

**Referee 2:**

This manuscript provides a summary of existing knowledge about biocrust distribution, identified factors that relate to the distribution, gaps in global distribution knowledge, and proposed tools to expand the knowledge. I proposed that potential reorganization of the paper and attention to topic sentences and grouping similar information together will help the reader efficiently find the most useful components of the paper.

**Response: Many thanks for your efforts to improve this manuscript, Eva.** In the revised manuscript, we have reorganized the main text to give a clearer logic for readers. For example, the original section 3.3 has been reframed as the new section 4, to explicitly introduce influencing factors of biocrust. The updated framework of main text includes Research Methods (section 2) - introduce how to study this topic, Current State of Knowledge (section 3) - what do we know about biocrust distribution, Influencing Factors of Biocrust Distribution (section 4), Challenges and Perspectives (section 5) – how to advance this topic. We believe that the reorganized framework is much clearer and smoother for readers to follow up.

*L34. suggest update to “continuous biotic complexes” to preface the next part of the sentence*

**Response: Done.**

*L35. This seems to narrow the focus from all photosynthetic organisms that live at the soil surface (e.g. mosses found when glaciers retreat that are early successional stages) to just arid and semiarid. Later (L 212) they do talk about middle latitudes and polar regions.*

**Response: Thank you for the suggestion. In the revised manuscript, we have replaced this expression with “They are able to occupy a wide ecological niche in mid latitudes, polar and alpine regions, covering approximately 11% of the global land area (Porada et al., 2019). In particular, biocrusts can be adapted to water-limited, nutrient-poor and hostile environments, such as arid and semi-arid areas characterized by low ratios of precipitation to potential evaporation (0.05-0.5 mm mm<sup>-1</sup>) (Pravalie, 2016; Read et al., 2014; Weber et al., 2016).”.** (lines 38-42)

*L45. Elbert is a modeled amount rather than an observed amount, I suggest revising to “biocrusts were estimated to contribute 15%...”*

**Response: Done. Please find the revised lines 46-48 “By participating in a suite of biogeochemical cycles, biocrusts were estimated to contribute to 15% of terrestrial net primary productivity and 40-85% of biological nitrogen fixation (Elbert et al., 2012; Rodriguez-Caballero et al., 2018).”.**

*L53. What is a carbon and nitrogen mechanism?*

**Response: Thanks for pointing out the confusing point. In the revised manuscript, the sentence has been rewritten “Despite the significance of biocrusts, previous studies have primarily focused on their contributions to C and N cycling in varying habitats and climates (Hu et al., 2019; Morillas and Gallardo, 2015), interspecific interactions and biocrusts biodiversity (Machado De Lima et al., 2021; Munoz-Martin et al., 2019), rather than their spatial distribution, particularly at the global scale.”** (lines 55-59)

*L68. Please revise the topic sentence to clarify the scope of the paragraph for the reader.*

**Response:** In the revised manuscript, we have rewritten the first sentence to lead the paragraph, “With advances in remote sensing and geo-information technology, spectroscopy provides a feasible method of characterizing distribution features from a physical point of view.” (lines 70-71)

L104. Revise to “focus”

**Response:** Done.

L185. The shift from statements to question was a little bit confusing – should this be a separate paragraph and leave the rest of the paragraph to summarizing the information from these different countries?

**Response:** We have replaced it with a declarative sentence in the revised manuscript, “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 1m<sup>2</sup> after which biocrusts cover remained approximately constant (Wang et al., 2022a).” (lines 197-200). As the context is juxtaposed to this sentence, showing separate findings from around the globe, the paragraphs no longer need to be separated. Thanks for the suggestion.

L200. These sentence likewise feels like a different topic – the previous part of that paragraph are defining the snapshots of distribution information and then this sentences talks about changes with future scenarios; may be worth moving it into in a separate paragraph, perhaps after the paragraph about factors that influence biocrust distribution (228).

**Response:** We agree with you. In the revised manuscript, we have moved this part to Chapter 4, Influencing factors of biocrusts distribution - temperature paragraph. (lines 273-276)

L227. I generally wonder if the order of this manuscript can be revised for clarity – on line 278, the authors say that traditionally, biocrust distribution methods were based on observational and controlled experiments, so this summary of factors that determine distribution – were these based on those three methods (spectral, vegetation dynamics, geospatial)? Or on the observational/experimental? If so, it may make more sense to summarize what is already known from traditional methods before discussing what new information can be gathered from these remote sensing-assisted options. If the structure is not changed, the authors should however be really clear about methods that were used in different parts of the paper so the reader can clearly discern what is the gap in knowledge so that the author’s proposed next steps are in context of the broader field.

**Response:** The points you raise are great. In the revised manuscript, we have systematically pointed out the contribution of different research methods in helping to solve the biocrust distribution issue “For assessing biocrust distribution patterns (Chapter 3), the methods are shifting from traditional approaches to spectral index, vegetation dynamics and geospatial model, that span multiple subjects like ecology, biology, geology and computer science.” (lines 346-349)

L228. I suggest being consistent – either have questions as section headers throughout, or remove the occasional instances.

**Response:** In the revised manuscript, we have replaced the occasional interrogative sentences with narrative sentences in section titles to make the text clearer (lines 244-320).

L228. I assume this refers to total precipitation because later the authors discuss seasonality/frequency. It will help the reader if the metric is described explicitly and specifically up front.

