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Alternative measure of nestedness

Bastolla *et al.* (ref. 1) independently developed a measure of nestedness almost equivalent to NODF, the nestedness measure used in this manuscript[2]. The only difference between the two measures is the absence of the criterion of "decreasing filling," that is, the condition imposed in NODF that $M_{ij} = 0$ if $k_i = k_j$.

In Supplementary Fig. 1, we show that the use of both measures results in highly-correlated values of individual contribution to nestedness. All additional results presented in the manuscript also hold when using this alternative measure of nestedness (Supplementary Figs. 2 and 3).

Alternative null model

As opposed to the probabilistic null model, one could alternatively "swap" or "shuffle" the interactions for a given node, as described in detail in ref. 3. For the case of an individual node, this null model is more conservative as it allows for repositioning interactions without taking into account the degrees of specialization or generalization of the other nodes. When measuring the node contribution to nestedness with this null model, one should keep in mind that our metric could not be estimated if a node interacts with all its partners, in which case the standard deviation of nestedness across replicates (the denominator in our measure) would be zero. In practice, this does not occur for any of the nodes in our networks.

In Supplementary Fig. 4, we show that the use of both null models results in highly-correlated values of individual contribution to nestedness. Using this alternative null model does not change any of the results presented in main text (see Supplementary Figs. 5 and 6).

Results at the set level: plants vs animals

The effect of nestedness contribution of the species driven extinct and the subsequent consequences of that extinction for network persistence reported in main text was calculated pooling all species (plants and animals) together. Although the focus of the paper is on overall network persistence, here we decompose the results for plant species and animal species separately. To measure the contribution of a node to overall network persistence, we calculate the difference between persistence of the network where the focal node has been removed and persistence of the original network.

While for the plant set we recover the global result of a positive, significant relationship between a node's contribution to nestedness and the probability of its removal leading to a decrease in network persistence ($p < 0.01$), for animals we find that the correlation is significantly negative ($p < 0.05$). To get some insight on the potential explanation for this difference between the two sets, we next explore whether there are differences in relative nestedness and persistence between plants and pollinators.

The nestedness measure used in main text and its equivalent in Supplementary Information can be defined at the level of each set by just comparing rows or columns and dividing by the appropriate number of comparisons (e.g., $P(P-1)/2$ for the case of plants). The significance of the observed nestedness or relative nestedness of each mutualistic set is quantified by the z-score:

$$z = \frac{N - \langle N^* \rangle}{\sigma_{N^*}},$$

where N corresponds to the nestedness value of the empirical set as defined above and $\langle N^* \rangle$ and σ_{N^*} are, respectively, the average and standard deviations of nestedness values across an ensemble of random replicates generated by the null model. Here we use the

z-score as a measure of relative nestedness to allow comparisons across networks with different size and fill.

Interestingly, we find that the collective benefits of nestedness are not directly translated to the level of the two different mutualistic sets. We observe that the relative nestedness for plants ($\langle z_p \rangle = 12.03$; 11.05 s.d.) is larger than that for pollinators ($\langle z_a \rangle = 7.7$; 4.58 s.d.) in a majority of networks (Supplementary Fig. 7a). Moreover, we find a significant, negative correlation between the difference of relative nestedness ($\Delta_z = z_p - z_a$) and difference of fractional survival ($\Delta_S = S_p - S_a$), defined as the difference between the fraction of each type of species remaining upon reaching equilibrium in the dynamic simulations (Supplementary Fig. 7b).

Similarly, while relative nestedness is greater for designers ($z_d = 13.01$) than for contractors ($z_c = 1.98$), designers have lower survival chances in the network ($S_d = 0.14$; $S_c = 0.17$). This further suggests that lower nestedness of one set is associated with increased survival at the expense of the other, just as we have demonstrated at the node level. These differences between the relative contribution and relative benefit between the two sets can help explaining the difference in sign of the relationship between nestedness contribution and effects on network persistence, albeit future work is needed before clear conclusions can be made. Nevertheless, the possibly added advantages of one subset over the other are intriguing.

Supplementary References

1. Bastolla, U. *et al.* The architecture of mutualistic networks minimizes competition and increases biodiversity. *Nature* **458**, 1018–1020 (2009).

