We suggest that environmental effects should be most prominent at large spatial scales and that ecosystem engineering should be realized at smaller spatial scales. We believe that Thakur's commentary also raises a number of interesting research questions: (i) how much do species alter the effects of environmental gradients in their surrounding landscapes? (ii) Does niche construction vary with environmental quality, for example, is it more common or important in stressful or benign conditions? (iii) How does the scale at which niche construction is most pronounced relate to the scale at which environmental effects are most prominent? Finally, (iv) how does niche construction relate to the density of a species, and how in turn does this alter responses to environmental conditions? We thank the authors for their thoughtful responses, and hope these discussions will continue to advance our understanding of observed communities and their environment.

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References
1. Kraft, N.J.B. *et al.* (2015) Community assembly, coexistence and the environmental filtering metaphor. *Funct. Ecol.* 29, 592–599
2. Cadotte, M.W. and Tucker, C.M. (2017) Should environmental filtering be abandoned? *Trends Ecol. Evol.* 32, 429–437
3. Thakur, M.P. and Wright, A.J. (2017) Environmental filtering, niche construction and trait variability: the missing discussion. *Trends Ecol. Evol.* 32, 884–886
4. Aguilar-Trigueros, C.A. *et al.* (2017) Environmental filtering is a relic. A Response to Cadotte and Tucker. *Trends Ecol. Evol.* 32, 882–884
5. Bever, J.D. *et al.* (2010) Rooting theories of plant community ecology in microbial interactions. *Trends Ecol. Evol.* 25, 468–478
6. Hubbard, M. *et al.* (2014) Fungal endophytes enhance wheat heat and drought tolerance in terms of grain yield and second-generation seed viability. *J. Appl. Microbiol.* 116, 109–122

Letter

Plant States and Fates: Response to Pimm and Raven

Eimear Nic Lughadha,[1,*] Steven P. Bachman,[1] and Rafaël Govaerts[2]

Pimm and Raven [1] shine a welcome spotlight on the 2016 *State of the World's Plants* (SOWP) report [2], an initiative by the Royal Botanic Gardens, Kew, with many collaborators. Pimm and Raven aim to examine numbers presented in the report, explain their origins, and consider what is left unsaid. They focus on SOWP assertions that '391,000 vascular plant species are known to science' and '21% currently threatened with extinction'. As coauthors of the relevant SOWP chapters we offer additional detail on these aspects to clarify potential misunderstandings reflected in the explanations of our methods by Pimm and Raven. We also address their stimulating comments on what we left unsaid.

Numbers of Known Plant Species

Diverse approaches to estimating the numbers of known plants give widely differing results [3]. For our estimate in SOWP [2] we adapted a method we had applied previously [4] based on the World Checklist of Selected Plant families (WCSP; apps.kew.org/wcsp) and the International Plant Names Index (IPNI; www.ipni.org), actively curated resources with growing coverage. We reported a strong linear relationship between the number of species currently recognised in a particular plant family in WCSP and the number of different plant names that have been used for these species. Our estimate was based on the assumption that the linear relationship observed in the names of these well-researched families also applies to vascular plant families not included in WCSP, such that the numbers of vascular plant species known to science can be estimated from the total number of species names for vascular plants in IPNI, which is comprehensive in coverage of names but not of synonyms. Because SOWP is written for a general audience, our explanation was of necessity concise, so we therefore published our method and results in detail separately, with comparisons to previous estimates [3].

Pimm and Raven describe a different approach that they have applied on two occasions [5,6] using The Plant List (TPL; www.theplantlist.org), a valuable product of which two of us (E.N.L. and R.G.) are co-creators, but that is regrettably static since 2013 and thus outdated. Their approach differs not only in source data (TPL 1.0 statistics) but also in their key assumption: that names treated as 'unresolved' in TPL will prove to represent accepted names and synonyms in the same proportions as those that have already been resolved (as accepted names or synonyms). In fact, we have shown elsewhere that a lower proportion of accepted names is to be expected among the unresolved names owing to the compilation sequence of TPL [3]. In light of the key differences between our (linear) and their (proportional) method we consider it important to rectify any misunderstanding that theirs was the method used in SOWP, and that our estimate is 'essentially the same' as their earlier 400 000 estimates [5,6].

Differences in estimates arise from methods and from focusing on different major groups of plants (Box 1). Only time and much taxonomising (especially synonymising!) will reveal which approach is more accurate in estimating known species; meantime we urge clarity in comparing numbers

Box 1. Comparing Estimates for Numbers of Known Plants

Estimates of numbers of known plants are sensitive to the method and dataset used. The SOWP estimate for flowering plants [2] is derived by a linear method and is therefore most directly comparable to the Paton *et al.* 2008 [4] estimate, which is 17 000 lower (Figure I), a difference largely attributable to the 19 000 new flowering plant species added to IPNI in the intervening years. The 400 000 estimate for flowering plants [6] is based on the alternative 'proportional method' and a misreading of TPL results ([3], confirmed by Stuart Pimm, personal communication, October 2016), and is therefore not comparable. Comparing land plant estimates derived from different data sources and methods is also problematic: the 400 000 figure for land plants of Pimm *et al*. [5] using TPL 1.0 and the proportional method is within 1% of our estimate of 404 000 land plants [3] using the linear method (Figure I). However, this apparent convergence is largely coincidence, as illustrated by the fact that, when the proportional method is applied to land plant totals from TPL1.1, it gives a greatly increased estimate of 454 000 land plants. Published figures are rounded to the nearest 1000.

