We compare the numbers of vascular plant species in the three major tropical areas. The Afrotropical Region (Africa south of the Sahara Desert plus Madagascar), roughly equal in size to the Latin American Region (Mexico southward), has only 56,451 recorded species (about 170 being added annually), as compared with 118,308 recorded species (about 750 being added annually) in Latin America. Southeast Asia, only a quarter the size of the other two tropical areas, has approximately 50,000 recorded species, with an average of 364 being added annually. Thus, Tropical Asia is likely to be proportionately richest in plant diversity, and for biodiversity in general, for its size. In the animal groups we reviewed, the patterns of species diversity were mostly similar except for mammals and butterflies. Judged from these relationships, Latin America may be home to at least a third of global biodiversity.
10,000 years ago (20). In Africa, the entire course of evolution of hominids over the past 6 to 8 million years took place in the presence of large mammals, many of which survive to the present. In addition, North American mammals originally invaded South America following the elevation of the Panama land bridge some 3.5 million years ago, with uplands developing about 2.2 million years ago (21). North American mammals invaded South America in far greater numbers than Eurasian ones invaded Africa, possibly another factor in reducing the diversity of the surviving South American mammals. In contrast, the reason that fewer ant species are recorded in the Neotropics than would be expected may well be that they remain understudied there.

For every group of organisms, except butterflies, Madagascar has remarkably many species relative to the rest of the Afrotropical Region, of which it constitutes just over 1/40th the size. Considering that there are probably at least 3000 additional species of vascular plants to be discovered and named in Madagascar (2), Madagascar’s contribution to the vascular plant flora of the Afrotropical Region is probably actually more than 20%.

Considering that a rapidly growing 118,308 species of vascular plants are known from Latin America and that the global total now is about 384,000 species (22), it seems likely that a third of more or all existing vascular plant species occur in Latin America and that the same may hold true for biodiversity in general. How many species that would imply depends on estimates for the total existing number of eukaryotes and so cannot be made with any degree of precision at this point.

It is important now to turn to a consideration of how well known vascular plants are in each of the three tropical regions we have
analyzed [Table 2 (1–3, 7, 23, 24) and Fig. 2]. On average, 173 newly described species have been added to the flora of the Afrotropical Region each year since 2008, with 54 of these from Madagascar [Table 2 (1, 7)]. An average of 749 new species has been described annually from Latin America for the past 25 years, with no demonstrable tendency to level off [Table 2 (23)]. The number of newly described plant species added for Southeast Asia (5,708,000 km²) has been growing at an average of 364/year for the past 12 years, more than twice as many as for the entire Afrotropical Region (22,657,000 km²), which is almost four times as large. This is a clear indication of how very rich in plant species and relatively poorly known Southeast Asia remains [see also (6)].

In recent years, the publication of new species of vascular plants by scientists living in Latin American countries has increased markedly. These increases have become possible because of freely available botanical online resources (e.g., Tropicos, The International Plant Name Index, and Biodiversity Heritage Library), low publication costs, and rapid electronic publication. At the same time, traditional studies of tropical plants have continued in Europe, North America, and Asia, as they have been increasing locally within the tropical countries themselves.

Since Latin America is somewhat smaller than the Afrotropical Region, the reasons for its far greater species richness deserve analysis. Comparing continental areas of rainforest, forest occupies about 5,500,000 km² in the Amazon Basin, with additional extensive areas in the Chocó of Northwest South America, the Mata Atlântica of Brazil (originally 1,500,000 km², but with only about 7% of the original area remaining), and especially the extraordinarily rich forests and highland vegetation of the Andes [e.g., (25), for butterflies]. In contrast, all of the rainforests in Africa occupy only about 3,900,000 km². Most of the 5,700,000 km² area of Southeast Asia was originally rainforest, so that species number comparisons with Africa seem reasonable. Overall, considering that, with respect to their biodiversity, tropical forests are the richest habitats on Earth, their regional representation obviously has an effect on the overall numbers of species found in the major regions considered here.

Although Latin America is somewhat smaller than the Afrotropical Region, it is home to more than twice as many species of vascular plants and of several groups of animals as well. A review of the geological and climatic history of Africa and South America provides some reasons for this major discrepancy (26). When these continents separated from their original positions as parts of Gondwanaland, about 88 million years ago, their floras, judged from the fossil record, were similar. The continents moved apart gradually, so that by the start of the Tertiary Era, 66 million years ago, they were only about 800 km apart, with islands scattered between them. Africa and Eurasia became relatively close by the middle Miocene Period, about 17 to 18 million years ago, with biotic exchange between them still limited but increasing from that time onward (27).

At the end of the Cretaceous Period, Africa and South America were low-lying and level, with moist subtropical forests extending from coast to coast. To the north, across the Tethys Sea, the plants and animals of Eurasia and North America were markedly different from their tropical counterparts. By the Eocene Period (56 to 34 million years ago), the plants and animals of the two southern continents had become significantly different (28), and they have continued to diversify further to the present. Subsequently, with the formation of the Rift Valley system of East Africa, the eastern and southern regions of the continent were gradually uplifted to their present heights, some of the mountains (e.g., Mt. Kilimanjaro, 5900 m) within the past 1 million years. The mountains of South Africa, which is topographically quite rugged, range up to 3450 m in height. Mostly subsea 17 million years ago, East Africa rose relatively rapidly to its present elevation, especially during the most recent 5 to 6 million years. As this process continued, the African mountains were attaining their present heights, and the contours of the modern Rift Valley were taking shape (29).

