- Supplementary Information -

Random population fluctuations bias the Living Planet Index

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Appendix S1: The effect of random population fluctuations on fitted GAM models.

Using the method described in the main manuscript, we simulated three trajectory shapes (concave-up, linear, and concave down) for populations declining from 100 individual to 40 individuals between 1970 and 2020 (d = 0.2, d =1 and d =5 respectively) (Extended Data Fig. 5). We also simulated populations that increased from 100 individual to 160 individuals between 1970 and 2020 along the same three trajectory shapes (Extended Data Fig. 6). We then added random noise to all points in the time-series besides the first and last population measurements, by drawing fluctuations from a random normal distribution with a mean = 0. This ensured that all time-series had the same starting and ending populations. We simulated three levels of randomness, by setting the standard deviation of the random normal distributions to 1, 4, and 7. We fitted a generalised additive model (GAM) to each of the time series (`gam` function in `mgcv` package, v1.8.33), using the restricted maximum likelihood method (REML) and by setting the smoothing parameter to half the length of the time-series as in the LPI[6].

We illustrated how random fluctuations affected the GAM model and, subsequently, the population estimates used to calculate λ in the LPI. For declining concave-up trajectories (Extended Data Fig. 5 a-c), larger fluctuations caused decreasing GAM estimates for the starting population size. The underestimation of starting populations is exaggerated further by the $\log_{10}$-transformation, which would lead to underestimating the declines in the LPI. For linear trajectories (Extended Data Fig. 5 d-f), the mean GAM estimate was generally robust, even though the confidence intervals increased with random fluctuations. The ending population size was slightly overestimated when population fluctuations were high (Extended Data Fig. 5 f), but this has a smaller effect on log10-transformed data compared to inaccurate starting populations. Declining concave-down trajectories showed results consistent with those for linear declines (Extended Data Fig. 5 g-i), where ending population estimates were slightly overestimated.

For populations increasing from 100 to 160 individuals (Extended Data Fig. 6), GAMs fitted to concave-up trajectories were accurate regardless of the magnitude of population fluctuations (Extended Data Fig. 6a-c). The same was generally true for populations that increased linearly, although high degrees of population fluctuation overestimate the ending population size (Extended Data Fig. 6f). Populations increasing along concave-down trajectories were most affected by population fluctuations, which overestimated starting population (Extended Data Fig. 6 g-i). GAM also overestimated the ending population when the magnitude of population fluctuations was very high (Extended Data Fig. 6i).