Matters arising

The Living Planet Index does not measure abundance

https://doi.org/10.1038/s41586-021-03708-8

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Received: 13 January 2021

ARISING FROM B. Leung et al. Nature https://doi.org/10.1038/s41586-020-2920-6 (2020)

Accepted: 3 June 2021

Published online: 26 January 2022

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The Living Planet Index (LPI), which is said to track changes in vertebrate abundance, has been in strong decline over the past decades¹, raising alarm about the state of biodiversity. Leung et al.² find that the strong declines in the global LPI are due to a small fraction of strongly declining population trends. Although the sensitivity of the LPI to outlier trends is an important finding, the exposition of Leung et al.² does not make it clear that the LPI does not really measure changes in abundance, and if interpreted as change in abundance, the conclusions are systematically biased downwards. We think that this is an important issue to clarify, given the role of the LPI as an indicator for the UN Convention on Biological Diversity (CBD) and the high media coverage the LPI receives.

The LPI is used as an indicator to track the progress towards five of the Aichi CBD biodiversity targets for the period 2011–2020 (targets 5, 6, 7, 12 and 14). Currently, multilateral negotiations in CBD are ongoing for the post-2020 targets, and the choice of indicators is a timely matter. The most recent Living Planet Report¹ states that the global LPI shows a 68% decrease in the monitored populations of mammals, birds, amphibians, reptiles and fish between 1970 and 2016. As the LPI is said to monitor 'abundance' and 'average abundance'¹, an intuitive interpretation of the reported decrease suggests that, on average, the abundance of vertebrates has decreased by 68%. This has been widely interpreted to be a terrifying result, indicating a catastrophic decline in biodiversity.

However, the LPI does not measure abundance, or changes in abundance, in the common sense of the word (that is, number of individuals, or a proxy thereof)³, and produces a systematically downwardly biased estimate if interpreted as change in the number of individuals. In the method for calculating the LPI⁴, the annual rate of change of a population *i* from year *t* – 1 to year *t* is calculated as

$$d_{it} = \log_{10} \left(\frac{N_{it}}{N_{i(t-1)}} \right)$$
 (1)

where N_{it} and $N_{i(t-1)}$ are the abundance measures of the focal and the previous year, respectively.

To calculate the LPI for a group of populations (or species), d_{it} values are arithmetically averaged over the n_t populations (or species) of interest for each year

$$\overline{d}_t = 1/n_t \sum_{i=1}^{n_t} d_{it}$$
(2)

and the index value for year t is obtained by multiplying the index value of the previous year by the antilog of the mean d_t , while setting the index value to 1 at the start of the time series.

$$I_t = I_{t-1} \times 10^{d_t}, \ I_0 = 1 \tag{3}$$

Arithmetic averaging of logarithmic values is one way of taking a geometric average. The geometric average is an accurate and informative way of calculating average growth rate when the final outcome (for example, the final size of a population or an investment) is the product of the initial size and the annual growth rates. However, in the LPI methodology, averaging is done over growth rates of mathematically independent units (that is, separate populations and species), which prevents any straightforward interpretation in terms of change in abundance(s).

If the LPI is erroneously interpreted as change in abundance, the measure is biased downwards because geometric averaging treats proportional increases and decreases as equal, when the impacts on abundance actually differ. Figure 1a gives a simple example of two populations in which one doubles in size and one shrinks to one half. Assume for simplicity that the initial populations both have 100 individuals. Then, in the end, there are 250 individuals in total, an increase of 25% in abundance. The LPI, however, indicates no change, as the LPI value is 1.

The more the populations vary in their rate of increase or decrease, the more downwardly biased the LPI will be as a measure of abundance. Figure 1b shows what happens if one population increases tenfold and the other shrinks to one-tenth. The LPI again indicates no change, when the total number of individuals (and hence mean abundance) has actually increased by 405%, from 200 to 1,010 individuals. In the LPI database, shorter population time series display more variation (stronger decreases or increases) than longer time series^{2.5}, so the downward bias in the LPI is expected to be stronger when short time series are included in analysis.

Another way to demonstrate the downward bias in the LPI as a measure of abundance can be seen in Fig. 1c, d. In Fig. 1c, one population increases from 100 to 150 and one decreases from 100 to 50. Mean abundance has therefore not changed, but the LPI indicates a decrease of 13%. In Fig. 1d, one population increases from 100 to 190 and the other decreases from 100 to 10. Again, no change in mean abundance has taken place. However, owing to the large variation among populations in their rate of increase or decrease, the LPI now indicates a huge 56% decrease.

