

SUSTAINING THE VARIETY OF LIFE

BY STUART L. PIMM AND CLINTON JENKINS

A new understanding of how species become extinct suggests how to preserve them—and at a cost that doesn't break the bank

We stand in warm rain on a dirt road and contemplate a cattle pasture. It forms a 100-meter-wide gap, a kilometer long, between two patches of forest. Here, a few hours drive from Rio de Janeiro, our generation will make decisions that will determine whether we can sustain the present variety of life on Earth—its biodiversity. Brazil once had more than one million square kilometers of coastal forest. In the remaining 10 percent lives the largest number of species at immediate risk of extinction in the Americas.

The “we” who stand in the rain are the two of us plus our Brazilian colleague Maria Alice Alves, an ecologist from Rio de Janeiro's State University. Present, too, is the rancher who cleared the forest for his cattle, thinking that it was the best way to make money, and a representative from a local NGO (nongovernmental organization), who wants to restore the forest. We scientists might convince the international community to support that effort, but it is the three Brazilians, representing millions of others, who will actually decide their country's balance between cattle ranching and environmental stewardship.

In this pasture, and across the land and oceans, Earth is poised to become irreversibly poorer. Nothing can bring extinct species back. We do not live in Jurassic Park. Elsewhere, it is too late. In upland Hawaii, we have shivered in cold rain, vainly looking for birds with strange-

sounding names—and stranger beaks. The *'akialoa*, *'o'u* and *nukupū'u* were last spotted decades ago. The *po'o uli* likely expired as we wrote this article. Visiting remote places is not necessary to sense the changes; the nearest fishmonger suffices. If you once served orange roughly for dinner, that fact dates you more accurately than buying a recording by Madonna. The fishery opened in the early 1980s but collapsed within the decade. Fishing has massively depleted most of the major fish populations worldwide.

“Isn't extinction a natural process?” you ask. “Certainly!” we reply. Most species eventually become extinct. Extinction would not provoke concern if it simply ticked along at a natural rate. Fossils and molecular traces of evolutionary lineages show that species “tick over”—they are born and die—on a million-year timescale. (The exceptions are during the five mass extinction events that eliminated dinosaurs, trilobites and many others.) Herein lies an analogy: We humans live for 75 years or so. In a sample of 75 people, one expects one death a year and, in a sample of seven people, one in about a decade. Taking a million years for a species' lifetime, one expects one in a million to go extinct naturally each year. Equivalently, of the 10,000 known species of bird, one should become extinct every century. The actual rate is a very unnatural one every *year*—100 times higher.

PRESERVING some two dozen scientifically determined locations, such as this coastal rain forest near Rio de Janeiro, Brazil, would go a long way toward maintaining Earth's biodiversity.



Extinctions of all well-known animals and plants are similarly unnatural. They share another feature: their cause is human actions, including hunting, the introduction of exotic species (such as rats and weedy plants) and especially the destruction of species' habitats. Other threats are coming: global warming poses a danger to biodiversity perhaps equal to—and additional to—habitat loss.

For reasons we will explain later, some species are much more vulnerable than others, and they are geographically concentrated. Unnatural rates of extinction arise when human actions collide with these concentrations. That is why we are in a cattle pasture in Brazil or a cloud forest in Hawaii and not a cornfield in Iowa. To sustain the variety of life, one must deal with special places. This creates opportunities, as well as problems. Among the latter is that the special places are mostly in developing countries across the world's tropics.

"Haven't we developed as we've used up our natural resources?" you may ask, implying that humanity might be better off despite—and perhaps because of—the loss of species. "Who are we to deny progress to poorer countries?" Too often the developed countries did not benefit from destroying their own resources. The world's rich are often unaware of

the massive taxes they pay to subsidize ecologically destructive activities. We lose both nature and money at the same time. Nor will the world's poor always benefit. For instance, they get much of their protein from fish. They cannot eat fish from the far side of the planet when their local fishery fails. They also depend on the free services the nearby forest provides—fuel, food, freshwater.

To sustain biodiversity, the world must first identify, then immediately protect the special places. In doing so, we must answer other questions. Can we eat and have biodiversity, too? Yes! Does saving species require humanity to revert to a preindustrial lifestyle? No! Certainly the costs of sustaining biodiversity are large. So, too, are the benefits.