This extensive orogeny profoundly affected regional climates and hence the nature of local ecosystems (26). In Sub-Saharan Africa, savannas and dry woodlands replaced many of the moist forests that had originally occupied about half the total area (30). Although still biologically rich, the drier habitats have proportionately many

| Year | Latin America | Southeast Asia | Afrotropical Region | Tropical Africa | Southern Africa | Madagascar |
|------|---------------|----------------|---------------------|-----------------|----------------|------------|
| 2008 | 697           | 298            | 190                 | 94              | 46             | 50         |
| 2009 | 704           | 291            | 223                 | 116             | 54             | 53         |
| 2010 | 807           | 291            | 172                 | 103             | 38             | 31         |
| 2011 | 647           | 246            | 155                 | 63              | 65             | 27         |
| 2012 | 633           | 401            | 134                 | 65              | 27             | 42         |
| 2013 | 729           | 317            | 166                 | 77              | 44             | 45         |
| 2014 | 707           | 374            | 153                 | 40              | 41             | 72         |
| 2015 | 873           | 453            | 212                 | 88              | 47             | 77         |
| 2016 | 833           | 404            | 178                 | 71              | 22             | 85         |
| 2017 | 917           | 448            | 152                 | 42              | 31             | 79         |
| 2018 | 728           | 450            | 126                 | 56              | 34             | 55         |
| 2019 | 714           | 395            | 169                 | 122             | 21             | 36         |
| 12-year mean | 749         | 364            | 173                 | 78              | 41             | 54         |
fewer species than do tropical moist forests. As they expanded, they greatly reduced Africa’s moist forests and left many of them as separate patches [e.g., (31)]. The separation of South America from Antarctica about 55 million years ago, eventually leading to the formation of ice sheets in the south, strongly cooled the Benguela Current, running up the west coast of Africa, and caused the spread of arid climates there too. The original rainforest, now much smaller and fragmented, also became much poorer in species of plants and animals than it had been originally (26).

The events that led to the formation of the modern biota of Africa were quite distinct from those that took place in Latin America and in Southeast Asia. In Latin America, the elevation of the Andes over the past 6 to 10 million years has protected most of South America from spreading aridity, with the effects of the cold, northward-flowing Humboldt Current mainly confined to the relatively narrow strip of level lands west of the Andes. In Southeast Asia, the predominant insularity and moisture have preserved the original biological richness, which has also been accentuated by extensive regional orogeny. Because of the factors discussed, the cool periods during Pleistocene affected Africa much more severely than they did the other two major tropical regions. The well-known and extensive biological interchange between North and South America following the establishment of their Pleistocene connection and of the nearly continuous mountains now linking them has enriched the biota of the Andes greatly. Rapid speciation in these mountains, partly based on the northern immigrants, has significantly added to the overall biological richness of most groups of South American organisms (27, 28, 32).

UNRESOLVED QUESTIONS
The destruction of ecosystems is taking place so rapidly throughout the tropics that it will be difficult to obtain additional information bearing on the matters reviewed here. With the global population currently 7.8 billion, projected to increase to nearly 10 billion over the next 30 years, and our current consumption of natural productivity having reached around 175% of what is available sustainably (www.footprintnetwork.org), the future for most natural ecosystems looks dim. In Sub-Saharan Africa, the situation is especially dire; the 1.2 billion people there are estimated to double by mid-century and quadruple by the end of this century. Few predict that there will be many areas of tropical forest left by the end of the century. Therefore, to find answers to the obvious questions of how many species are there, how their ecosystems function, and so forth, we will need to do the best we can as soon as we can. Thus far, we have named no more than 10% of tropical plants and animals, and at current rates of discovery, most are likely to be long gone before we become aware of their existence. A division of effort between strengthening our knowledge of well-known groups, similar to those reviewed here, to reveal general patterns, and gaining some knowledge of the lesser-known groups by carefully designed sampling approaches, is apparently the best that we can do. But it is well worth the effort to do so, for its own sake and to provide the best possible basis for conservation.

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Acknowledgments: We are grateful to the following people for the invaluable discussion on data for selected groups of animals that allow for comparison with our data with plants: A. Bauer (reptiles) and B. Fisher (ants); lepidopteran data were discussed with S. Collins, J. Dobson, J. D. Holloway, D. Lees, R. K. Rollins, R. Vane-Wright, and M. Williams. We are also grateful to D. Middleton, National Parks Board, Singapore, for the valuable discussions on Southeast Asia and to S. Miller, U.S. National Museum, Smithsonian Institution, for additional discussions. We thank C. Davidson and S. Christoph (Flora of The World), C. Davis, and D. C. Western for permitting use of their photographs. Funding: No grants were received for any aspect of this study. Author contributions: P.H.R., R.E.G., and P.B.P. contributed equally to the aspect of this study.

Citation: P. H. Raven, R. E. Gereau, P. B. Phillips, C. Chatelain, C. N. Jenkins, C. Ulloa Ulloa, The distribution of biodiversity richness in the tropics. Sci. Adv. 6, eabc6228 (2020).