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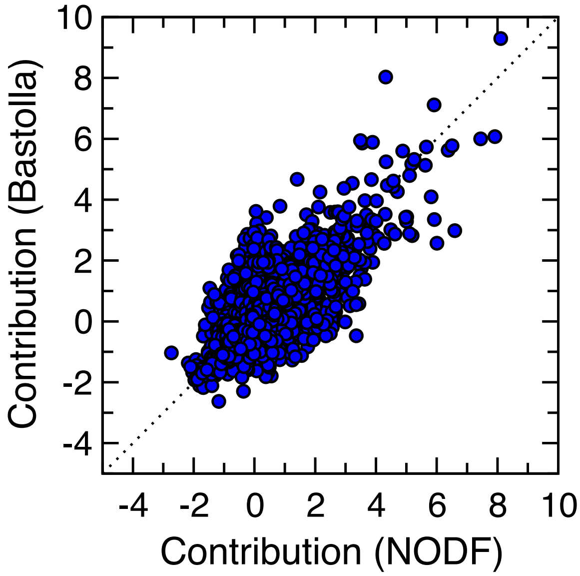

Figure 1: Robustness of our results to an alternative measure of nestedness. We show the relationship ($r = 0.75$, $p < 10^{-12}$) between the individual contribution calculated using NODF (*S1*) and the individual contribution calculated using the nestedness measure introduced by Bastolla *et al.* (*S2*).

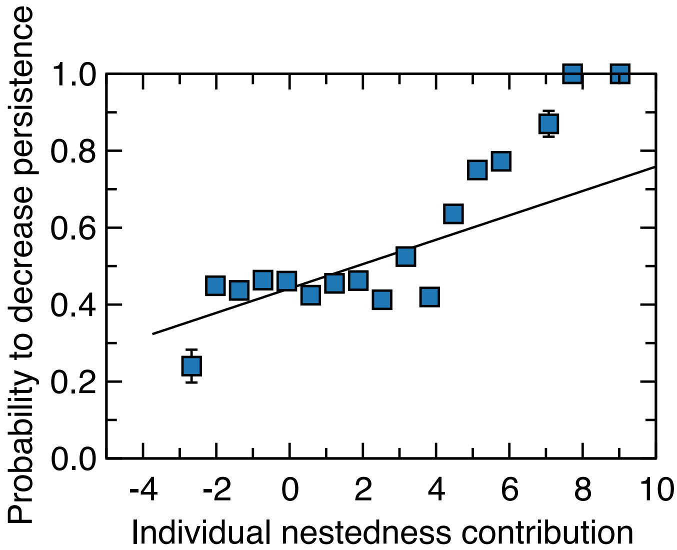

Figure 2: This is equivalent to Fig. 2 in main text for the alternative measure of nestedness by Bastolla *et al.* (*S2*). Results are equivalent: the higher the contribution of a node to overall nestedness, the higher the probability of its removal leading to a decrease in network persistence. All species in the 20 empirical pollination networks are pooled together. The standard errors of the reported averages are shown as error bars; in some cases they are too small to be seen. The solid line is the best-fit linear regression ($p < 10^{-5}$).