The Geography of Unnatural Extinction

HIGH RATES OF EXTINCTION are not everywhere; they are in unexpected places. Intuition suggests that extinctions will occur where more people live and where more species live (because more will be at risk). That intuition is wrong. Human actions dominate eastern North America and Europe, but these regions have few extinctions. There are also few in the places where the most species live, such as the Amazon basin. Extinction black spots include almost all species on islands, mammals in Australia, plants in the southern tip of Africa, and freshwater fish in the Mississippi basin and East African lakes.

Four laws of biogeography explain these odd patterns [*see box on opposite page*]. Nature has created an unusually large number of "eggs" (very vulnerable species), placed them in a very few baskets and put them in harm's way.

Clearing a forest, draining a wetland, damming a river or dynamiting a coral reef to kill its fish can more readily eliminate species with small ranges than more widespread species. The first law says that there are usually many such vulnerable species. In everyday experience, "on average" is commonplace—in a group of people, most are near average height. Not so species ranges: if they were people, then most would be very short with a few professional basketball players thrown in for variety.

The second law makes the situation worse, because the vulnerable species with small ranges are usually locally rare—making them even more vulnerable. Law 3 shows that the world's tropical forests hold the greatest number of species—and these forests are shrinking rapidly. Law 4 shows that it gets even worse: the vulnerable species live in—they are endemic to—only a few, special tropical forests. The laws generate the observed pattern: extinctions occur where fronts of habitat destruction—principally deforestation—meet concentrations of vulnerable species.

Probably half the world's species live in some 25, mostly forested, tropical areas, where human actions have already removed more than 70 percent of the natural vegetation. This combination of high numbers of vulnerable species and high rates of habitat destruction defines these areas as what our Duke University colleague Norman Myers calls "hot spots" [*see box on pages 70 and 71*]. Researchers know less about the

CROSSROADS FOR BIODIVERSITY

THE PROBLEM:

- Extinction rates of animals and plants are much higher than we would expect from fossil and molecular evidence, approaching 1,000 times higher than the benchmark. Earth is poised to become irreversibly poorer because of these disappearances.

THE PLAN:

- To sustain biodiversity, we must immediately protect special places where the most species are at risk. These have been identified as 25 "hot spots" around the globe and areas of wilderness forest.

Photographs throughout the article show rare species from the world's hot spots.



Slender loris, Sri Lanka

THE LAWS OF BIOGEOGRAPHY

Ecological laws are patterns that hold globally and for many different groups of species. Four such laws describe where species live and how abundant they are.

LAW 1. Most species' ranges are very small; few are very large. One in 10 birds, one in six mammals, and over half of all amphibians have ranges smaller than the state of Connecticut. Most birds and mammals and almost all amphibians have ranges smaller than the states of California, Oregon and Washington combined. Familiar birds of town and country, such as cardinals, grackles and cowbirds, have exceptionally large ranges.

LAW 2. Species with small ranges are locally scarce. For birds, a third of those that have Connecticut-size ranges are "rare"—it takes several days of fieldwork to find one. Only a few are "common"—one sees them on every trip. Almost all species with ranges approximately the size of North America are common.

LAW 3. The number of species found in an area of given size varies greatly and according to some common factors. For example, the Arctic has few species and the tropics many.

LAW 4. Species with small ranges are often geographically concentrated.

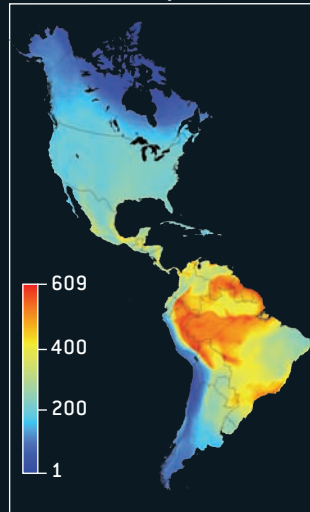
The numbers of bird and amphibian species, in an example of Law 3, vary by more than 100-fold from the tundras of northern Canada to the forests of the Amazon.



