones, the cover could be as high as 26% (Pietrasiak et al., 2014).” (lines 186-188, 188-190).

L185, 228: avoid using questions in the text, simply state the results

Response: Thanks for your suggestions, and we have changed these two expressions to declarative sentences in the revised version “In the Loess Plateau, RGB image-based biocrusts monitoring showed that variability in biocrusts cover decreased logarithmically with increasing plot size until a critical size of 1m2 after which biocrusts cover remained approximately constant (Wang et al., 2022a).” (lines 197-200) and “Numerous experimental observations and modelling (Kidron and Xiao, 2023; Li et al., 2023; Rodriguez-Caballero et al., 2018) have proved that, on the global scale, biocrust distribution is mainly influenced by water conditions, temperature, soil properties, fire and disturbance (Bowker et al., 2016).” (lines 240-243).

L262: there is an abrupt shift from soil variables to fire

Response: As above in response to you and reviewer 2, here we have set up a separate paragraph on the effects of fire.

L267: Brianne should be Palmer et al. 2020

Response: Done (line 292).

L274: Please summarize Bowker 2016 then cite correctly

Response： Bowker 2016 has been clarified and correctly cited. “For further insights, readers are encouraged to consult Chapter 10 of Biological Soil Crusts: An Organizing Principle in Drylands, which overview of the control and distribution patterns of biocrust from micro to global scales (Bowker et al., 2016).” (lines 317-320)

L289: check the grammar

Response: We have checked the grammar of this sentence and rewritten it as “Due to the difficulty of conducting field surveys worldwide, compilating biocrusts data from the published literatures or other sources would be the major approach (Fig. 4(a)).” (lines 359-361). In the revised manuscript, we have carefully checked the whole main text by ourselves and by ChatGPT.

L290-292: rephrase this sentence, the grammar is off

Response: The sentence has been rewritten as “To date, several published studies have assembled 900 ~ 1,000 data on biocrust presence or absence from the literature (including 584 data on biocrust cover)”. (lines 361-362)