OPINION

Birds and grapes on mountaintops

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Global climate change today includes an average warming trend (global warming) that affects the distributions of animal and plant species, both directly and indirectly (1, 2). The direct effect arises because a given species can survive or maintain itself only up to and down to its own characteristic maximum and minimum environmental temperature, respectively. In addition, temperature may limit species ranges indirectly by controlling distributions of other species on which a given species depends.

The most familiar examples of these climate effects on species distributions are recent historical shifts of tropical species toward the poles. For instance, when I revisited my childhood home in Boston after being away for many years, I was astonished to find that the most common bird species now living around my former home (cardinal and mockingbird) were ones that I had never recorded there during my many years of childhood bird watching, at a time when the northern geographic limits of those species still lay hundreds of miles south of Boston. However, temperature is also driving shifts of montane species up mountains, from warmer zones at the bases of mountains to the cool summits.

Most field studies of animals and plants are carried out in the temperate zones, simply because that's where most zoologists and botanists live. However, most animal and plant species live in the tropics. Will tropical species be affected on the average more or less than temperate species? One can make a priori arguments either way. On the one hand, temperatures are increasing more in temperate than in tropical areas, which would lead one to expect smaller effects of ambient temperature on tropical species. On the other hand, normal seasonal variation in temperature is much greater in temperate than in tropical areas, which would lead one to expect tropical species to have evolved narrower ranges of thermal tolerance and hence to be more susceptible to a given change in ambient temperature than are temperate species.

Resolution of this important question requires more field studies in the tropics. In particular, what's needed is to resurvey today some groups of species on some tropical mountains that were well surveyed many decades ago. In PNAS, Freeman and Class Freeman now provide such resurveys for birds of two previously surveyed mountains of the New Guinea region (3).

The mountains chosen by Freeman and Class Freeman were Mt. Karimui, an extinct volcano on the main island of New Guinea itself, and Karkar Island, an active volcano lying off the northeast coast of New Guinea. I had measured altitudinal ranges of birds on the former mountain in 1965 and on the latter mountain in 1969. Freeman and Class Freeman resurveyed both mountains 47 and 43 years later, respectively, in 2012. On Mt. Karimui, they were fortunate to find a New Guinea villager who had participated in my 1965 expedition and who showed them the exact ridge and campsites that I used. By listening to, watching, and netting and releasing birds, Freeman and Class Freeman succeeded in measuring the altitudinal ranges for 138 Mt. Karimui bird species and 26 Karkar bird species whose ranges I had also measured in the 1960s. In case that sounds like pure romantic bird-watching fun, I must warn you that most birds in New Guinea jungle are heard but rarely seen, it rains much or all of the day on most days on Mt. Karimui, dense deep moss-covered tangles of exposed roots make movement on Mt. Karimui's summit difficult for humans, and volcanic bombs thrown out from Karkar's active central cone killed two scientists there.

It turned out that, since the 1960s, bird species on both mountains have shifted both their lower and their upper altitudinal limits upward, by 95–153 m on average. From estimates of temperature changes as a function of altitude on those mountains between the 1960s and 2012, Freeman and Class Freeman calculated that those observed altitudinal shifts are only slightly greater than would be expected if birds were moving upward just enough to maintain themselves in 2012 at the same environmental temperatures that they experienced at lower elevations in the 1960s.

Freeman and Class Freeman then extracted results from the published literature for similar resurveys on a total of 28 temperate and 7 tropical mountains. Their tentative conclusion was that tropical species shift upward approximately as much as expected from warming

The stunning magnificent bird-of-paradise *Diphyllodes magnificus* has shifted its elevational distribution upslope by more than 100 m on Mt. Karimui, Papua New Guinea, in response to nearly a half-century of global warming.

temperatures, whereas temperate species shift upward by only one-third as much as expected. That is, tropical species, which constitute the vast majority of the world's species, are the ones most sensitive to global warming. As the authors point out, this conclusion is tantalizing but still preliminary, because resurveys are available for so few tropical mountains and because the 35 resurveys variously involve birds, lizards, moths, trees, and plants, among which further studies are likely to reveal differences of detail.

What broader significance does this project hold? I'll mention four conclusions, of which the first affects birds and other species, and the other three conclusions affect humans.

First, these results are doubly bad news for species of mountaintops. As mountains get warmer, and as species ranges shift upward, populations formerly confined to cool

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The northwestern ridge of Mt. Karimui, Papua New Guinea, is entirely forested. However, a recent resurvey revealed that this mountain's diverse bird communities are rapidly shifting their distributions upslope in response to anthropogenic global warming.

mountaintops will tend to go extinct, because their thermal zone gets lifted off the top of the mountain into the sky. For example, Freeman and Class Freeman found that the white-winged robin, which occupied the top 295 m of Mt. Karimui in 1965, is now crammed into just the top 117 m of that mountain. In addition, mountains do not have the form of mushrooms with broad summits perched on narrow stems; they tend instead to have the form of cones, such that the total area within an elevational band of, for example, 100 m decreases as one goes up the mountain. Hence, most mountain species tend to lose habitat area as their ranges shift up the mountain.

