

COMMENTARY

Global biodiversity loss from tropical deforestation

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Tropical forests are incredibly biodiverse; they support at least two-thirds of the world's biodiversity (1) despite covering less than 10% of Earth's land surface (2). Unfortunately, prospects for tropical forests and the biodiversity therein are becoming increasingly bleak owing to unabated deforestation and forest alteration (3) that stem from human activities such as logging, hunting, agricultural expansion, and human settlement (4, 5) (Fig. 1). Previous studies have summarized how local or subregional biodiversity values differ across primary forests and other land-use types (6, 7), but it is unclear how site- and landscape-level impacts scale up globally. In PNAS, Alroy (8) addresses this challenge by compiling and analyzing a pantropical dataset of 875 local species assemblages sampled in primary forest and 10 other land-use types previously converted from forest.

The task of estimating global biodiversity losses that accrue with tropical deforestation might seem straightforward at first. For example, one might approach this problem by collating global distributions of different taxa, removing increasing extents of forest, and then counting the extinctions that accumulate when entire species ranges become deforested. This approach suffers from a number of pitfalls. First, it assumes populations originally occurring in forests can never survive in altered habitats. Indeed, it is well documented that altered forests and other land uses often support some species previously found in continuous primary forests (9, 10) and that biotic responses vary across taxa and disturbance types (6, 7). Further, such an analysis would be necessarily limited to the few vertebrate groups with reasonably complete and reliable global distribution and habitat information (*i.e.*, amphibians, birds, mammals), precluding groups such as arthropods that make up the overwhelming majority of Earth's terrestrial macroorganismal diversity (11).

To examine the impact of a particular disturbance on species communities, ecologists often identify a landscape consisting of undisturbed and disturbed areas and sample ecological communities at sites or transects nested within these areas (6, 9, 10). It is also



Fig. 1. Human activities that threaten tropical forests and the biodiversity therein. (A) Logging in Peninsular Malaysia. (B) Oil palm monoculture in Kalimantan, Indonesia. (C) Cattle grazing on pastures converted from forests in Mato Grosso, Brazil. (D) Smallholder cropping (of cassava) in Loreto, Peru. (E) Harvesting of wood for charcoal production in Benin. (F) Hunting threatens many forest species, including the Malayan tiger caught here on a camera trap in Peninsular Malaysia. Photographs courtesy of Rimba (A and F), X.G. (B), Jacob Socolar (C and D), and Orou Gaoue (E).

common for ecologists to characterize only intact forest communities or compare biotic responses across different altered habitats. Because human activities have been so pervasive in and around tropical forests, there is now a large collection of studies sampling local species communities in different land uses across the tropical forest biome. These local field studies are an excellent starting point for estimating global biodiversity loss because they provide information on species occurring in intact forests as well as those species that persist after deforestation or

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forest alteration for a large variety of taxa, including particular arthropod groups.

Alroy (8) took this approach. To scale up local impacts, he devised a creative bootstrapping algorithm in which primary forest communities were gradually replaced by randomly chosen communities occurring in other land-use types, thus mimicking the progression of deforestation and forest alteration. At each step, species presences were summed across all sites and species absent from all sites were considered globally extinct. By tracking changes in the number of extant species as communities from other land uses replace primary forest communities, Alroy (8) was able to project how species loss might proceed at the global scale for different taxonomic or ecological groups as tropical forests continue to be altered or lost.

Interestingly, there was notable variation in both the extent and shape of biodiversity loss across different groups of organisms. Reductions in global species richness following complete forest degradation and deforestation ranged from <10% in mosquitoes to >50% in ants and lizards, probably reflecting differences in the proportion of strict forest endemics across groups. In bats, richness reductions accelerated with forest loss/degradation, whereas biodiversity loss decelerated or increased linearly in all other groups (except for trees, which showed a decelerating and then accelerating trend, and mosquitoes, which increased in richness at intermediate levels of forest loss/degradation). By conducting a simulation exercise in which all species were forest endemics (i.e., 100% susceptible to forest loss/degradation), Alroy (8) demonstrates that groups comprising (uniformly) small-ranged species produce decelerating curves, whereas groups with (uniformly) large-ranged species display linear or accelerating trends of biodiversity loss. This finding is intuitive; however, factors such as the shape and form of range size distributions for both forest endemics and generalists may yet modify this finding. Future studies can use the same simulation framework to explore such issues further.

