WORLDS COLLIDE (Assisted Migration)
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A dying race is making its last stand in the drippy forests of Florida. Its name is *Torreya taxifolia*, a conifer tree. Only a few dozen of its kind remain—in some cases, nothing but a few green twigs pleading for life on a rotting stump. But this tree's quiet demise far away in the woods is causing lots of hubbub.

Torreya is a charismatic tree. Its needled branches have touched the heart of many a naturalist. And so a loose band of enthusiasts, calling themselves the Torreya Guardians, is now doing exactly what we're scolded *not* to do in this post-kudzu, exotic-wary age. They're spreading *Torreya* around.

Like a church smuggling illegal aliens to safe houses, they're planting *Torreya* seeds in spots from Georgia to North Carolina—up to 800 kilometers north of its current geographic range. The Torreya Guardians hope to stem their tree's decline—which they blame on global warming—by moving it north, to cooler climes.

It may sound like a one-off case of eco-vigilantism, a charismatic tree with a cult following—but it's also a sign of the times.

Species around the world are shifting their range toward higher ground and higher latitude to keep pace with global warming. A spate of recent studies documents the stampede: hundreds of species, from butterflies to birds, plants, bats, and rats, moving pole-ward by up to 300 kilometers. These surprising numbers are but a prelude of things to come—triggered by a minuscule temperature rise of just 0.6 ºC over the last century.

The next 100 years will be worse. The upcoming IPCC report, due out this March, will forecast up to 10 ºC of warming for the next hundred years—a rate of heating several times faster than our only historical frame of reference, the last glacial retreat 12,000 years ago. Some species will move thousands of kilometers closer to the poles, says Camille Parmesan, an ecologist at the University in Texas in Austin who is monitoring the movement.

That kind of movement—in today's fragmented habitats—spells trouble. "Many species that shifted habitat thousands of years ago may not be able to do it now," says Parmesan. One oft-cited study, published in *Nature*, predicts that 35% of species on Earth will vanish by the year 2100, simply because their ecological niches evaporate before they escape.

That impending doom is driving some observers to consider the unspeakable—picking up threatened species and moving them to cooler places.

Human-assisted migration is a perfect example of how global warming pushes us toward frightening solutions—like nuclear power. It pits the desire to prevent extinctions against deep-rooted values of preserving ecosystems in their native state. It involves a level of human meddling that some have called hubris.

But the big picture is more complicated than that. If predictions are right, then climate change over the next 200 years will make anything that a few wayward naturalists do look tame. It will melt away biological communities that we know today, shuffling the deck of surviving species into new ecosystems. We humans will see changes of a magnitude that hasn't occurred since our heady days of flint spears, clubs, and bison kills.

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"When you go to meetings, people are talking about [assisted migration]," says Richard Primack, a plant ecologist at Boston University. "Some people think it's a good idea, and other people become quite angry when I mention this."

Transplantation, after all, can turn the meekest bunny into a marauding invader.

Consider the Monterey pine. It inhabits just a few narrow strips along a hundred miles of California's coastal waterfront. Most biologists consider it threatened in its native range. In fact, it's just the kind of species that you would expect to suffer climate change: it requires an odd combination of saltwater spray and arid soils to thrive, and cannot naturally disperse due to commercial development hemming it in on all sides. But move it, and it spreads. From Hawaii to New Zealand to South Africa and the Galapagos Islands, the Monterey pine has escaped ornamental stands and stream-rolled its way up and down the coasts.

The black locust tree, native to the Appalachian Mountains of North America, provides another cautionary tale. Originally planted for firewood and fence posts, its roots have laid a firm grip across much of Europe and Asia; one estimate now calls this *McDonaldland* special the second most common deciduous tree in the world.

One might have expected serious invasions to happen on other continents where black locust hasn't historically lived. But what's happening right here in North America should be a wakeup call to people who want to move species around. From New York to Wisconsin, clonal colonies of black locust are pushing aside native forests—in some cases, rare endemic communities. Worse yet, this is happening right where you'd want to move the tree—several hundred kilometers north of its current distribution, where climate models predict it will thrive in 100 years.

