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Comment on "Global distribution of earthworm diversity"

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Phillips *et al.* (Reports, 25 October 2019, p. 480) incorrectly conclude that tropical earthworm communities are less diverse and abundant than temperate communities. This result is an artifact generated by some low-quality datasets, lower sampling intensity in the tropics, different patterns in richness-area relationships, the occurrence of invasive species in managed soils, and a focus on local rather than regional richness.

Phillips *et al.*'s (*1*) conclusions about earthworm latitudinal abundance and species richness gradients are incorrect. Getting the correct picture requires an approach to data gathering and analysis different from the one presented there. In the first version of the paper, abundance and richness mapped in tropical areas were generally well below those observed in our research (*2*–*12*). After Phillips *et al.* corrected their dataset [see their erratum (*13*)], their local (figure 1) and regional (figure 2) estimates only became less aligned with our experience and data.

Phillips *et al.* focused on an apparent positive relationship between latitude and species diversity. The data search specified estimates of earthworm abundance and biomass for species-level identified datasets. That filter excluded roughly 92% of all post-2000 publications on earthworm abundance or biomass, with or without species-level IDs, and all post-2000 taxonomic or biodiversity survey-oriented publications wherein reside the primary data on species diversity. In addition, no pre-2000 papers were included.

We know from extensive qualitative sampling—defined as finding all species present within an area of a hectare or two—that tropical sites commonly support >10 species, and often many more, not the expected value of 1 or 2 indicated by the map (*2*). In 19 sites of tropical rainforests from America, Africa, and Asia, species richness varied from 2 to 14 with an average of 6.4 species, 70.5 individuals m^{-2}, and biomass of 12.9 g m^{-2} fresh mass (*3*). East and Southeast Asian records in >50 papers published after 2000 (*4*) showed >1500 earthworm species, with montane tropical locations and many intact lower-elevation locations having ~10 species per site. On an altitudinal transect in Taiwan, most sites had 5 to 15 species (*5*). A typical montane forest remnant in the Philippines holds 20 to 25 species (*6*), with high turnover between mountains within a single island, and 100% turnover among islands. In Ivory Coast, natural savannahs had 7 to 12 species, crop fields 8 species, and rubber plantations 16 species (*7*, *8*); these African studies include extensive quantitative sampling and average annual biomass from 3.5 to 54 g m^{-2}. In natural savannas and gallery forests of Colombia, species numbers were 7 to 8 (*9*, *10*). Regarding β-diversity, species turnover among sites separated by ~100 km, or even by a steep-sided montane river valley, approaches 100% (*11*). In contrast, the most diverse known temperate earthworm faunas of the Balkans, Carpathians, and southwestern Europe (*12*) hold far fewer species than a comparable tropical land area. Given the very high β-diversity we and others have observed (*2*), it is quite likely that a small polity such as French Guyana holds far more species than all of Europe.

In sites with equal area, accumulation curves in temperate regions are steeper and saturate at lower species richness than in the tropics. Under the low effort of 3 to 10 standard 25 cm × 25 cm × 30 cm soil monoliths commonly used in quantitative ecological studies, steeper temperate curves indicate higher species richness relative to tropical sites, but with more effort (e.g., 30 monoliths), the tropical curve goes much higher.

There are other problems that invalidate the positive latitude-diversity relationship found by Phillips *et al.* Sampling density in the high latitudes is an order of magnitude greater than in the low latitudes. Statistical compensation for the lack of comparable sampling across all latitudes is not enough. Does Rapoport's rule [species latitudinal ranges are narrower in low latitudes than in high (*14*)] apply to earthworms? If so, then much greater sampling intensity in the tropics is needed to evaluate the latitudinal diversity gradient paradigm. Figure 2 in Phillips *et al.* shows the latitudinal bands of roughly equal numbers of sites and indicates that sampling needs to be concentrated in the very broad band from 30°N to 35°S. The highest species richness in the eastern Asia and western Pacific regions is actually found between 0° and 30°N (*4*). Figure 2 suggests that regional species richness is likely higher in the tropics, but they base their conclusion on observed patterns of local richness (figure 1), which are not appropriate to test the latitudinal gradient hypothesis.

Taxonomic issues also affect the quality of the data. In temperate zones, the predominant species pool is ~20 common Lumbricidae easily identified with external characters. In the tropics, expert identification is required and undescribed species often constitute the majority of the species pool. Thus, species diversity, accurately estimated in the high latitudes, is most often undercounted at low latitudes, unless invasive species, identifiable from external features, occur: the nominal *Pontoscolex corethrurus* and various invasive Asian and African species [but see (*15*, *16*)]. Meta-analyses could assign a weight to species richness estimates in tropical areas linked to the expertise of the scientist in charge of identification (e.g., based on the number of new species described or the number of studies in the tropics) to avoid lowering data quality due to taxonomic difficulty bias.

An additional distortion comes from including anthropogenic habitats, which are frequent objects of study at all latitudes. In high latitudes, these areas are occupied by the same 20 to 25 common Lumbricidae from Europe and site species richness values vary from 5 to 10. This is the case in the "high-diversity belts" of North America and northern Europe, which are almost entirely occupied by these species. In tropical anthropogenic habitats, it is typical to find only one or two species, such as the pantropical *Pontoscolex corethrurus*. This fact alone will distort the comparison of α- and β-diversity across latitudes: the same one or two invasive species across most tropical sites, versus various subsets of the 20 to 25 common Lumbricidae.

We advocate greater qualitative and quantitative sampling of earthworm communities at many tropical sites, distinguishing natural from managed sites, under a uniform protocol such as in (*2*), with the use of molecular data to detect species not represented by identifiable adults and the application of rarefaction curve analysis and other estimates of total species richness. Otherwise, tropical earthworms remain a largely blank patch on the map.

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