In addition to presenting a new approach to estimate global species losses, Alroy (8) advances the literature on species richness estimation by introducing two new methods: λ_5 richness estimator and multiton subsampling (MS). These methods were applied to allow fair comparison of biodiversity values in the bootstrapped primary forest versus the bootstrapped deforested/degraded forest samples. The λ_5 estimator belongs to a class of richness estimators that extrapolate a given observed community sample to include species that are likely present in the habitat but not observed in the sample. Other estimators in this class that use species abundance (versus presence/absence) data include the commonly used Chao1 (12) and abundance-based coverage (ACE) (13) estimators. Different from Chao1 and ACE, the λ_5 estimator assumes that observed species abundances are drawn from a Poisson distribution, explicitly accounting for the often uneven nature of species abundance distributions.

MS, on the other hand, is an individual-based interpolation (rarefaction) technique that estimates the number of species in a reduced sample. Individual-based rarefaction is often used to render two or more community samples comparable by computing richness values expected from a given number of sampled individuals (14) or, more recently, a sampling completeness (coverage) target (15, 16). MS is similar to the latter in that it computes the number of species encountered when the fraction of nonsingletons (i.e., "multitons") reaches a target number. The fraction of species with abundance ≥ 2 increases as sampling becomes more complete; therefore, setting a common multiton target at which

richness is evaluated is akin to standardizing samples by sampling completeness. Techniques that standardize sampling completeness rather than the number of individuals are recommended because they produce richness estimates that preserve true richness ratios across different communities (16). Although both λ_5 estimator and MS are likely useful for comparing the richness of different communities, a simulation study that evaluates the performance of these methods against others via simulated assemblages drawn from a variety of species abundance distributions is required to understand their relative utility better.

The main goal of Alroy (8) is to estimate the extent of global biodiversity loss with mounting deforestation and forest degradation.

By extrapolating samples of local species assemblages, Alroy estimates global biodiversity losses equaling a mass extinction event if tropical deforestation continues unabated.

Given the results, one might question whether the loss of all tropical forests by itself would cause the sixth mass extinction. I attempt to explore this question using simple back-of-envelope calculations. Barnosky et al. (17) defined a mass extinction event as one having a similar magnitude (>75% biodiversity loss) or rate as the Big Five mass extinctions. Alroy (8) predicted greatest species richness declines in ants (65.4%), lizards (51.1%), and dung beetles (44.7%), suggesting that in terms of absolute magnitude, tropical forest loss by itself may not result in a mass extinction event as defined by Barnosky et al. (17). However, these estimates are likely too low (8). First, in the simulations, primary forests were replaced largely by relatively benign land uses (selectively logged forests, secondary forests, and forest fragments) rather than more destructive ones such as croplands, plantations, or pastures. Second, richness in degraded/deforested areas was likely overestimated due to incidental dispersal of species from primary forests and the persistence of species committed to extinction in degraded/deforested areas. Third, estimated changes in overall species richness included nonprimary forest species gained from forest conversion.

In terms of extinction rate, if we assume tropical primary forest loss to proceed linearly at the current rate [74,532 km²·y⁻¹ for forests with >50% tree cover (3)], it will take just 225 y [from year 2000, so as to coincide roughly with Alroy's dataset (8)] for all primary forests to be altered or lost. Assuming conservatively that tropical primary forests only support two-thirds of the species (1) within each group, tropical forest loss/degradation will result in global richness declines of 43.8% (65.4% × 0.67) in ants, 29.9% in dung beetles, and 19.9% in trees, for example. Converting these numbers and the numbers of the other groups to proportions and dividing the proportions by the number of years within which complete deforestation is expected (225 y) produces extinction rate estimates ranging from 229 (mosquitoes) to 1,947 (ants) extinctions per million species-years (E/MSY) (17, 18). These values are two or more orders of magnitude higher than extinction rates associated with four of the five previous mass extinction events (Ordovician, Devonian, Permian, and Triassic), comparable to the rate associated with the Cretaceous event (17), and ~2,000–20,000 higher than the background rate of ~0.1 E/MSY (19). These results indicate that tropical forest loss/degradation alone, even without considering other human stressors such as climate change and habitat loss in other ecosystems, will precipitate a mass extinction event over the next couple of centuries.

