Referee 1:

This MS provides a literature review on the mapping of biological soil crusts and presents the author's perspectives on future developments. The study of biological soil crust mapping is an intriguing and essential research direction. While there are existing studies on mapping, a comprehensive synthesis of these efforts is lacking, making the author's research significant. Although the descriptive aspects of the MS are well-done, it lacks theoretical depth and the author's viewpoints. Therefore, major revisions are necessary before considering publication. Specific issues include:

Response: Thank you for acknowledging the merits of this study. We are so happy to contribute to advance studies on mapping biocrust distribution. In the revised manuscript, we have revised the manuscript according to your comments and suggestions. We hope that you will agree with us.

In section 2.2, the limitations of this model should be addressed, particularly regarding monitoring areas, as no model can feasibly cover anywhere.

Response: We totally agree with you. In the revised manuscript, we have acknowledged the disadvantages of dynamic modelling of vegetation and related them to Table 1 "The method possesses significant advantages to map biocrusts distribution because its assumptions have clear biological implications (Cuddington et al., 2013), yet may lead to poor predictions of global-scale distributions due to subjective regional experience and insufficient amounts of biocrust data (Table 1) (Quillet et al., 2010)." (lines 107-111). To address this bottleneck, we provided suggestions in subsections 2 and 4 of the chapter "Challenges and Perspectives", such as integrating vegetation with more comprehensive biogeochemical and hydrological processes and processing big data based on machine learning for modelling the predicted distributions. (lines 395-412, 429-440)

In section 2.3, the influence of human activities on the growth of biological crusts in many areas, such as afforestation, should be considered. This may not necessarily be related to local climatic conditions and should be included in section 2.3.

Response: Thank the reviewer for the suggestion. In the revised manuscript, we have added a note to the environmental information referred to in the geospatial model "Besides, not only natural conditions such as climate, topography, soil, etc. that affect biocrust distribution, but also data about human activities such as afforestation, trampling, population density, etc. also need to be considered as environmental indicators in the model." (lines 144-147)

In section 3.1, it is recommended to incorporate research hotspot maps or tables, categorizing cited and uncited literature and research areas. This provides readers with an intuitive understanding of the research hotspots and identifies regions where research has not yet been initiated.

Response: The reviewer gets a point. In the revised manuscript, we have updated the new Figure 2 with maps of research hotspot countries and location maps of global biocrust distribution based on field surveys and literature compilation.