It is one thing to decide to move a species, concludes Mark Schwartz, an ecologist at the University of California in Davis. "It is much harder to find people who want to bring these outside species into their communities."

But not everyone agrees on the invasives threat.

“I think that’s kind of a false argument,” says Primack. “Really the other danger is much more serious—that our efforts to introduce species will fail.” Species with specialized niches are generally the ones we’ll need to move, he says, and despite rare examples like Monterey pine, kick-starting new populations is usually challenging.

Primack points to the example of Minot Pratt, a close friend of Henry David Thoreau who once prowled the woods around Concord Massachusetts. Pratt liked to garden with Nature. Throughout the 1850s, he worked to introduce new plants into the Concord area that he felt would grow there, based on his own observations. He planted over 60 species—but his efforts never ignited an invasive explosion.

“One hundred and forty years later, only two of these species remain,” says Primack. “They exist as just a few individuals.”

But never mind invasives; human-assisted migration could turn haywire in plenty of other ways, too. Guy Midgley, an ecologist at the South African National Biodiversity Institute in Cape Town, personally shrinks from the idea, even though it could possibly save some of his pet species.

Midgley studies the Cape Floristic Province, an area of low coastal mountains that hosts 6,000 endemic species, including 300 species of the flowering plant protea. Many protea seeds are dispersed by ants or rodents—meaning they move just a few meters per generation. As little as a kilometer of rolling sandstone hills separate communities of entirely different species. And there, within this hotbed of biodiversity, lies the problem.

Given their recent evolutionary separation, protea species readily interbreed—which worries Midgley. “If you start moving these around,” he says, “you’ll get hybrid zones. What happens if you evolve a new hybrid species that eliminates the parent species you were trying to save?”

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The concerns about invasive species and hybrids may actually overlook a larger problem—that even without human meddling, climate change itself will re-arrange our ecosystems.

One hundred and fifty years ago, Charles Darwin imagined that the movement of species in response to climate change was an orderly affair. He assumed that as glaciers expanded and retreated over the eons, species had shuffled north and south en masse, as intact communities. “As they all migrated in a body together,” wrote Darwin, “their mutual relations will not have been much disturbed.”

If that were true, then it might bolster the naysayers' claims that assisted migration would do more harm than good, by disrupting ecosystems. But it turns out that Darwin could not have been more wrong.

Studies of pollen, seeds, and other fossils from the last glacial retreat 10,000 to 16,000 years ago regularly show species living in odd combinations. Twelve thousand years ago, mixed forests of spruce, oak, ash, and hornbeam dominated much of the American Midwest. "That's a combination we just don't see today," says Stephen Jackson, a paleo-ecologist at the University of Wyoming in Laramie. "The ranges of all of those taxa overlap today, but we don't see areas where they're the dominant combination."

Paleo-ecologists call these odd combinations no-analog communities; nothing like them exists in the present world. They arose from odd combinations of climate variables—temperature, precipitation, seasonality, fire, floods, soil type, and topography—that don't exist today. Two species that lived side-by-side in the same ecosystem for eons often reacted differently to climate change. One species might creep uphill or up-globe, while the other persisted in the same place, even as half the trees in the forest canopy faded to brown.

The lesson from our past is that biological communities are ephemeral things. As the globe warms and weather patterns shift, it could also be a lesson for our future.

"There's a good deal of evidence that points to our going into a no-analog world within the next 100 to 200 years," says Jackson. "The communities of the future will look very different from the communities of today."

What, exactly, that no-analog world will look like is difficult to predict. But the changes could be drastic.

A team lead by A. Townsend Peterson at the University of Kansas in Lawrence has modeled the likely movements of 1,870 species of birds, mammals, and insects across Mexico, based on projected climate change for the year 2055. Their model, published in *Nature*, predicts that species turnover due to local die-offs and new arrivals will exceed 40% in many places.

