Reply to: Maximising time-series inclusion reduces geographic and taxonomic biases in the Living Planet Index

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We welcome the discussion on the reliability of the Living Planet Index (LPI). Many of the points raised by McRae et al.[1] have already been discussed during the review process and are available in Peer Review File of our original paper[2]. Here we focus on what we consider the major misunderstandings of the problems we have raised in our critique[2].

First, we followed all published steps for calculating the global LPI[3], but could not maintain complete alignment with the ongoing updates in the Living Planet Database (LPD) throughout the whole process. The full LPD is not publicly available and is continuously updated between the publications of the biennial Living Planet Reports, so that our results were indeed not directly comparable to the latest version of the LPI[4]. McRae et al.[1] themselves show that this is not a substantial problem, as the differences between respective LPIs are not too large. However, this updating does affect our example concerning the very high sensitivity of the LPI to a few time series that represent particular regions and taxa. We chose an example of one population of the viper *Vipera berus*, which caused the Palearctic LPI to decrease only due to its four records (four years at the beginning of the study period). This particular population has been indeed removed from the data used, but only after we published a preprint of our article (this comprises also the information on other removed populations, as well as the replicates). We admitted this update in our study[2], but we also noted that the removal of this population did not solve the general problem, as one or a few populations with the strong influence on the LPI always remain in the data. This problem is even exaggerated in regional LPIs based on smaller sets of time series. Therefore, although the viper example is only illustrative and does not concern the current LPI, the problem with extreme sensitivity of the LPI to the initial trend of a few populations that represent otherwise highly underrepresented groups remains. Inspecting each population time series and identifying replicates and unsuitable population time series is thus necessary, and we are glad that the dataset has been recently treated this way for the calculation of the global LPI.

That said, we agree (and we pointed this out in our study[2]) that some problems of the LPI cannot be solved without obtaining better data. This is often impossible, especially in the case of the beginning of the study period. Also, we are aware of the low representativeness of regions which are crucial in terms of biodiversity loss, namely tropical ones. However, we do not agree with McRae et al.[1] that this justifies using any data available for these regions, including sparse population time series that are vulnerable to sampling errors, especially time series with only two records. We have argued that the better geographic cover cannot be obtained at the expense of biased data. McRae et al.[1] seem to ignore our main point in this respect, i.e. that the spurious trends of sparse time series may be driven by sampling errors (see ref.[5]), since sampling errors on arithmetic scales produce asymmetries of population increases and decreases on logarithmic (multiplicative) scales, which is used in the LPI calculation (see Fig. 3 in ref.[2]). In the most simplified example, if the recorded population size of two individuals decreases due to a sampling error by one individual, it is a decrease by one-half, whereas if it increases by one individual, it is an increase by only one-third. It is impossible to estimate how this asymmetry actually affected the resulting LPI, as we do not know what actually drives the trends in measured time series. Our finding that removing sparse time series leads to substantially weaker LPI declines indicates at least that including them may lead to a risk of biased LPI. We argue that bigger data with wider geographic coverage are not necessarily better if there is a high probability of any bias.

Our general argument could be formulated as follows. The calculation of the LPI is based on (multiplicative) population growth between every two consecutive years, and this approach thus becomes inappropriate in any case when multiplicative growth is not in play. This applies especially to the treatment of zeros. We have put considerable effort to explain that the problem does not lie in our inability to distinguish real zeros from observation errors. Instead, we have argued that no zeros can be included if an index is multiplicative, and any way to mitigate this problem by replacing zeros by something else introduces artefacts. We never cast doubt on the fact that zeros may be very informative – after all, extinction is what concerns us the most. However, since zeros are not compatible with multiplicative population growth, they should be treated separately from the calculation of a multiplication-based index (see ref.[6]). McRae et al.[1] state that they considered zeros informative, and thus their decision was taken not to disregard this information, and that other indicators use a similar process. We do not consider this as a valid argument, as it does not violate our point that any treatment of zeros within the LPI machinery introduces artefacts. This also includes capping (i.e. limiting high population growth to a certain threshold), because capping simply introduces a new, completely artificial value of population growth and smoothens the index (see SI in ref.[2]). We argue that if we decide to use the multiplicative growth rate, the only consistent approach is the removal of zeros. It indeed leads to the fragmentation of time series that contained a zero in the middle, but it does not represent a problem, given that the LPI is based on a

comparison of pairs of consecutive years, and thus it does not matter if a time series is taken as a whole or as several pieces.

McRae et al.[1] are right in their statement that any index calculation necessarily involves several subjective decisions. We admit it in our paper[2] and agree that being subjective does not mean being wrong. But we also show (Fig. 1 in ref.[2]) that all the decisions made by the authors of the index lead to a more severe decline in the LPI than if alternative decisions were made. Indeed, the decision to include data-poor time series, to give higher weight to less-represented regions, and to include zeros and treat them as a considerable population decline, all lead to the LPI which is more severely declining than in the case of alternative decisions. Such decisions would be valuable if the only purpose of the LPI was to alarm the public. However, a set of decisions that all push the LPI in one direction (downward) is not appropriate if the purpose is to provide a balanced picture of the state of the world. All these decisions can be certainly justified somehow. On the other hand, we do not think all of them are equally valid. To be specific, we understand that including all available time series from underrepresented regions and taxa may seem rather appropriate if we aim toward an index that is geographically balanced – we still feel that it is not worth including too sparse time series, given the risk of introducing serious bias, but this is probably a matter of taste. Weighting could be considered potentially more problematic, as weighting is always somehow arbitrary process, even if it is justified by highly unequal geographic coverage. In our view, the most problematic decision is the third one, comprising the way zeros are treated in an essentially multiplicative world.

In this respect, we feel important to stress that the primary purpose of our study was not to improve the algorithm of the LPI calculation. We have pointed out the sensitivity of the LPI to some decisions and have shown how alternative decisions lead to an index that does not reveal such strong declines. McRae et al.[1] are right that we could not demonstrate that these alternative decisions are better. But our point was more general: The whole algorithm of the LPI is so vulnerable to various biases (including those due to sensitivity to a few population time series at the beginning of the study period) that it does not represent a proper way to show general and reliable trends of population changes. This does not mean that we should give up a utilization of the huge (and necessarily highly heterogeneous) data from the Living Planet Database. But we argue that instead of relying on the geometric mean of inter-annual growth rates, as implemented in LPI methodology, it is better to treat individual time series as data points and explore the distribution of the properties of the whole time series, as has been done by Daskalova et al[7,8]. This procedure should also exclude zeros and treat extinction dynamics separately, as it is a distinct process that is informative and important by itself[6,9].

Although we are critical of the way the algorithm was set and we showed that the subjective decisions did push the LPI towards more severe declines than if alternative decisions were made, we agree we cannot evaluate whether actual vertebrate population declines are really less severe than shown by the

current version of the LPI. The alternative ways of data analyses mentioned above indicate surprisingly balanced population declines and increases[6,7], but, as we mention in our paper[2], available data may be biased in both directions, and thus new frameworks and analyses are required in order to develop a more confident picture of population changes. We appreciate that all our analyses were possible only due to freely available data and code, according to the best scientific practices. We can only hope that this way of open science opens the possibility of resolving the question of global trends in vertebrate population change in the future.

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Author contributions

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Competing interests

The authors declare no competing interests.