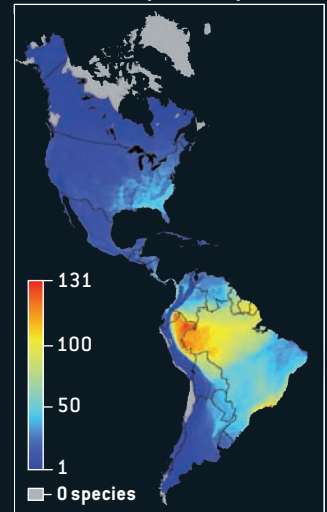
Glass frog, Central and South America

Small-ranged species often do not live in areas that are otherwise rich in species. The Amazon, for example, has almost no species with small ranges, whereas the forests along the base of the Andes and in coastal Brazil have many, as law 4 suggests. Small ranges are those that fall below the median size for a group of species.

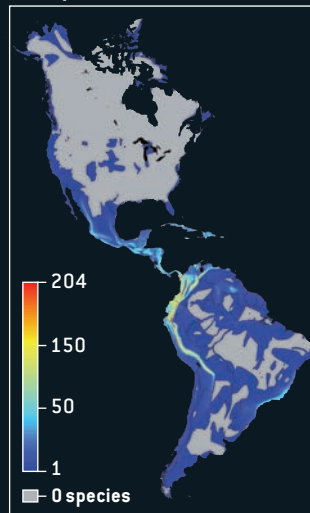
Number of bird species



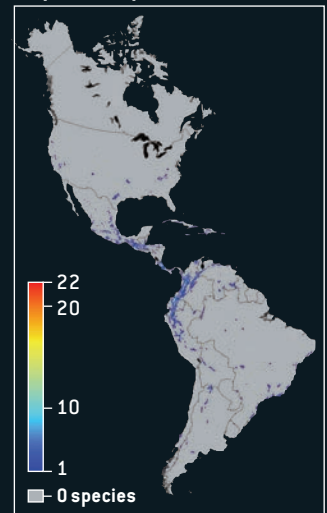
Number of amphibian species



Number of small-ranged bird species



Number of small-ranged amphibian species



oceans, but they, too, have similar concentrations of species with small ranges. These concentrations lie in coral reef ecosystems that, like their terrestrial counterparts, fall in the direct path of human actions.

Substantial tracts of intact wilderness remain: humid tropical forests such as the Amazon and Congo, drier woodlands of Africa, and coniferous forests of Canada and Russia. If deforestation in these wilderness forests continues at current rates, the combined extinction rate in them and in the hot spots will soon be 1,000 times higher than the benchmark "one in a million."

Finding Solutions for Special Places

HAVING DECIDED ON the areas to protect, how should the world accomplish the task? In particular, who will pay for the protection? Developed countries are the obvious source, but the solution is complicated. Most of the wilderness forests and 25 hot spots were once European colonies. (New Caledonia remains a French territory.) These now independent countries need not look favorably on efforts by former colonials to "save" their forests. Understandably, they often view their forests as sources of income rather than as future national parks.

Selling logging leases does provide income for cash-poor

BIRD DATA FROM NATURESERVE IN COLLABORATION WITH ROBERT RIDGELY, JAMES ZOOK, THE NATURE CONSERVANCY-MIGRATORY BIRD PROGRAM, CONSERVATION INTERNATIONAL-CABS, WORLD WILDLIFE FUND-U.S. AND ENVIRONMENT CANADA-WILDSPECIE; AMPHIBIAN DATA FROM GLOBAL AMPHIBIAN ASSESSMENT, BY IUCN, CONSERVATION INTERNATIONAL AND NATURESERVE, 2004 (WWW.GLOBALAMPHIBIANS.ORG), AS OF APRIL 1, 2005; HEIDI AND HANS-JUERGEN KOCH Minden Pictures (glass frog)

SAVING SPECIAL PLACES

The world's three remaining tropical forests and 25 "hot spots" (indicated on map) harbor most of the world's species of plants and animals. Norman Myers of Duke University defines hot spots as areas that have large numbers of endemic plants and that have lost at least 70 percent of their vegetative cover. Protecting these places and the remaining tropical wilderness forests would support the most species at the least cost.