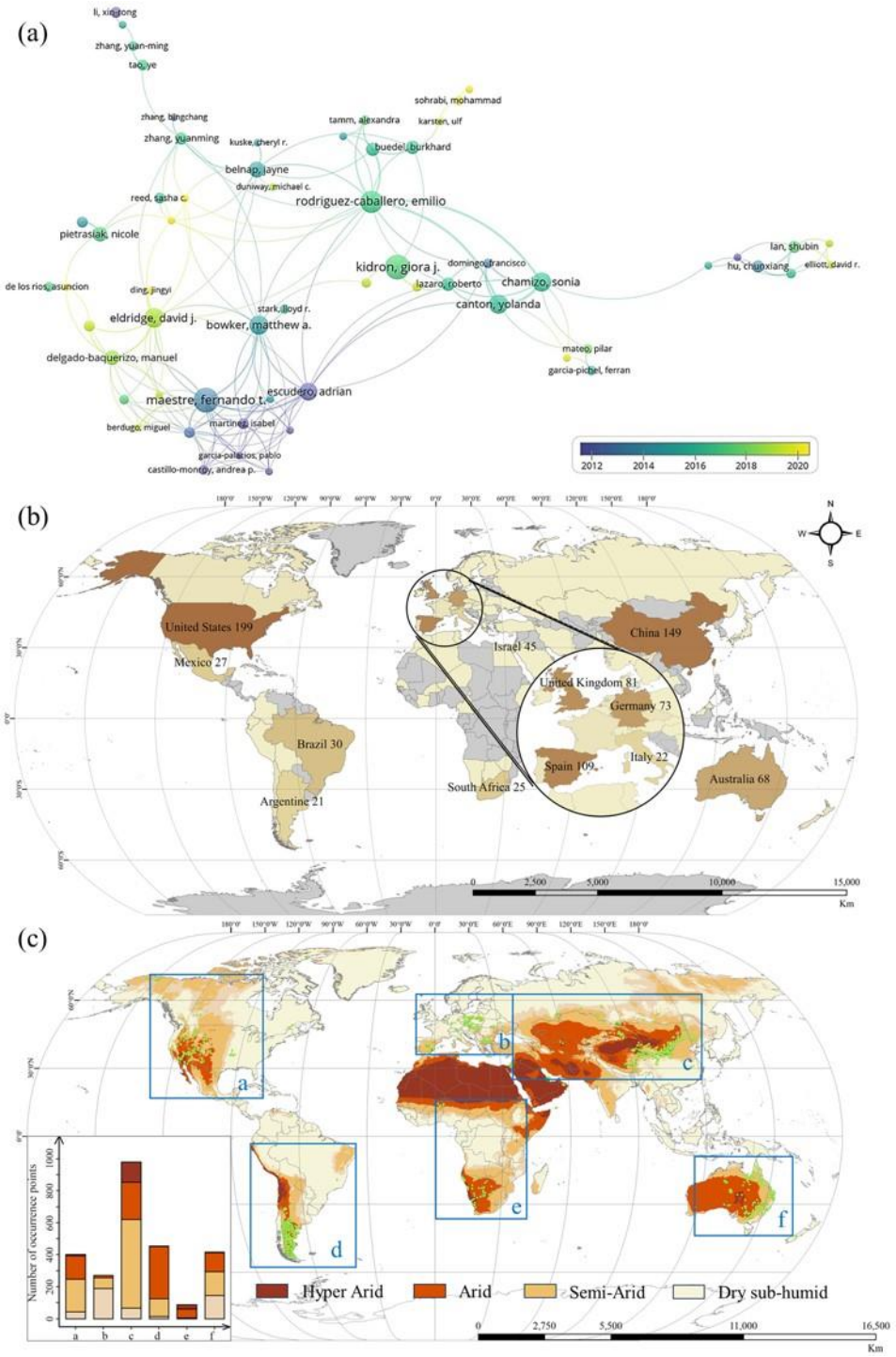

Fig. 2 Literature review of biocrust distribution studies. (a) Representative authors associated frameworks for biocrusts distribution studies (1990 to 2022). The time series is the average time of the year of publication, e.g., if the number of articles is 2 in 2004 and 8 in 2019, the node in this figure 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.

Lines 218-222: Inconsistencies can be circled in the fig and analyzed to determine why they are higher in Rodriguez Caballero et al. (2018).

Response: In the revised manuscript, inconsistencies have been marked with circles and explained accordingly in the text. "We estimate that the reason may be that geospatial modeling focuses more on the influence of climate, as the Mediterranean climate and tropical desert climate in the Sahara Desert, as well as the tropical desert climate of northwestern South Asia, which is suitable for biocrust surviving. Additionally, the large number and high cover of biocrust training sets in the central North America could have contributed to the generally high predicted cover in machine learning." (lines 229-234)

Section 3.3, the first question is why these influencing factors should be selected. The second issue is that the theoretical expression lacks depth, and some visual or intuitive numbers should be given. The entire 3.3 section only has two numbers, which is regrettable. The third issue is that this paragraph lacks a summary and the author's viewpoint, not just descriptive language. The fourth question, the author uses two paragraphs to describe. The first paragraph describes the impact of climate on biocrust, while the second paragraph mainly describes the impact of soil on biocrust. Additionally, the author adds a sentence about the impact of human activities. Is this structure reasonable.

Response：Thank you for giving these wonderful suggestions about organization of this section. In the revised manuscript, the following improvements have been made to the original section 3.3:

Q1, In the revised manuscript, we have clarified that these factors are selected according to previous understandings that are mainly based on previous empirical and modelling studies "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). Specifically, according to Bowker's book chapter (10), the dominant factors of biocrust distribution are variable at different spatial scales. In the article, we mainly chose the most relevant factors for biocrust distribution at the global scale which has been clarified in the article.

Q2, based on the theoretical description, we added some literature as an extension, as well as using figures as much as possible to present the ideas quantitatively. (lines 265-276, 294-311)

Q3 and Q4, as suggested by the reviewers, we have restructured the chapter structure, turning section 3.3 into a stand-alone chapter 4 "Influencing factors of biocrust distribution". In addition, each of water conditions, temperature, soil properties, fire, disturbance and other factors were discussed in a separate paragraph. At the end of Chapter 4, we have added a summary paragraph to show our points about this issue, "To sum, climate is the most important factor of influencing global biocrust distribution, especially in drylands where water is precious to the organisms. But exploration of the roles of climatic factors such as rainfall seasonality and atmospheric drought still

needs much more further efforts (Wright and Collins, 2024), especially context of global climate change. Although more attention has been paid to physical properties of soils, the roles of its chemical properties such as the N, P content need to be taken more seriously. Fire and disturbance are usually ignored. Whereas due to the trend towards warmer and drier environments, as well as increasing population and the need to sustain livelihoods, their influences on biocrust distribution may become more important. As one of the basic processes on global scale, biogeographic isolation or changes in land use should be paid more attentions. As amounting data points of biocrust, we can expect this aspect will see a surge in research". (lines 321-331)

Line 248: Confirm if it should be "20,000 years."
Response: We've checked and confirmed it's 20,000 years.

Lines 312-315: Clarify the relationship between high-resolution imagery and the database.
Response: Thank you for pointing out the issue. In the revised manuscript, we have moved this sentence to the end of the paragraph in section 5.3, "Integrated application of high-quality sensors". (lines 425-427)

Lines 347-349: Provide examples or precedents for this point. If none exist, explain the scientific basis for this method.
Response: In the revised manuscript, we have cited a reference (Wang et al., 2022) to show that a case that it used multiple sensors to construct biocrust indices, improving the accuracy of cover prediction by 6% ("If the biocrusts index can be constructed by combining and comparing the full-band spectral data from multiple terrestrial sensors and infrared cameras and other devices, the errors will be reduced to a certain extent, thus improving the classification accuracy (Wang et al., 2022b)."; line 418-421).

The conclusion lacks an overall summary of the entire article. The author is encouraged to provide a concluding paragraph that synthesizes the key findings and insights.
Response: Thank you for the suggestion. In the revised manuscript, a new chapter 6 on conclusion was written "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)

Additionally, review the entire manuscript for grammar, capitalization, and singular/plural form correctness.

Response: In the revised manuscript, we have carefully checked the grammar and writing for several times. Furthermore, Large Language Model – ChatGPT-3.5 was employed to check grammar and to avoid typos.