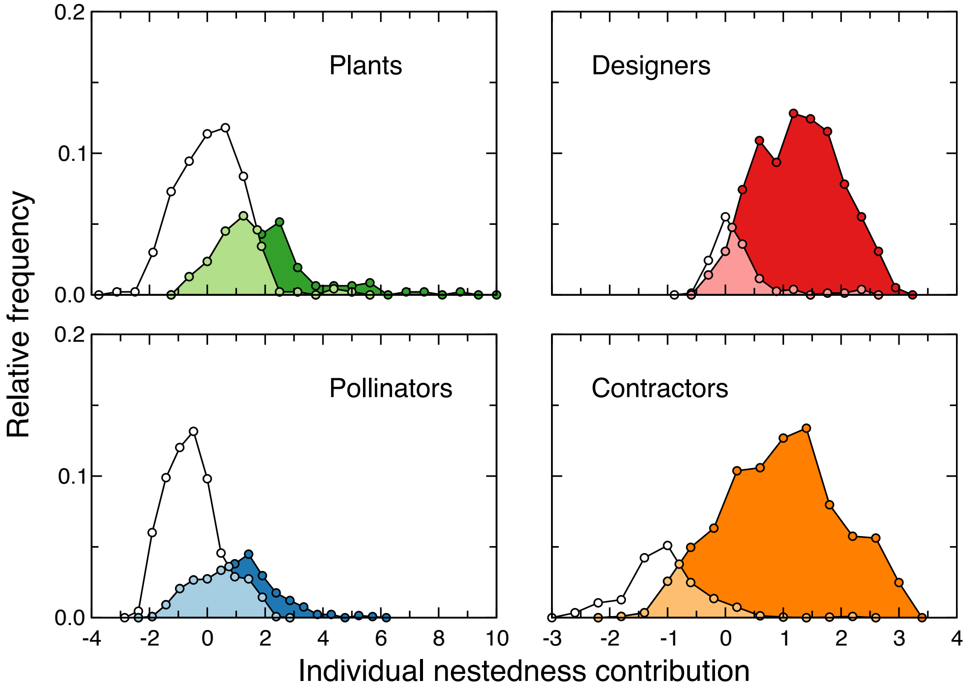

Figure 3: This is equivalent to Fig. 3 in main text for the alternative measure of nestedness by Bastolla *et al.* (*S2*). Results are equivalent: strong contributors to nestedness are the most vulnerable to extinction. We plot histograms of individual nestedness contribution for nodes that survive, shaded in white, and for those that do not, shaded in color. Individual nestedness contribution has a significant, negative correlation with survival probability for plants ($p < 10^{-11}$), pollinators ($p < 10^{-15}$), designers ($p < 10^{-9}$), and contractors ($p < 10^{-12}$). Nodes from all networks are pooled together for each class of node studied.

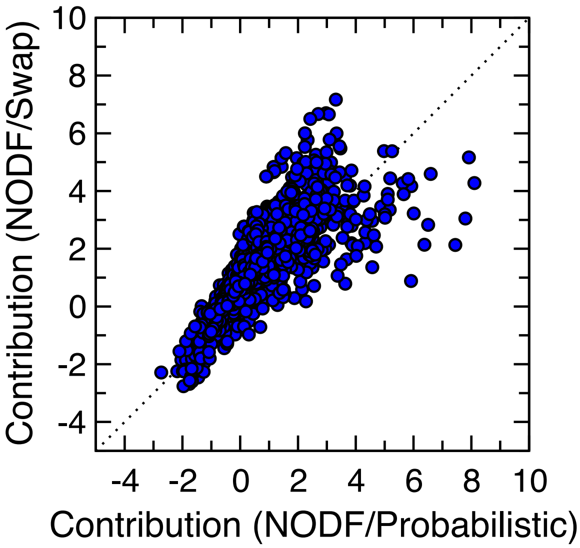

Figure 4: Robustness of our results to an alternative null model used to randomize the nodes' interactions. We show the relationship ($r = 0.83$, $p < 10^{-12}$) between the individual contribution calculated using NODF with the probabilistic null model and the individual contribution calculated using the swap null model.

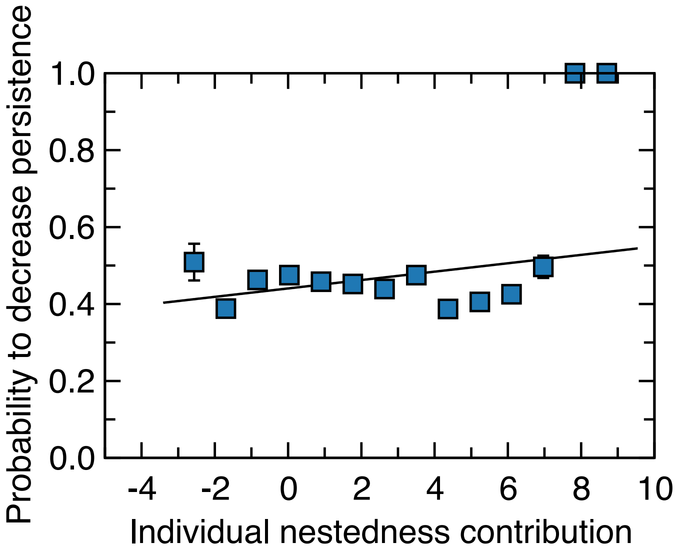

Figure 5: This is equivalent to Fig. 2 in main text for the swap null model used to randomize the nodes' interactions. Results are equivalent: the higher the contribution of a node to overall nestedness, the higher the probability of its removal leading to a decrease in network persistence. All species in the 20 empirical pollination networks are pooled together. The standard errors of the reported averages are shown as error bars; in some cases they are too small to be seen. The solid line is the best-fit linear regression ($p < 0.05$).

