

# THE WEEDS SHALL INHERIT THE EARTH

## Tallying the losses of Earth's animals and plants

by David Quammen

Hope is a duty from which paleontologists are exempt. Their job is to take the long view, the cold and stony view, of triumphs and catastrophes in the history of life. They study teeth, tree trunks, leaves, pollen, and other biological relics, and from it they attempt to discern the lost secrets of time, the big patterns of stasis and change, the trends of innovation and adaptation and refinement and decline that have blown like sea winds among ancient creatures in ancient ecosystems. Although life is their subject, death and burial supply all their data. They're the coroners of biology. This gives to paleontologists a certain distance, a hyperopic perspective beyond the reach of anxiety over outcomes of the struggles they chronicle. If hope is the thing with feathers, as Emily Dickinson said, then it's good to remember that feathers don't generally fossilize well. In lieu of hope and despair, paleontologists have a highly developed sense of cyclicality. That's why I recently went to Chicago, with a handful of urgently grim questions, and called on a paleontologist named David Jablonski. I wanted answers unvarnished with obligatory hope.

Jablonski is a big-pattern man, a macroevolutionist, who works fastidiously from the particular to the very broad. He's an expert on the morphology and distribution of marine bivalves and gastropods--or clams and snails, as he calls them when speaking casually. He sifts through the record of those mollusk lineages, preserved in rock and later harvested into museum drawers, to extract ideas about the origin of novelty. His attention roams back through 600 million years of time. His special skill involves framing large, resonant questions that can be answered with small, lithified clamshells. For instance: By what combinations of causal factor and sheer chance have the great evolutionary innovations arisen? How quickly have those innovations taken hold? How long have they abided? He's also interested in extinction, the converse of abidance, the yang to evolution's yin. Why do some species survive for a long time, he wonders, whereas others die out much sooner? And why has the rate of extinction--low throughout most of Earth's history--spiked upward cataclysmically on just a few occasions? How do those cataclysmic episodes, known in the trade as mass extinctions, differ in kind as well as degree from the gradual process of species extinction during the millions of years between? Can what struck in the past strike again?

The concept of mass extinction implies a biological crisis that spanned large parts of the planet and, in a relatively short time, eradicated a sizable number of species from a variety of groups. There's no absolute threshold of magnitude, and dozens of different episodes in geologic history might qualify, but five big ones stand out: Ordovician, Devonian, Permian, Triassic, Cretaceous. The Ordovician extinction, 439 million years ago, entailed the disappearance of roughly 85 percent of marine animal species--and that was before there were any animals *on land*. The Devonian extinction, 367 million years ago, seems to have been almost as severe. About 245 million years ago came the Permian extinction, the worst ever, claiming 95 percent of all known animal species and therefore almost wiping out the animal kingdom altogether. The Triassic, 208 million years ago, was bad again, though not nearly so bad as the Permian. The most recent was the Cretaceous extinction (sometimes called the K-T event because it defines the boundary between two geologic periods, with K for Cretaceous, never mind why, and T for Tertiary), familiar even to schoolchildren because it ended the age of dinosaurs. Less familiarly, the K-T event also brought extinction of the marine reptiles and the ammonites, as well as major losses of species among fish, mammals, amphibians, sea urchins, and other groups, totaling 76 percent of all species. In between these five episodes occurred some lesser mass extinctions, and throughout the intervening lulls extinction continued, too--but at a much slower pace, known as the background rate, claiming only about one species

in any major group every million years. At the background rate, extinction is infrequent enough to be counterbalanced by the evolution of new species. Each of the five major episodes, in contrast, represents a drastic net loss of species diversity, a deep trough of biological impoverishment from which Earth only slowly recovered. How slowly? How long is the lag between a nadir of impoverishment and a recovery to ecological fullness? That's another of Jablonski's research interests. His rough estimates run to 5 or 10 million years. What drew me to this man's work, and then to his doorstep, were his special competence on mass extinctions and his willingness to discuss the notion that a sixth one is in progress now.