KEY

Name of hot-spot region	
Original extent in square kilometers	Percentage that remains (percentage of remaining land protected)
Number of endemic plant species	
■ Remaining tropical forest	
■ Cleared tropical forest	
■ Other areas designated as hot spots	





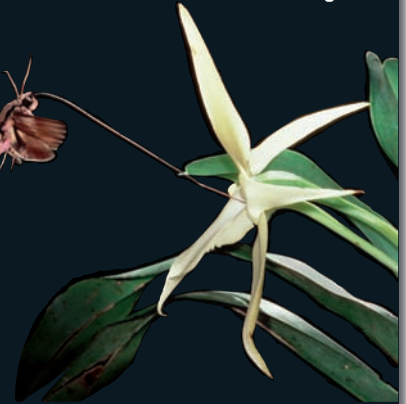
Monster flower,
Borneo



Red-knobbed hornbill,
Sulawesi



Moth feeding on orchid,
Madagascar



Caucasus
500,000 km²
10% (28%)
1,600

South-Central China
800,000 km²
8% (26%)
3,500

New Guinean Forest

Philippines
300,800 km²
3% (43%)
5,832

New Caledonia
18,600 km²
28% (10%)
2,551

Western Ghats/Sri Lanka
182,500 km²
7% (100%)
2,180

Indo-Burma
2,060,000 km²
5% (100%)
7,000

**Eastern Arc and Coastal
Forests of Tanzania and Kenya**
30,000 km²
7% (100%)
1,500

Sundaland
1,600,000 km²
8% (72%)
15,000

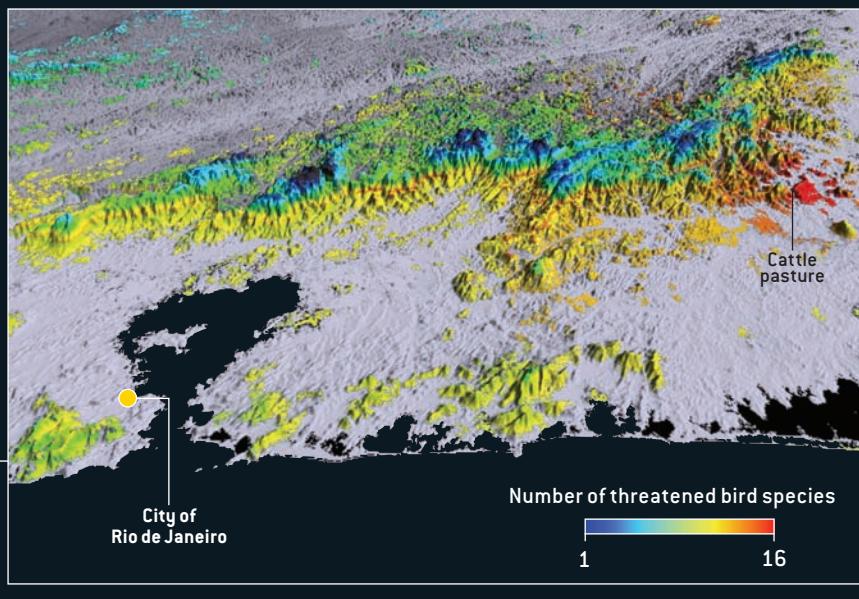
Wallacea
347,000 km²
15% (39%)
1,500

New Zealand
270,500 km²
22% (88%)
1,865

**Madagascar (including Mauritius,
Reunion, Seychelles and Comoros)**
594,150 km²
10% (20%)
9,704

Southwest Australia
309,850 km²
11% (100%)
4,331

BRAZILIAN STATE of Rio de Janeiro (in red below and shown on elevation map at right) has one of the largest concentrations of species at risk in the world. The cattle pasture that the authors are visiting at the start of the article lies in a patch of lowland forest there. Most of the state's threatened endemic bird species live in such fragments. Reconnecting these areas to the higher elevation forests is the major conservation priority. (Gray areas no longer have forest.)



countries, but not much. The damage extensive logging causes to natural areas—and to the people who live there—can be considerable. What would it cost for conservation groups to buy out the leases? Based on actual purchases, the cost would be \$5 billion for the roughly five million square kilometers of wet forests that are still wilderness. That does not seem to be an impossible task given how much private money flows into international conservation organizations.

