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1 LETTER TO THE EDITOR

2  
3 **Understanding bat ecosystem services on a global scale requires caution and wider**  
4 **collaboration: a critical evaluation of Ramírez-Fráncel et al. (2021)**

5 **Running title:** Understanding bat ecosystem services on a global scale

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Global biodiversity is currently in the midst of the sixth mass extinction, and countless species and their key ecosystem services are threatened across different habitats (Vos et al. 2015). Constructive actions to address the negative impacts of changing conditions require rigorous biodiversity data integration and synthesis to inform effective policy-making decisions (Heberling et al. 2021). Care is needed to ensure objectivity and remove biases in analyses to avoid generating misleading conclusions. Recently, Ramírez-Fráncel et al. (2021) published a review offering an update on the vital ecosystem services of bats on a global scale. We applaud the authors for their attempt to conduct an extremely challenging large-scale analysis in major areas of bat ecosystem services. The work provides a valuable set of analyses to improve our current knowledge, and thus bolster bat conservation and public support. However, the review contains several inaccuracies and biases related to the review framework, methods, and screening of literature from different regions. We believe these limitations may hinder an accurate understanding of bat ecosystem services, particularly in identifying regional strengths and gaps in the Palaetotropics. We base this

statement on problems we identified in the areas of bat-plant interactions, but several of the issues potentially affect other services discussed by the authors. Here, we highlight several key points that warrant corrections and/or clarifications from the authors.

The review of Ramírez-Fráncel et al. (2021) aims to summarize what is known about the impacts of bat ecosystem services such as pollination, seed dispersal, insect-pest consumption, and nutrient yield on a global scale. Although the authors state that they systematically gathered and synthesized existing literature from different biogeographical zones, the methods of literature selection as well as much of the content, discussion, and examples are skewed towards studies from the Neotropics. This bias has led to the conclusion that there is a lack of studies from other regions. This is not true for bat-plant interactions in the Palaeotropics, where there is a solid history of studies (Kunz et al., 2011), and many of which (e.g., seed dispersal and pollination studies) have been reviewed very recently (Aziz et al., 2021). In the introduction, Ramírez-Fráncel et al. state that there has been a lack of exhaustive reviews in the past, but Kunz et al. (2011) published an extensive review in all aspects of bat ecosystem services ten years ago, and this provides a representative overview of service provision. In addition, there have been numerous exhaustive reviews of Palaeotropical bat-plant interactions both before that of Kunz (e.g., Marshall 1983, 1985; Fujita and Tuttle 1991; Fleming et al. 2009), and a very recent review by Aziz et al. (2021). The authors did not mention some these previous reviews, or any of the underlying papers, suggesting that the regional bias in their data collection (towards the Neotropics) has falsely given an impression of an overall lack of research.

Details within the methods are not clear regarding how the literature was selected and evaluated, what studies were included, and how the selection was standardized. Firstly, the 2000-2020 timeframe is not well justified and is problematic for the context of the review. The 2000 cut-off may have missed a large fraction of studies from many regions. In fact, the

dataset in the Aziz et al. (2021) review shows that the chosen timeframe missed numerous important studies. The use of contemporary post-2000 literature is useful and informative when examining recent research trends and efforts to direct future efforts, but not when the goal is to provide a comprehensive review of a topic. We suggest in future studies to reanalyze the dataset by adjusting the timeline and coverage (e.g., 1991 to 2021), and comparing the difference in data turnover.

The scope of exclusion criteria is confusing and difficult to reproduce, which may have affected the results and subsequent discussion. The authors have excluded 294 studies (51%), including 94 studies due to the lack of “*clear research questions*” or “*did not postulate a hypothesis*” about the functional role of bats. However, these criteria are not explicitly explained or defined in the methods, nor do they support the review’s goal of providing a comprehensive overview of bat ecosystem services. Some examples and more elaboration of the criteria would have helped to clarify the justification for exclusion. With only 283 publications included in the analysis, this is simply too few to reliably assess all ecosystem services provided by over 1400 known bat species.