**Response: Yes, precipitation means total precipitation here.** In the revised manuscript, we had replaced “precipitation” with “total precipitation” and rephrased the sentence as “In general, total precipitation (Fig. 4b) is considered to be critical in determining the distribution of biocrusts (Eldridge and Tozer, 1997).” (lines 244-245).

L235. In what situations did small rain events benefit biocrusts most? That will set up the reader for the contrast with the moss die-off in the Colorado Plateau.

**Response: In the revised manuscript, we have added the supplementary explanation of this issue** “Winter precipitation and/or smaller rain events benefit biocrusts, especially when mean annual precipitation is <500 mm, and high frequency of precipitation can lead to the dominance of biocrusts over vascular plants (Chamizo et al., 2016; Jia et al., 2019). It was experimentally proven that precipitation events of 5 mm were able to maintain normal physiological and ecological functions of the biocrust on the Colorado Plateau, USA, while ever lower precipitation event of 1.2 mm could rapidly kill the moss biocrust (Reed et al., 2012).” (lines 251-257).

L240. I think that fog has also been ascribed to biocrust in the Columbia Basin, WA/OR USA. Check papers from the McCune Lab.

**Response: Thank you for letting know the works of McCune’s lab,** and we've cited McCune's papers on the subject in the revised manuscript “Additionally, under future scenarios of increased temperature and aridity, biocrusts cover is predicted to decrease by approximately 25% by the end of the century, with communities shifting towards early cyanobacterial biocrusts (Rodríguez-Caballero et al., 2022).” (lines 273-276).

L243. This transition to temperature is confusing because no where else in the paragraph was temperature mentioned. Please make a separate paragraph and flesh out the impacts of temperature and the interaction with moisture.

**Response: In the revised version, we have moved the contents on temperature as a separate paragraph to distinguish the effects of water conditions on biocrust distribution** (lines 265-276).

L246. What is the relevant information for the reader from the Ferrenberg study that relates to the rest of this paragraph?

**Response: In the revised manuscript, we have re-summarized the main findings of Ferrenberg's study** “Regarding air temperature, warming by 4°C could alter biocrust community structure, resulting in a sharp decrease in moss biocrust cover and an increase in cyanobacterial biocrust cover, which became even more significant when warming was interacting with time and precipitation treatments (Ferrenberg et al., 2015).” (lines 266-270)

L247. Again, this sentence would better serve the reader if the “state of knowledge” section about precipitation patterns and biocrust distribution were separate from “how climate has or will change

*and effects on biocrusts” paragraph or paragraphs.*

*L262. This discussion of disturbance should be a separate paragraph from the one discussing soil parent material and characteristics to help the reader clearly follow the key information.*

*L270. This sentence doesn't make sense next to the intensification of human disturbance topic. Also, please summarize the key information from the Bowker 2016 publication for the reader.*

**Response: Thank you. We agree with your suggestions. In the revised manuscript,** we have transformed the initial section 3.3 into chapter 4, "Influencing Factors of Biocrust Distribution", while describing each of the influencing factors (water conditions, temperature, soil properties, fire and disturbance) of biocrust distribution in global drylands as a separate paragraph (lines 244-311). Finally, for the content of Bowker's book, we made additional notes " [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).

*L277. Please revise this sentence for clarity: “... and thus biocrust distribution gradually becomes a hot spot since the turn of the century” – is this “hot spot” referring to the importance for dryland ecosystems? Is it referring to the number of publications?*

**Response:** In the revised manuscript we have reorganised the sentence as [“Biocrusts are very important for dryland ecosystems, and thus, it is of outstanding significance to understand the current status and dynamics of biocrusts distribution.”](#) (lines 343-344)

*L284. Revise to include verb. “We suggest that a global effort should build a standardized and specialized... “ or something like that.*

**Response: Done as suggested** (the revised lines 354-357).

*L288. I think that this paragraph is trying to set up the difference between traditional methods which are compiling available information from the literature with building a database with instructions for new observations that would ensure that the same data items and inclusion criteria are added. Adding a topic sentence that sets out explicitly the purpose of this paragraph rather than initially discussing the recommendation may help clarify.*

**Response: As you suggested, in the revised version, the topic sentence has been added at the beginning of the paragraph to clarify the theme** [“Currently, biocrust data are fragmented, low in volume and accessed from narrow sources, largely limiting spatial prediction from points to areas.”](#) (lines 353-354).

*L319. PROVAV\_LC100 database not discussed in text while other databases in that figure were discussed in text.*

**Response: Thank you for the reminder. A description of the PROVA\_LC100 data has been added to the text.** [“Concerns about land use products are also necessary. Global land use maps, based on the PROBA-V sensor, which contain spatial information for Moss & Lichen layer, have an annual update frequency and a resolution of 100 m.”](#) (lines 378-380)

*L369. Revise topic sentence to include climatic characteristics in addition to spatial characteristics for this paragraph.*

**Response:** In the revised manuscript, we rephrased the topic sentence as “Research of biocrust distribution have shown significant spatial and climate imbalances.” (line 442).

*L380. Please revise – biocrusts are not an organizing principle, they were previously described as continuous complexes.*

**Response:** In the revised manuscript, we removed this sentence and added a new conclusion paragraph to organize the purpose and results of this work “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).

*L382. Suggest remove the study “this study summarized” sentence unless the authors next these conclusions into the broader literature.*

**Response: Done.**

*Thank you for your work and I hope my review is helpful to maximize the impact of your research.*

**Response: Thank a lot for your patience and detailed comments, Eva. We hope that with revisions the work will be even better!**