Of course predictions are just that. But in some places, the tilt toward an age of no analogs may have already begun.

Take, for example, the die-offs that have withered juniper-pinyon woodlands across the American Southwest. The region suffered from drought in the 1950s and again starting around 2002. During the most recent drought, 100% of pinyon trees died in some parts of Arizona and New Mexico. Grasses—already reduced by grazing—have also died. The impact has been profound.

Erosion has swept away topsoil, carving channels and in some places marooning the surviving trees on mounds of fertile dirt. If topsoil disappears then plants cannot re-grow,

says David Breshears, a University of Arizona ecologist who has helped document the die-off. “You’re probably not going to have a similar system, with similar energy and water budges, for 50 to 70 years at best.”

What actually happens will depend on future dry spells; climate models predict increasingly frequent droughts in the Southwest. “It’s one of the most disturbing questions from a conservational point of view,” says Jackson. “Will these dead trees be replaced by pinyons, or will we be ratcheted to something else?” No one can say.

The no-analog scenario also invites a different view of the black locust invasions in New York.

Black locust generally invades pine barren communities. As an avid nitrogen fixer, it enriches the nutrient-poor soils—setting the stage for future dominance by weedy pests, even after the trees are gone. “You could end up with very a different soil substrate in time,” says Steven Rice of Union College in Schenectady, New York. “The possibility that it might alter successional trajectories is real.”

It’s true that humans set this ecological Rube Goldberg machine in motion by introducing trees—but it could also be seen as a natural process. Regardless of how they got there, those nitrogen-spewing trees are growing exactly where climate models predict they will thrive in 100 years. So even without human help, they might have gotten there, anyway—meaning that the ecosystems they’re invading may have been threatened in any case.

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The fact that assemblages of species will migrate more like cats than a herd of buffalo poses problems for anyone trying to transplant them in an intelligent way. The other problem is that it’s one thing to move a few charismatic species such as leopards, pandas, or *Torreya taxifolia*—but quite another to move every anonymous species, every low-down soil fungus or belly-crawling centipede that lives alongside those biodiversity superstars. That has ecologists thinking along different lines.

“What we’re trying to do is enable nature to migrate on its own,” says Bill Stanley, Director of the Global Climate Change Initiative at The Nature Conservancy (TNC). His NGO and others are working to design nature reserves that will accommodate the natural movement of species as they respond to climate.

In the Yunnan Province of China, TNC and partners are working not only to protect temperate mountain forests, but also to secure grassland areas immediately upslope of those forests, where at least some of the forest species will migrate as temperatures rise. The World Wildlife Foundation has pursued a similar strategy with its coastal marine reserves in East Africa, working to establish a series of stepping-stone reserves that will help species to hop pole-ward in small increments. And in the Cape Floristic Province of South Africa, three migration corridors, including the Cederberg Mega-Reserve, were established to connect mountains with coastlines in the south.

The challenge is to predict where, and how quickly, species will actually move. In the Cape Floristic Province, Midgley and Lee Hannah (of Conservation International, in Los Angeles) have modeled the future movements of 280 species of protea. Their models incorporate not only changes in climate, but also modes of seed dispersal—ant versus wind—for each species. Their results could help prioritize what other land should be set aside to protect the largest number of species.

But migration corridors aren't all laze-faire. Making them work could sometimes involve hands-on management—such as fire.

In the foothills of the Sierra-Nevada Mountains of California, the endemic blue oak is expected to migrate upslope as far as 300 meters in the next century. But those upslope areas are already covered in conifer forests—blocking blue oaks from moving in. "If you have fire in that forest above the blue oaks, that would open things up," says Hannah, who is working with TNC to model likely scenarios. "Blue oaks might then be able to establish seedlings up there." In other words, the swiftness of climate change could necessitate actively burning some areas in order to shortcut normal succession and speed the movement of species.