Similarly, the review approach of Ramírez-Fráncel et al. 2021 requires a systematic approach, which should standardize and maximize information rather than exclude a large fraction of possible information without a clear justification. The proportion of excluded literature in the study is high for a systematic review, and numerous key items of information may have been missed. For example, conference proceedings, summaries, review papers, project reports, as well as grey literature reports and student theses would have been missed using the search criteria chosen; hence leading to the omission of a large body of work that would have made this review truly comprehensive. This is especially problematic in that many students who do not have English as a first language may present research at conferences and online theses but may not be published in international journals. This is

important since these criteria were used to exclude 200 papers, and the contents of these papers are thus not possible to assess. Natural history studies and short communications could still prove useful sources of data for bat ecosystem services, not found elsewhere (see Valdez, 2020 for an excellent example of in/exclusion methods of literature for systematic review). Furthermore, there is no mention of cross-referencing review papers to extract or compare further information. In addition, the authors could have also included or examined relevant papers and syntheses such as Aziz et al. (2021), which is freely available and is still the most comprehensive review available for pteropodid-plant interactions, and the “Bat Eco-interactions” database <https://www.batbase.org/>, which at present includes 14551 interactions from 518 bat species from 104 countries globally, and could increase their dataset for a more meaningful and representative review. Additionally, the Ramírez-Fráncel et al. review and its supplementary files did not specify how many and what bat species are interacting with what plant species (i.e., for seed dispersal and pollination), which for pteropodids is provided in existing and more comprehensive review databases, such as Aziz et al. (2021). The authors also claimed that “*Our review identified 130 plant genera dispersed by fruit bats that were not reported in the review by Kunz et al. (2011).*”, but the newly compiled data of individual and specific bat-plant interactions in the review are not presented, either in the main manuscript or in the supplementary information, making this claim impossible to assess. We encourage the authors to make this information available to make it useful for future syntheses and updates.

The search languages used were limited to English, Spanish, and Portuguese, thereby preferentially searching for all Neotropical languages only, whilst simultaneously excluding Francophone African countries and the diverse languages used in Asia. This results in biased searches for a global review and may have neglected numerous works from other parts of the globe (e.g., Chinese and Indonesian in Asia). Consequently, using this limited scope of languages may lead to misleading and unsubstantiated conclusions; for

example, the authors stated that “*Most (70%) of the studies that evaluated this ecosystem service were conducted in the Neotropical region*”. Also, search terms such as “ecosystem service\*”, “ecological service\*” or “human benefit\*” are missing in the search string implemented by the authors. This is unexpected given the review’s aim to synthesize the benefits of bats to humans. In addition, the term “flying fox” should have been included in the search strings to include literature for the Palaetropics, as its omission has resulted in missing many studies focused specifically on *Pteropus* and *Acerodon* species, and the common name “flying foxes” should not be assumed to merely function as an alternative for all pteropodids, as used in the introduction of this review.

The goal of the review was to understand the direct benefits bats bring to humans, but the results listed broader aims and include ecological roles that are not directly linked to humans. For example, in the results, the authors generalized all seed dispersal and pollination studies as being evidence of ecosystem services but without explicitly explaining how the cited interactions fit these criteria. They attempt to strengthen the link to humans in the discussion by mentioning reforestation as an implication of such interactions, but this link is tenuous given that it relies on the tendency of a bat species to use degraded areas – a factor that is not included. Also, bat diet papers that did not provide evidence for ecological roles, nor claim to do so, were cited as such. There is also inconsistent and confusing use of terms such as “environmental services” and “ecological services” interchangeably used with “ecosystem services”. The unclear definition of bat ecosystem services, such as the mechanisms of bat pollination and seed dispersal used in the review, hampers an overall understanding of the review synthesis. As such, caution is required when examining papers that claim to have evidence for these.

In the summary of methods used to study pollination, the authors failed to mention exclusion experiments, which is the most common method to confirm pollinator

effectiveness, but instead listed flower availability, fecal content analysis, direct observations, and chemical analysis – none of which can confirm effective pollination and are therefore a flawed basis for determining pollination services (see Aziz et al., 2021). Similarly, in the summary of methods used to study seed dispersal, the authors seem to have missed out the use of seed traps to quantify seed rain, direct observations of feeding bats, and quantification of seedlings/saplings under feeding roosts (i.e., evidence of plant regeneration). They instead recommend the use of exclusion experiments for seed dispersal without citing previous use or evidence of the method's effectiveness for this aspect; these are widely used for studying pollination, but not seed dispersal by pteropodids, whereby temporal sampling using seed traps is a more common method (e.g., Sritongchuay et al., 2014; not included in the review).