Certainly there are many other challenges in helping forest-rich nations develop alternatives to logging, not least of which is that the value of forests to loggers might increase as more were protected. Illegal logging is widespread: What guarantees are there that the forests will remain protected? Indonesia, for example, has the second largest forest reserves. It ranks near the bottom of the league in international evaluations of freedom from corruption and has a bad record of violating the rights of its forests' indigenous peoples.

Displaced poor people clear the largest fraction of the shrinking tropical forests. Some were coerced to leave their farms elsewhere; others were encouraged by governments

seeking a solution to urban poverty. Practically or ethically, we cannot simply admonish them to not clear forest. If we, the rich, value these forests as forests and not as pastures for scrawny cattle, then we must find ways to reward financially the countries that keep forests intact. Vitally, we must find ways to ensure that those rewards go to the people at the forests' edges who make the daily decisions about the forests' fate. Like politics, conservation is local.

Hot spots present challenges different from those of the sparsely populated wilderness forests. Hot spots are heavily populated, and land prices are much higher. Is it practical to protect what remains of them? Yes, but we have to be smart.

Consider Brazil's remaining coastal forests. Working with Alves and her colleagues, we have reached a joint solution that combines knowledge of species' distributions with remotely sensed maps of remaining forest cover and elevation [see illustration above]. The higher-elevation forests survive in large, continuous blocks. Their physical inaccessibility protects them, and they have few species at risk. Our greater concern is the lowland forests. They have the highest numbers of vulnerable species and are chopped up into small patches. Fragmentation is a problem, because the vulnerable populations of animals and plants in each piece may dwindle to extinction in the absence of occasional immigrants. Fragmentation also prevents species from dispersing to cooler habitats upslope, as they may need to do because of global warming.

Restoring forests to the gaps between lowland forests—such as the cattle pasture—is effective and, because of the small areas involved, relatively cheap. Crucially, we work with local scientists and at the behest of local organizations. Biodiverse countries are all desperately short of personnel to tailor their problems of species loss to the hugely variable local economies, political systems, and religious and cultural beliefs. One cannot expect natural areas to remain intact unless well-trained, local

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PIMM and JENKINS work at the Nicholas School of the Environment and Earth Sciences at Duke University. They are conservation ecologists who seek to document past and probable future extinctions to find effective methods to prevent the latter. Jenkins specializes in using GIS (geographic information systems) and remote-sensing technology to map priorities for conservation actions.

DATA SOURCES ON PAGES 70 AND 71: TROPICAL FOREST DATA FROM THE GLOBAL 200: PRIORITY ECOREGIONS FOR GLOBAL CONSERVATION, BY D. M. OLSON AND E. DINNERSTEIN IN *ANNALS OF THE MISSOURI BOTANICAL GARDEN*, VOL. 89, NO. 2, PAGES 99–125, 2002; CURRENT FOREST COVER DATA FROM THE GLOBAL LAND COVER MAP FOR THE YEAR 2000, GLC2000 DATABASE, EUROPEAN COMMISSION JOINT RESEARCH CENTER, 2002 (WWW.GVM.JRC.IT/GLC2000); HOT-SPOT DATA FROM NORMAN MYERS *Duke University*; THIS PAGE: DATA ABOUT THREATENED BIRDS FROM ECOSYSTEM AND DISTRIBUTIONAL DATABASES, BY T. A. PARKER III, D. F. STOTZ AND J. W. FITZPATRICK IN *NEOTROPICAL BIRDS: ECOLOGY AND CONSERVATION*, BY D. F. STOTZ, J. W. FITZPATRICK, T. A. PARKER III AND D. K. MOSKOVITS, UNIVERSITY OF CHICAGO PRESS, 1996

PHOTOGRAPHS ON PAGES 70 AND 71: FRANS LANTING Minden Pictures [chameleon, monster flower and maned wolf]; W. WAYT THOMAS New York Botanical Garden [N. corticalis]; MARK JONES Minden Pictures [hornbill]; MITSUHIKO IMAMORI Minden Pictures [moth]; THIS PAGE: FRANS LANTING Minden Pictures

conservation professionals are on hand to resolve creatively the inevitable disputes over using their country's resources.