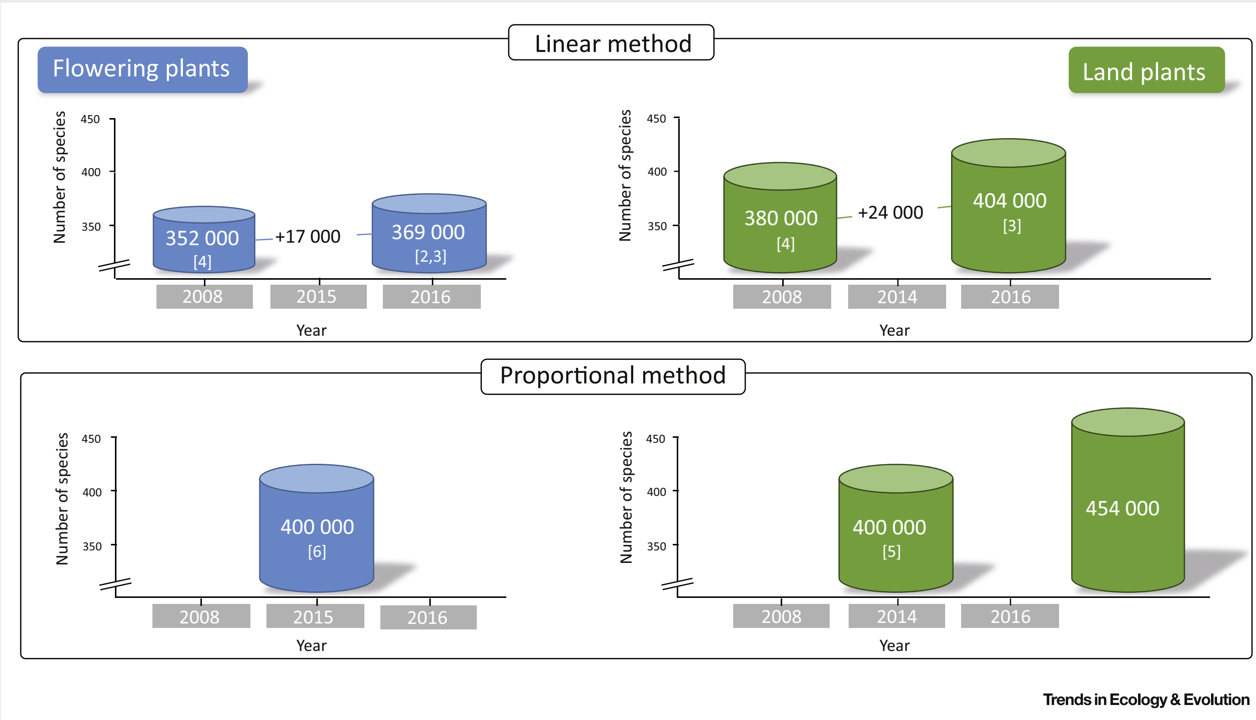

Figure I. Results of Linear and Proportional Methods for Estimating Numbers of Known Plants.

resulting from different approaches because changes to methods and datasets may influence estimates more than real change over time.

How Many Species Are Currently at Risk of Extinction?

Pimm and Raven summarise the SOWP tabulation of estimates of extinction risk in plants as 'mostly in the 20–33% range', and then comment that we 'plump for' '1 in 5'. Their colloquial 'plump for' may reflect the limited rationale provided in our SOWP narrative given the non-specialist nature of our target audience. In fact, our preferred '1 in 5' figure represents the culmination of many years work by dozens of collaborating scientists and volunteers in evaluating extinction risk of 3990 species from a carefully sampled subset of the known plant species worldwide [7,8], avoiding bias towards species at high risk [2]. Merits of this (sampled) Red List Index approach include transparency, reproducibility, and ease of comparison with extinction risk estimates for animal groups to which zoologists are applying identical protocols [9–12].

What Was Left Unsaid

We agree with much of what Pimm and Raven consider 'reasonable' or 'sensible' concerning undescribed plant species already at risk, but the evidence-base for quantitative projections is patchy, and building estimates upon estimates multiplies uncertainty. For example, we cannot reconcile the numbers they presented under 'How many species remain undiscovered?' with their concluding generalisations. Accepting their estimates of 460 000 flowering plants, including 70 000 unnamed, it is neither reasonable nor arithmetically possible to argue that 'half of all species, most unknown at the time of their loss, may disappear' by 2100. Even if all 70 000 unnamed species disappeared, more than twice that many extinctions of known plant

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species would be required to bring overall loss to 230 000 (~one half). The purpose of SOWP demands authoritative, evidence-based numbers from analyses of high-quality datasets presented for a non-specialist reader. With improvements to knowledge bases, including the IUCN Red List, Plants of the World Online (http://plantsoftheworldonline.org), and World Flora Online (www.worldfloraonline.org), future SOWPs will address more of what the first report left unsaid.