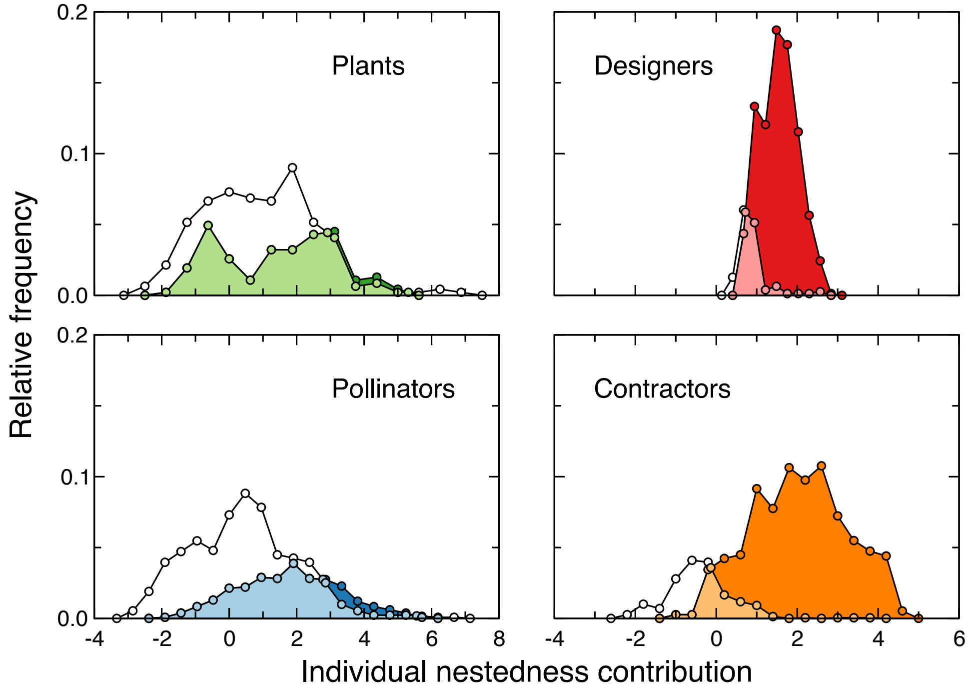

Figure 6: This is equivalent to Fig. 3 in main text for the swap null model used to randomize the nodes' interactions. Results are equivalent: strong contributors to nestedness are the most vulnerable to extinction. We plot histograms of individual nestedness contribution for nodes that survive, shaded in white, and for those that do not, shaded in color. Individual nestedness contribution has a significant, negative correlation with survival probability for plants ($p < 10^{-15}$), pollinators ($p < 10^{-13}$), designers ($p < 10^{-9}$), and contractors ($p < 10^{-10}$). Nodes from all networks are pooled together for each class of node studied.

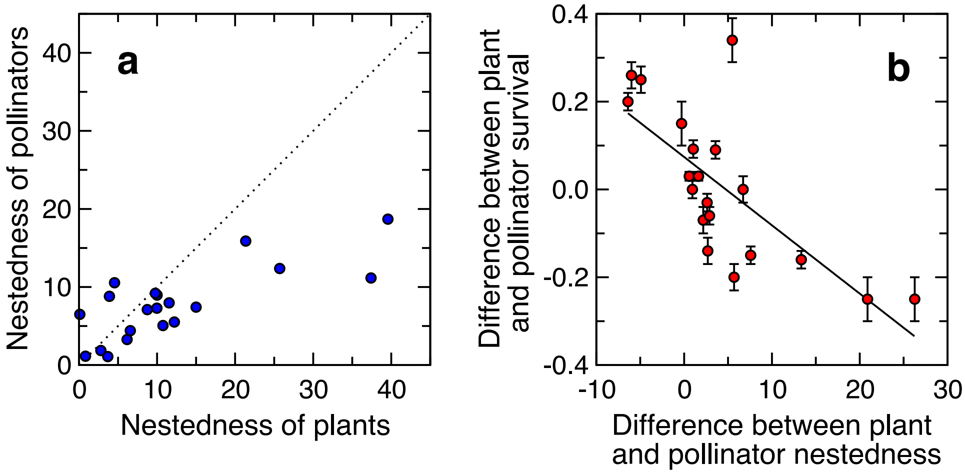

Figure 7: The different nestedness and survival of the two mutualistic sets. **a**, For each pollination network, we show the relationship between the relative nestedness of pollinators z_a and that of plants z_p. Note that the nestedness of plants is larger than that of pollinators in a majority of the networks studied. **b**, We show the relationship between the relative survival $S_p - S_a$ and relative nestedness $z_p - z_a$ of plants compared to pollinators. We observe a negative correlation ($r = -0.72$, $p < 10^{-4}$) between the nestedness and survival of plants relative to pollinators (solid line). This reveals that the collective benefits of nestedness are not directly translated to the set level. Error bars, 2 s.d.