Readers who don't care about elevational shifts and the resulting plights of the white-winged robin may be more interested in elevational shifts of human disease vectors and the resulting plights of humans (4). Many human diseases are carried by insects and other arthropod species, whose altitudinal ranges are also shifting upslope on mountains due to climate change. Millions of New Guinea Highlanders live at elevations above 1,500 m, which historically has been a healthy environment because of being too cold for the mosquito species carrying malaria, New Guinea's leading infectious disease. Alas, malaria-carrying mosquitoes, and hence malaria itself, are now spreading up into the New Guinea Highlands. Around the world, global warming has brought malaria and dengue fever into North America, brought Chikungunya fever into Europe, and increased the risk of tick-borne diseases in the United States and elsewhere.

A third consequence of global warming on mountains is touristic. At only three places in the world are there tropical mountains high enough to support summit glaciers at the equator: on the South American Andes, on Kilimanjaro and the other highest mountains of East Africa, and on the highest mountains of New Guinea. Some of New Guinea's snow-capped mountains lie sufficiently close to the coast that New Guinea is (or was) the only place in the world where one can stand in the hot sun on a coral reef, look up into the distant sky, and glimpse the shimmering white of a glacier. However, glaciers on all three of those equatorial high mountain ranges, as well as on temperate mountains, are melting and vanishing at an alarming rate. If you've read Ernest Hemingway's *The Snows of Kilimanjaro*, and if you want to climb Kilimanjaro to walk on those snows yourself, then hurry, don't wait; they are shrinking. Within the next few decades, Glacier National Park on the Montana/Canada border will have to be renamed Glacierless National Park.

Finally, I'll mention a consequence of global climate change for those of you who are wine-lovers. The good news is that reportedly decent wines are now being produced in Southern England and Southern Sweden. The mixed news is what's happening in Germany's northernmost major wine-growing area, the hilly terrain of the Mosel River with its tributaries the Saar and the Ruwer. When I began drinking wines in Germany in 1959, the Saar was usually an extremely difficult, occasionally an extremely rewarding, area for vintners. In most years, the Saar was so cold that its grapes did not produce enough sugar within a growing season, and so its wines had to be artificially sugared and then relegated to making Sekt (a German substitute for champagne). In a few years in each decade, the Saar produced sharp steely wines best enjoyed by Saar fanatics; in a few other years, wines that were good but not outstanding. However, one or two times in a decade, the Saar yielded what in my opinion are the greatest white wines of the world—light in alcohol content, dry, acidic, sparkling like a miniature champagne, delicate but overwhelmingly flavorful and perfumed, and with a uniquely wonderful earthy taste. [I'm paraphrasing what Frank Schoonmaker's 1983 book of German wines (5) wrote about Scharzhofberger, Wiltinger, and Ockfener, the best Saar wines].

Now, due to global warming, wine production on the Mosel and its Saar and Ruwer tributaries has shifted from the valley bottoms (too hot now for good wine growing) toward the ridge tops (formerly too cold, but no longer). Under current warmer temperature regimes that accelerate grape ripening, most Mosel wines are no longer their airy magical former selves: they have become stronger, more alcoholic, and potentially sweeter unless the sugar has been removed by fermentation. Only a few vintners still manage to coax light dry miniature champagne-like wines from the Saar's warming hills.

So, think about it. As you board your flight to Atlanta without bothering to take along your antimalarial medication, or as you sip your glass of Scharzhofberger and enjoy the view of glaciers from the deck of the lodge in Glacier National Park, or as you sort through your photographs of polar bears from your Arctic cruise—remember. Someday, you'll have to explain to your child, "I belonged to the last generation that was able to do all of those things, and now you can't do any of them." How will you reply when your kid asks you, "Mommy and Daddy, why did you and your generation mess up my world?"

1 Hansen J, et al. (2013) Assessing "dangerous climate change": Required reduction of carbon emissions to protect young people, future generations and nature. *PLoS ONE* 8(12):e81648.

2 Lobell DB, Schlenker W, Costa-Roberts J (2011) Climate trends and global crop production since 1980. *Science* 333(6042):616–620.

3 Freeman BG, Class Freeman AM (2014) Rapid upslope shifts in New Guinean birds illustrate strong distributional responses of tropical montane species to global warming. *Proc Natl Acad Sci USA* 111:4490–4494.

4 Heymann DL, ed. (2004) *Control of Communicable Diseases Manual* (American Public Health Association, Washington, DC), 18th Ed.

5 Schoonmaker F (1983) *The Wines of Germany* (Faber and Faber, London).