Another important issues we found in the review are the several erroneous and misleading citations (see Appendix 1) that may have affected the accuracy and weakened the conclusions and their ability to help us understand patterns of research or ecosystem services. For example, the statement “*the emblematic baobabs of the Ethiopian region are pollinated by bats*” cited the work of Acharya et al. (2015), Nor Zalipah et al. (2016), Aziz et al. (2017); however, these papers are not from Ethiopia nor the Afrotropical region and did not investigate bat pollination of baobab trees; all three studies investigated interactions between bats and durian or mangrove trees in the Indo-Malayan region (Malaysia and Thailand). In the discussion, the authors mentioned “*A recent study in Malaysia has shown that a common urban bat (Cynopterus brachyotis) disperses seeds of both native and exotic species that assist forest regeneration in degraded landscapes* (Lim et al. 2018a)”. This assertion is misleading, however, because the study did not empirically investigate seed dispersal or provide evidence of the impacts on “forest regeneration” and the authors are cautious in acknowledging that their results merely suggest the potential for this. Several earlier and more recent studies that are similar or do provide more concrete, empirical



evidence of this (e.g., Tan et al., 2000; Relox et al., 2014; Sheherazade et al., 2017; Chan et al., 2020) are not cited. In the same section, the authors misleadingly cited Lim et al. (2018b) as evidence for bat pollination of 500 angiosperms worldwide along with tropical crops such as durian, bitter beans, and jackfruit. This is not what the study investigated nor provided evidence for, as it focused on molecular analyses of diet, for only one pteropodid species in Malaysia, and merely suggested pollination potential. In addition, thus far there is still no evidence that bats pollinate jackfruit.

In their conclusion, the authors sum up their review and synthesis suggesting that there is a disproportionate number of studies across a small number of biogeographical regions, however, the regionalization applied in the methods is problematic. Following Morrone (2015), the authors divided and classified the bat-plant interaction records according to Neotropical, Nearctic, Afrotropical divided to Saharo-Arabian and Ethiopian, and then the Palearctic divided into Chinese and Oriental (Indo-Malayan division would be more appropriate, and Japan and Taiwan are missing in the classification), and Australian (but the Pacific Islands are missing in the classification). While this regionalization is generally correct, it is often applied in macroecological studies of plants, and not commonly used otherwise. This regionalization is problematic in the context of bats and has resulted in the review's biased understanding of research distribution and gaps (e.g., regional research efforts), especially for regions that share similar bat species. A better approach for the study would be to remove the small portion of data from outside the Americas and focus entirely on the Americas where a more comprehensive approach, including representative linguistic diversity, has enabled the collation of more representative literature. Understanding how these patterns vary across regions and bat species will require more work, especially given the dispersal of Old World fruit bats across islands, and the delineation of Wallacea and Sundaland. The authors claim *"There is a knowledge gap in documenting the ecosystem services provided by bats in the Australian, Chinese, Ethiopian, and Saharo-Arabian regions*

or *transition zones*” but it is not clear what is meant by “a knowledge gap” when a recent review by Aziz et al. 2021 did find studies from most of these regions, and therefore this supposed lack of data could be due to a lack of systematic searches or appropriate language inclusion, resulting in missing papers from across these regions. We suggest reassigning biogeographical realms following the example of Olson et al. (2001) or from WWF ecoregions from 2017 (<https://ecoregions.appspot.com/>), which are also used in delineating global mammal distribution in Burgin et al. (2018). By considering this, the conclusion would be more realistic and congruent with recent and intensive region-based analyses. Also, by using such an approach, validation of patterns in future studies will be easier and more comparable.