By extrapolating samples of local species assemblages, Alroy (8) estimates global biodiversity losses equaling a mass extinction event if tropical deforestation continues unabated. Judicious expansion (20) and sound management (21) of a global protected area network remain the best strategies for conserving tropical forest biodiversity. However, most tropical countries, many of which are developing and are of low to middle income, would likely prioritize economic growth. Conservation strategies that consider economic realities of the tropics

are more likely to be effective; therefore, one of the main challenges in the coming years would be to investigate where (and how) to expand forest and biodiversity protections while striving to meet the developmental aspirations of developing tropical countries.

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- 1 Raven PH (1988) Our diminishing tropical forests. *Biodiversity*, eds Wilson EO, Peter FM (National Academy Press, Washington, DC).
- 2 Bradshaw CJA, Sodhi NS, Brook BW (2009) Tropical turmoil: A biodiversity tragedy in progress. *Front Ecol Environ* 7:79–87.
- 3 Hansen MC, et al. (2013) High-resolution global maps of 21st-century forest cover change. *Science* 342:850–853.
- 4 Wilcove DS, Giam X, Edwards DP, Fisher B, Koh LP (2013) Navjot's nightmare revisited: Logging, agriculture, and biodiversity in Southeast Asia. *Trends Ecol Evol* 28:531–540.
- 5 Dávalos LM, Sanchez KM, Armenteras D (2016) Deforestation and coca cultivation rooted in twentieth-century development projects. *Bioscience* 66:974–982.
- 6 Barlow J, et al. (2007) Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. *Proc Natl Acad Sci USA* 104:18555–18560.
- 7 Gibson L, et al. (2011) Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature* 478:378–381.
- 8 Alroy J (2017) Effects of habitat disturbance on tropical forest biodiversity. *Proc Natl Acad Sci USA* 114:6056–6061.
- 9 Edwards DP, et al. (2011) Degraded lands worth protecting: The biological importance of Southeast Asia's repeatedly logged forests. *Proc Biol Sci* 278:82–90.
- 10 Wearn OR, Carbone C, Rowcliffe JM, Bernard H, Ewers RM (2016) Grain-dependent responses of mammalian diversity to land use and the implications for conservation set-aside. *Ecol Appl* 26:1409–1420.
- 11 Stork NE, McBroom J, Gely C, Hamilton AJ (2015) New approaches narrow global species estimates for beetles, insects, and terrestrial arthropods. *Proc Natl Acad Sci USA* 112:7519–7523.
- 12 Chao A (1984) Non-parametric estimation of the number of classes in a population. *Scand J Stat* 11:265–270.
- 13 Chao A, Lee S-M (1992) Estimating the number of classes via sample coverage. *J Am Stat Assoc* 87:210–217.
- 14 Colwell RK, et al. (2012) Models and estimators linking individual-based and sample-based rarefaction, extrapolation and comparison of assemblages. *J Plant Ecol* 5:3–21.
- 15 Alroy J (2010) The shifting balance of diversity among major marine animal groups. *Science* 329:1191–1194.
- 16 Chao A, Jost L (2012) Coverage-based rarefaction and extrapolation: Standardizing samples by completeness rather than size. *Ecology* 93:2533–2547.
- 17 Barnosky AD, et al. (2011) Has the Earth's sixth mass extinction already arrived? *Nature* 471:51–57.
- 18 Pimm SL, Russell GJ, Gittleman JL, Brooks TM (1995) The future of biodiversity. *Science* 269:347–350.
- 19 Pimm SL, et al. (2014) The biodiversity of species and their rates of extinction, distribution, and protection. *Science* 344:1246752.
- 20 Venter O, et al. (2014) Targeting global protected area expansion for imperiled biodiversity. *PLoS Biol* 12:e1001891.
- 21 Laurance WF, et al. (2012) Averting biodiversity collapse in tropical forest protected areas. *Nature* 489:290–294.