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References
1. Pimm, S.L. and Raven, P.H. (2017) The fate of the world's plants. *Trends Ecol. Evol.* 32, 317–320
2. Royal Botanic Gardens Kew (2016) *The State of the World's Plants Report – 2016,* RBG, Kew
3. Nic Lughadha, E. *et al.* (2016) Counting counts: revised estimates of numbers of accepted species of flowering plants, seed plants, vascular plants and land plants with a review of other recent estimates. *Phytotaxa* 272, 82–88
4. Paton, A.J. *et al.* (2008) Towards target 1 of the Global Strategy for Plant Conservation: a working list of all known plant species – progress and prospects. *Taxon* 57, 602–611
5. Pimm, S.L. *et al.* (2014) The biodiversity of species and their rates of extinction, distribution, and protection. *Science* 344, 1246752
6. Pimm, S.L. and Joppa, L.N. (2015) How many plant species are there, where are they, and at what rate are they going extinct? *Ann. Missouri Bot. Gard.* 100, 170–176
7. Brummitt, N. *et al.* (2015) The Sampled Red List Index for Plants, phase II: ground-truthing specimen-based conservation assessments. *Phil. Trans. R. Soc. B* 370, 20140015
8. Brummitt, N.A. *et al.* (2015) Green plants in the red: a baseline global assessment for the IUCN sampled Red List Index for plants. *PLoS One* 10, e0135152
9. Clausnitzer, V. *et al.* (2009) Odonata enter the biodiversity crisis debate: the first global assessment of an insect group. *Biol. Conserv.* 142, 1864–1869
10. Cumberlidge, N. *et al.* (2009) Freshwater crabs and the biodiversity crisis: importance, threats, status, and conservation challenges. *Biol. Conserv.* 142, 1665–1673
11. Richman, N.I. *et al.* (2015) Multiple drivers of decline in the global status of freshwater crayfish (Decapoda: Astacidea). *Phil. Trans. R. Soc. B* 370, 20140060
12. Böhm, M. *et al.* (2013) The conservation status of the world's reptiles. *Biol. Conserv.* 157, 372–385

Letter

Reply to Nic Lughadha *et al.*

Peter H. Raven[1,*] and Stuart L. Pimm[2]

We are puzzled that Nic Lugadha *et al.* [1] found reason to comment on our necessarily condensed paper on plant extinction [2]. In doing so they agreed with us that there are about 390 000–400 000 distinct named species of plants, and then explained some of the methods that they used in arriving at this estimate in their *State of the World's Plants* report. They appear to agree with our estimate of about 70 000 additional species to be named as a best current approximation. Their comments on projected extinctions do not seem to be related to what we actually presented in our paper, or to the reasons given for our extrapolations, and we are therefore at a loss as to how to deal with them.

It is perhaps useful that they gave a clearer explanation for some of their projections, but we are not sure why they considered their clarifications a comment on our paper that so favorably highlights the report they published.

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References
1. Nic Lughadha, E. *et al.* (2017) Plant states and fates: response to Pimm and Raven. *Trends Ecol. Evol.* 32, 887–889
2. Pimm, S.L. and Raven, P.H. (2017) The fate of the world's plants. *Trends Ecol. Evol.* 32, 317–320

Letter

Towards a Common Toolbox for Rarity: A Response to Violle *et al.*

Carlos P. Carmona,[1,*] Francesco de Bello,[2,3] Takehiro Sasaki,[4] Kei Uchida,[4] and Meelis Pärtel[1]

In a recent review, Violle *et al.* [1] presented the concept of functional rarity along with ways to quantify it by combining species functional traits and abundance information. Classifying species according to their rarity will improve conservation strategies, and the ideas by Violle *et al.* [1] are a timely step forward in this direction. Building on these solid bases is certainly advisable, although there is room for improvement in the scope and in the methods proposed. We stress here some points to help advancing this approach into a more general and flexible tool.

The strategy proposed in Violle *et al.* [1] involves setting different categories; a methodological step that deserves thoughtful attention. Specifically, the authors defined 12 categories of rarity, ranging from infrequent species with rare traits to abundant species with common traits. Although it might be useful in some circumstances, the lack of a more continuous ranking of species complicates comparisons between studies and statistical analyses of the drivers of rarity. A general framework to consider rarity would be improved by estimating it, and ranking species, using a purely quantitative and probabilistic approach (Figure 1).

Rarity indeed depends on the scale at which it is defined (a species is rare or not when compared to some pool of