Facilitating the movement of species could also involve genetic manipulation.

People usually assume that as isotherms on the weatherman's map move pole-ward, it will be the individuals at the warmer end of a species' geographic range that experience problems first. But some species could decline simultaneously across their entire range.

The devil in the details is local adaptation, says Julie Etterson, an evolutionary biologist at the University of Minnesota in Duluth. Even in species with wide north-south ranges, individuals in a given location are often genetically adapted to soil and local conditions unrelated to climate. "A plant smack dab in the center of the range may experience as much challenge with climate change as something on the southern margin," says Etterson. Her own experiments, transplanting partridge pea plants north and south within their range, back up this claim.

Etterson suggests overcoming this problem by promoting the migration of genes rather than individuals ("Evolutionary Tinkering", *Conservation in Practice*, July-Sept 2006). Hybridizing plants from warmer areas of a species' distribution with those at the cooler edge might improve heat tolerance and by time for migration.

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One thing is certain: species will move—tens of thousands of them—whether or not humans do the moving. Unless global warming changes course, many currently protected habitats will become populated with exotic species—whether or not it is humans who introduce them.

“We certainly see things moving up the mountains,” says J. Alan Pounds of the Monteverde Cloud Forest Preserve in Costa Rica. “We have a lot of unwelcome visitors.” One prominent highland bird, the quetzal, has come under fire from low-land birds and mammals moving in, competing for food and devouring eggs. “To what extent can we intervene?” asks Pounds. “Generally, we probably don’t have a good enough understanding of the ecology to make good decisions.”

The hope is that newly populated habitats will at least function on a basic level.

“You may have the same hydrology or ecosystem services,” says Etterson. “But whether or not that’s what we want, that’s a question of our values.” The single comfort may be that people working at cash-strapped NGOs have already looked that question in the eye plenty of times before.

“The closest analogy that I can think of is Hawaii,” says Stanley. “You have a large percentage of the community, large parts of Hawaii, that are not native. And they have value because they are a distinct and unique community. I think that with climate change you’re going to be looking at that [kind of situation]. Those new communities that are moving in could very well be of interest to The Nature Conservancy.”

And then there’s the starry-eyed notion of moving species in order to save them one by one—assisted migration *a la* Torreya Guardians. On the surface, it’s impractical. NGOs are unlikely to have much cash to support it in the future, says Lara Hansen, Chief Climate Change Scientist for the WWF in Washington, DC.

“That said, there may be some incredibly iconic species that people decide this is worthwhile for,” says Hansen. By that, she means the pandas, tigers—and yes—*Torreyas* of the world, which humans already have a history of manipulating in and out of captivity.

The decision to do so—or not—will be an emotional one.

“I don’t see it as any kind of broad solution to the problem of climate change,” says Pounds, who has personally witnessed the highest-profile climate extinction to date: an estimated 70 species of harlequin frog over 25 years. “In many cases it will come down to the aesthetics of the situation, and how important an organism is to certain people.”

The global amphibian crisis is already pushing people to that tipping point. In a desperate bid to stop the decline, a new plan was recently announced: a network of zoos will archive up to several hundred species for future reintroduction or relocation. That archiving, or captive breeding, will serve as a final resort. The Amphibian Conservation Action Plan also calls for population monitoring, habitat restoration, and disease research. It could cost $US 80 million per year.

By some accounts, the Torreya Guardians couldn’t look any more different—and yet, there are hints of a common thread. The operation was started by Connie Barlow, a

citizen naturalist who fell in love with the tree and now coordinates the volunteer effort via the web—Wikipedia-style—for almost nothing.

Or perhaps you might call it adopt-a-highway. Barlow hopes to broaden the effort—host an online community where volunteers can nominate and adopt new endangered species, and coordinate their relocation.

For better or for worse, we humans have played favorites with species for thousands of years, from our first days of burning forests and scattering the seeds of useful plants. Whatever surprises climate change might bring, that long history seems likely to continue.