The review aims to assess bat ecosystem services in areas of “Pollination”, “Seed dispersal”, “Insect-pest reduction” and “Guano as nutrient source” but many of the papers referenced from the exhaustive review do not discuss ecosystem services, nor is the connection made between pollination and seed dispersal of native plants, and services or benefits to humans. The results of this review thus suggest more of a gap analysis and overview of what is published where, rather than providing useful recommendations for what needs to be studied. Unfortunately, the analysis and results were not streamlined in the discussion and ultimately did not offer a concrete synthesis or conclusion regarding the benefits humans derive from bats. In addition, the purpose of conducting a regression analysis on the results of a (non-exhaustive) literature review is unclear, as is the question the authors were looking to answer with the analysis.

The authors also provided suggestions and recommendations to bolster studies on bat ecosystem services, but some are misleading and unsubstantiated. For example, the authors claim that “*For seed dispersal and plant pollination services, experimental en/exclosures, and construction of roosts in agricultural areas can provide valuable insights*”, but it was not explained how these suggested methods would be suitable or appropriate

221 especially for studying bat seed dispersal; indeed, the effectiveness of artificial roosts has  
222 not been proven for pteropodids, which have specific habitat requirements that cannot be  
223 met by such structures. In the same section, the authors claim *“Our analyses show that the*  
224 *assessment of ecosystem services provided by bats in transformed landscapes and*  
225 *agricultural crop areas remains largely unexplored”* but multiple pollination and seed  
226 dispersal studies in the Palaeotropics have, in fact, been conducted in transformed  
227 landscapes and agricultural crop areas (e.g., Bumrungsri et al. 2009; Deshpande & Kelkar  
228 2015; Sheherazade et al. 2017; Sheherazade et al. 2019; Sritongchuay et al. 2019; Chan et  
229 al. 2020). The discussion also states that *“It is necessary to undertake new investigations to*  
230 *evaluate whether bat pollination translates into increased fruit production”*, which implies that  
231 it hasn’t been studied, but this is exactly what exclusion experiments and the published  
232 durian pollination studies have evaluated (e.g., Bumrungsri et al. 2008, 2009; Aziz et al.  
233 2017; Sheherazade et al. 2019; Sritongchuay et al. 2019). In the “Pollination” section, the  
234 authors stated that *“Additionally, previous studies have not been able to isolate the impact of*  
235 *bat pollination on crop performance from other vertebrate and invertebrate pollinators”*, but  
236 there are numerous case studies from the Palaeotropics that have done so (e.g., Bumrungsri  
237 et al. 2008, 2009; Sritongchuay et al. 2016; Wayo et al. 2018; Sheherazade et al. 2019),  
238 which the authors have overlooked.

239 Lastly, the authors proposed three strategic actions to promote bat ecosystem services  
240 research, which includes (i) increasing environmental education based on the latest scientific  
241 studies, (ii) more research on bat ecosystem services and making information available to  
242 the public, and (iii) increase the size of conservation areas and raise the protection level of  
243 sites vital for bats. Then, the authors provided a notable example from Aguirre et al. (2014),  
244 which focuses on site-level protection of high bat biodiversity; however, there was no clear  
245 link as to how this example and proposed actions can substantially promote bat ecosystem

services studies. Further, the authors also failed to note that the Bat Eco-Interactions Database is already an existing initiative for making such information publicly available.

Given the inaccuracies and biases discussed above, we believe this is sufficient to warrant appropriate actions from the authors. The review by Ramírez-Fráncel et al. is a valuable contribution, but the breadth of the information the authors presented could have been better used to provide a more encompassing and meaningful synthesis of all vital aspects of bat ecosystem services or focused on the region where their data were more complete. Their work could also be useful for bat conservation if the review framework and methods of data synthesis were made clearer and more reproducible. The current review needs a clear framework of how the identified ecological interactions can benefit humans and the environment. By drawing attention to these shortcomings, we hope to enable biodiversity synthesis such as Ramírez-Fráncel et al. to better inform future decision-making that is inclusive, data-driven, and pragmatic. We hope that our criticisms will be taken constructively, and the authors will address the genuine gaps we have highlighted. More importantly, ambitious global reviews in areas of zoology, ecology, and conservation such as this should involve wider and more representative collaborations of different regional experts and practitioners across the globe to maximize the inclusion of accurate information and perspectives.

#### **Conflict of Interest**

The authors declare no conflict of interest.

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## SUPPLEMENTARY MATERIALS

### Appendix 1 List of some miscited literature in the review