Moreover, as the LPI is calculated over time by multiplying the index value of the previous year by the index value of the current year (see equation (3)), the downward-biased values at any point in time are propagated to LPI values at all future timesteps. The global LPI for 1970–2016 indicates a 68% decrease, translating to an LPI value of 0.32 for 2016¹. A

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а	Pop. A Pop. B	N _{t-1} N _t 100 200 100 50	$N_{t/N_{t-1}} = d_t$ 2 0.30 0.5 -0.31	LPI	500%	Total abundance	Arithmetic average of proportional change	Living Planet Index
	Average Change	100 125 +25%	1.25 0 +25%	1 0%	0%	25%	25%	0%
b	Pop. A Pop. B Average Change	100 1,000 100 10 100 505 +405%	10 1 0.1 -1 5.05 0 +405%	- 1 0%	500% 0%	405%	405%	0%
C	Pop. A Pop. B Average Change	100 150 100 50 100 100 0%	1.5 0.18 0.5 –0.30 1 –0.06 0%) 5 0.87 –13%	0% –80%	0%	0%	-13%
d	Pop. A Pop. B Average Change	100 190 100 10 100 100 0%	1.9 0.28 0.1 –1 1 –0.36 0%	6 0.44 -56%	0% –80%	0%	0%	-56%
е	Pop. A Pop. B Average Change	100 136 100 70 100 103 +3%	1.36 0.13 0.7 -0.15 1.03 -0.07 +3%	5 1 0.976 –2%	5% 0% –5%	3%	3%	-2%
f	Pop. A Pop. B Pop. C Average Change	50 45 25 5 20 8 47.5 29 -38%	0.9 -0.05 0.2 -0.7 0.4 -0.4 0.5 -0.38 -50%	5 3 0.42 -58%	0% -100%	-39%	-50%	-58%

Fig. 1 | Numerical examples illustrating the relationship between population trends and percentage change in total abundance, arithmetic average of proportional change, and the LPI. See text for descriptions of examples.

drop of this magnitude comes about with a rather moderate constant vearly index value of $0.976(0.976^{45}=0.32)$. The example in Fig. 1e shows that an index value of 0.976 can arise as a result of moderate variation among population trends without a decrease in abundance (and actually even with increasing abundance). Indeed, the Living Planet Report⁶ and other studies⁷⁸ have found that increasing and decreasing population trends are approximately equally common in larger datasets. It thus seems plausible that the discrepancy between the marked decline in the global LPI¹ and the other studies, which did not find strong evidence for global declines in vertebrate abundances^{7,8}, is likely to result from the geometric averaging in the LPI method causing bias when interpreted as abundance. We also point out that we do not intend to downplay the importance of extreme outliers in driving the decrease in the global LPI identified by Leung et al.², but rather to illustrate that the trouble with the LPI methodology is deeper than that, and cannot be resolved by removing extreme population trends from the analysis.

In the numerical examples above, we have made the simplifying assumption that all the initial populations are of the same size. Added complications arise if populations differ in absolute size and there is a correlation between population size and rate of change. This problem has been acknowledged in the Living Planet Report⁶ (page 18), with a numerical example (replicated in Fig. 1f) showing how a negative correlation between population size and the rate of decline—with smaller populations declining faster than larger populations—results in a larger drop in the index value than in the proportion of individuals lost. However, this is a separate issue from the systematic downward bias caused by geometric averaging (when the LPI is interpreted as change in abundance), which arises even without a correlation between population size and rate of increase or decrease. Incidentally, in the Living Planet Report example⁶, the 'percentage change' (standing in for the LPI) is reported to be -50%, but this is the arithmetic average of proportional changes in abundance, not the value obtained by the LPI methodology. As Fig. 1f shows, the LPI method yields a value of 0.42, corresponding to -58%; the additional eight-percentage-point reduction is caused by the geometric averaging in the LPI method. Furthermore, recent analysis of the data in the Living Planet Database suggests that absolute population size does not predict whether the population trend is increasing or decreasing⁷, implying that correlations between population size and rate of increase or decrease are not likely to cause considerable bias in global estimates.

The decline in biodiversity is a real and serious phenomenon⁹. Thus, the technical issue identified here regarding the incorrect interpretation of the LPI must not be interpreted as a failure of conservation science in general, or as evidence that nature is not at risk. For example, the International Union for Conservation of Nature assessments of extinction risk, which are based on clearly defined criteria and do not use the LPI methodology, indicate that the extinction risk of mammals, birds, amphibians, reef-forming corals and cycads is increasing (https://www.iucnredlist.org/assessment/red-list-index, accessed 11 January 2021).