Getting the Incentives Right

WHY SHOULDN'T BRAZIL clear the forests of the Amazon to reap the benefits that the U.S. once did by clearing its forests? (Brazil has an ambitious plan, *Avança Brasil*, to do just that.) To begin with, the analogy between the two nations is flawed. The soils underlying many humid forests, unlike those in temperate forests, are extremely poor. Globally, some seven million square kilometers of wet tropical forest have been cleared, about half its original extent. Because of the poor soil and inefficient agricultural practices, only two million square kilometers have become cropland. The remainder is often unusable, infested with unpalatable weeds and able to support few cattle or goats. The tracts of abandoned, once forested land provide ample refutation to those who think forest clearing will inevitably drive an economic boom.

Second, a country that argues that it must destroy its natural resources to develop often incurs untoward consequences from that decision. The U.S. offers a case in point. It has harmed most of its rivers by damming and channeling them. The tremendous cost of these projects to the taxpayer has often been financially disastrous. For example, a monumental series of dikes and levees massively damage the Everglades of southern Florida, mostly to facilitate growing sugarcane on reclaimed wetland. To maintain homegrown production, Americans pay approximately \$1 billion a year more for sugar than they would on world markets. The costs to the taxpayer of building and maintaining those dikes and levees, of cleaning up the pollution and of subsidizing local property taxes are additional. So, too, is a \$10-billion restoration plan for the Everglades that funds future water deliveries to southern Florida but provides little or no benefits to the Everglades in its first quarter of a century of operation.

Fisheries offer even more examples, because, as a result of general government subsidies, the world fish catch is worth less than it costs to acquire. In their book *Perverse Subsidies*, Myers and Jennifer Kent quote an estimated market price of \$70 billion in 1989. The cost of catching the fish was \$124 billion, and even this number overlooks additional subsidies from provincial or state governments.

The other side of this coin is that nature provides crucial but undervalued services. The recently released Millennium Ecosystem Assessment report has a long list: food, freshwater, fuelwood, medicinal plants, wild varieties of crop plants, flood prevention and climate regulation, among others. All these values are in addition to recreational, aesthetic and spiritual ben-

efits that a country should consider as it decides whether chopping down a forest is really worth it.

One way that rich nations could support the decision to preserve a forest would be to extend the Kyoto carbon-trading system to developing nations [see "How Shall We Set Priorities?" by W. Wayt Gibbs, on page 108]. According to the Intergovernmental Panel on Climate Change, alterations in land use, of which forest clearing is the most important, produce a quarter of global carbon dioxide emissions. An international market in carbon could create incentives for forest-rich countries to keep their forests, rather than converting them to cattle pastures.

Another international incentive is ecotourism. Tropical forests, coral reefs and wetlands—indeed the entire range of places where vulnerable species live—are fascinating for exactly that reason. The ecotourist often ventures to places far from a nation's capital and what largesse its leaders can distribute. In the remote village in northwestern Madagascar where our group works, the average income is less than \$1 a day. The money tourists pay to visit the nearby national park, to eat at a local restaurant and to stay at a campsite is small by international accounting stan-

dards, but locally it is a powerful reason not to burn the forest and the lemurs that live in it.

Protecting biodiversity—whether in remote forests or in the concentrated hot spots on land and in the oceans—is achievable. Many of the necessary measures are inexpensive, and many supply local economic benefits. Whether we effect such measures is up to this generation. By the time the next generation has the opportunity to decide, it may be too late. **SA**



I'iwi and Ohia flower, Hawaii

Seven million km² of humid tropical forest have been cleared, about half its original extent, but only two million km² have become productive cropland.

MORE TO EXPLORE

Biodiversity Hotspots for Conservation Priorities. N. Myers, R. A. Mittermeier, C. G. Mittermeier, G.A.B. da Fonseca and J. Kent in *Nature*, Vol. 403, pages 853–858; February 24, 2000.

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