LETTER

Reply to Feeley and Rehm: Land-use intensification increases risk of species losses from climate change

A growing body of evidence challenges the view that species' ranges are shifting unidirectionally in response to anthropogenic climate change (1). As Feeley and Rehm (2) point out, our resurvey of Chimborazo's vegetation (3) presents yet another example of the complex dynamics of ongoing range shifts. Although we do find a strong average upslope trend, we also note that several species are lagging behind. We agree with Feeley and Rehm (2) that the observed downward expansion of the grass-dominated Pajonal vegetation into lower elevations is likely the result of land-use changes, as illustrated in our updated version of Humboldt's *Tableau Physique* (3).

The idea that land-use activities may limit climate-driven range shifts is not new (4). The direct land-use effects mentioned by Feeley and Rehm (2) promote the expansion of Pajonal vegetation, which hinders tree establishment and thus the potential upward range shift of cloud forests from lower elevations. Indeed, we can expect strong disequilibrium dynamics in the leading edge of cloud forests because of the barriers that habitat loss and fragmentation of source populations pose to low-elevation species (1).

Water availability may also limit the upward migration of cloud forests. The pollen record provides examples in which reduced precipitation—rather than human activities—possibly hindered the expansion of cloud forests to higher elevations in times of warming (5). If the current climate is shifting toward drier conditions in tropical mountain regions, as suggested for Chimborazo (3) and predicted under most future climate-change scenarios for the tropical Andes (6), more research should be directed toward the effects of this aspect of human-driven climate change on the ability of species to respond to the warming climate.

It is clear that species' range shift dynamics in response to the ongoing climate changes are not a simple matter (1), and we can only encourage further research, in particular for the understudied case of plants in the biodiverse tropics (1). The fact that increasing land-use intensity may strongly modulate climate-change impacts on species' distributions—often facilitating range adjustments of human-dispersed plants (frequently invasive exotics), but limiting expansions of many other species—is worrisome. Although climate-change mitigation requires global-scale efforts, the impacts of land use can be mitigated through local and regional conservation planning. Socioeconomic considerations need to be integrated in such actions, but ecological research toward quantifying and understanding past changes and improving predictive modeling of future ones is a first step toward reducing the risks.

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1 Lenoir J, Svenning J-C (2015) Climate-related range shifts—A global multidimensional synthesis and new research directions. *Ecography* 38(1):15–28.
2 Feeley KJ, Rehm EM (2015) Downward shift of montane grasslands exemplifies the dual threat of human disturbances to cloud forest biodiversity. *Proc Natl Acad Sci USA*, 10.1073/pnas.1518708112.
3 Morueta-Holme N, et al. (2015) Strong upslope shifts in Chimborazo's vegetation over two centuries since Humboldt. *Proc Natl Acad Sci USA* 112(41):12741–12745.
4 Sarmiento FO (2002) Anthropogenic change in the landscapes of highland Ecuador. *Geogr Rev* 92(2):213–234.
5 Bush MB, Silman MR, Urrego DH (2004) 48,000 years of climate and forest change in a biodiversity hot spot. *Science* 303(5659):827–829.
6 Duque A, Stevenson PR, Feeley KJ (2015) Thermophilization of adult and juvenile tree communities in the northern tropical Andes. *Proc Natl Acad Sci USA* 112(34):10744–10749.

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