For a biodiversity index to be useful, it must not only have mathematically and statistically desirable properties, but also be easily understood¹⁰. The LPI clearly is not a good metric for abundance, and while the arithmetic average of proportional changes in abundance is easier to interpret with just two time points (Fig. 1), it does not serve well as a metric for abundance index either³. Finally, we urge scientists that have used the LPI methodology to scrutinize the conclusions of their work, and those negotiating future indicators for the UN CBD to critically review the interpretation of the LPI.

Data availability

All data generated or analysed during this study are included in this published article.

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Author contributions M.P. initiated the comment and led the writing process. All authors contributed to the text and approved the final manuscript.

Competing interests The authors declare no competing interests.

Additional information

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Matters arising

Reply to: The Living Planet Index does not measure abundance

https://doi.org/10.1038/s41586-021-03709-7

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Published online: 26 January 2022

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REPLYING TO M. Puurtinen et al. Nature https://doi.org/10.1038/s41586-021-03708-8 (2022)

In the accompanying Comment¹, Puurtinen et al. provide a clear example of why one must be careful when interpreting analyses using the Living Planet Database (LPD). We were pleased to read this Comment inspired by our recent paper². It is an important continuation of the discussion about what can be learned from the rich data in the LPD. In brief, we concur that the Living Planet Index (LPI), and any summary analyses using the LPD (including ours), do not reflect changes in abundance. This is an important point that is often missed by the media, and it is exactly the type of nuance we wanted to promote with our paper.

Although the data in the LPD are based on estimates of population abundance, the database was never meant for comparisons of absolute abundance. The reason is that the metrics are standardized only within populations. The diversity of sampling methodologies and spatial scopes for each population makes it intractable to compare absolute abundance among species. What analyses of the LPD can provide, however, are comparable estimations of population trends. Population trends yield insight into whether populations are increasing or decreasing and the relative (rather than absolute) magnitudes of these changes. We believe that these are also important elements of changing biodiversity patterns.

More generally, we also want to recognize the difficulty in interpreting any conglomerate index, irrespective of whether it measures abundances or trends. The key difficulty, of course, is that the index is actually composed of non-interchangeable units (that is, different populations and species); a reduction in population 1 does not necessarily reflect any change in population 2, but the composite can make it appear as though it does. Thus, for indices based on geometric means, such as the LPI, extreme trends in a few populations can drive large declines in aggregate indices, which are easily misinterpreted as the entire system declining (as highlighted in our Article²). Alternatively, if one used an index based on absolute abundances, if species A doubled and species B went extinct, the index would suggest no change. Most conservationists would be likely to disagree that such a scenario reflects a stable system. Yet, simultaneously, owing to some set of underlying factors, systems can be broadly declining (or broadly improving), and it is important to identify such widespread trends.

A better approach would be to explicitly model the distribution of population trends. This is the basis of the Bayesian hierarchical mixture (BHM) model², which allows one to separate and consider both unexpectedly strong trends and more typical trends. A BHM approach thus provides a more accurate picture of how populations are doing, rather than being dominated by the extremes. Furthermore, the BHM model summarizes both general behaviour (primary clusters), and variation, and so can reveal the fraction of populations undergoing different levels of decline or growth (for example, in the ten taxonomic or geographic systems showing strong mean declines, 87% of those populations also showed strong mean declines). Finally, a BHM approach makes it difficult to conflate abundance with the distribution of trends. There are other advantages of a BHM model (for example, accounting for population fluctuations and differences in time series size), which we described in our paper².

In summary: (1) Puurtinen et al.¹ raise an excellent and correct point: both researchers and the media must guard against the unfortunately common mistake of interpretating the LPI as measuring abundance loss. (2) Analyses using the LPD necessarily refer to trends, given the type of data available. (3) Aggregate measures are inherently difficult to interpret, given the non-equivalence of species.

 Puurtinen, M., Elo, M. & Kotiaho, J. S. The Living Planet Index does not measure abundance. Nature https://doi.org/10.1038/s41586-021-03708-8 (2021).

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Author contributions B.L. wrote the response. A.L.H. and D.A.G. helped with writing, editing and discussing ideas. B.M., M.D. and R.F. discussed ideas and did some editing.

Competing interests The authors declare no competing interests.

Additional information

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