Some people will tell you that we as a species, *Homo sapiens*, the savvy ape, all 5.9 billion of us in our collective impact, are destroying the world. Me, I won't tell you that, because "the world" is so vague, whereas what we are or aren't destroying is quite specific. Some people will tell you that we are rampaging suicidally toward a degree of global wreckage that will result in our own extinction. I won't tell you that either. Some people say that the environment will be the paramount political and social concern of the twenty-first century, but what they mean by "the environment" is anyone's guess. Polluted air? Polluted water? Acid rain? A frayed skein of ozone over Antarctica? Greenhouse gases emitted by smokestacks and cars? Toxic wastes? None of these concerns is the big one, paleontological in scope, though some are more closely entangled with it than others. If the world's air is clean for humans to breathe but supports no birds or butterflies, if the world's waters are pure for humans to drink but contain no fish or crustaceans or diatoms, have we solved our environmental problems? Well, I suppose so, at least as environmentalism is commonly construed. That clumsy, confused, and presumptuous formulation "the environment" implies viewing air, water, soil, forests, rivers, swamps, deserts, and oceans as merely a milieu within which something important is set: human life, human history. But what's at issue in fact is not an environment; it's a living world.

Here instead is what I'd like to tell you: The consensus among conscientious biologists is that we're headed into another mass extinction, a vale of biological impoverishment commensurate with the big five. Many experts remain hopeful that we can brake that descent, but my own view is that we're likely to go all the way down. I visited David Jablonski to ask what we might see at the bottom.

On a hot summer morning, Jablonski is busy in his office on the second floor of the Hinds Geophysical Laboratory at the University of Chicago. It's a large open room furnished in tall bookshelves, tables piled high with books, stacks of paper standing knee-high off the floor. The walls are mostly bare, aside from a chart of the geologic time scale, a clipped cartoon of dancing tyrannosaurs in red sneakers, and a poster from a Rodin exhibition, quietly appropriate to the overall theme of eloquent stone. Jablonski is a lean forty-five-year-old man with a dark full beard. Educated at Columbia and Yale, he came to Chicago in 1985 and has helped make its paleontology program perhaps the country's best. Although in not many hours he'll be leaving on a trip to Alaska, he has been cordial about agreeing to this chat. Stepping carefully, we move among the piled journals, reprints, and photocopies. Every pile represents a different research question, he tells me. "I juggle a lot of these things all at once because they feed into one another." That's exactly why I've come: for a little rigorous intellectual synergy.

Let's talk about mass extinctions, I say. When did someone first realize that the concept might apply to current events, not just to the Permian or the Cretaceous?

He begins sorting through memory, back to the early 1970s, when the full scope of the current extinction problem was barely recognized. Before then, some writers warned about "vanishing wildlife" and "endangered species," but generally the warnings were framed around individual species with popular appeal, such as the whooping crane, the tiger, the blue whale, the peregrine falcon. During the 1970s a new form of concern broke forth--call it wholesale concern--from the awareness that unnumbered millions of narrowly endemic (that is, unique and localized) species inhabit the tropical forests and that those forests were quickly being cut. In 1976, a Nairobi-based biologist named Norman Myers published a paper in *Science* on that subject; in passing, he also compared current extinctions with the rate during what he loosely called "the 'great dying' of the dinosaurs." David Jablonski, then a graduate student, read Myers's

paper and tucked a copy into his files. This was the first time, as Jablonski recalls, that anyone tried to quantify the rate of present-day extinctions. "Norman was a pretty lonely guy, for a long time, on that," he says. In 1979, Myers published *The Sinking Ark*, explaining the problem and offering some rough projections. Between the years 1600 and 1900, by his tally, humanity had caused the extinction of about 75 known species, almost all of them mammals and birds. Between 1900 and 1979, humans had extinguished about another 75 known species, representing a rate well above the rate of known losses during the Cretaceous extinction. But even more worrisome was the inferable rate of unrecorded extinctions, recent and now impending, among plants and animals still unidentified by science. Myers guessed that 25,000 plant species presently stood jeopardized, and maybe hundreds of thousands of insects. "By the time human communities establish ecologically sound life-styles, the fallout of species could total several million." Rereading that sentence now, I'm struck by the reckless optimism of his assumption that human communities eventually will establish "ecologically sound life-styles."

Although this early stab at quantification helped to galvanize public concern, it also became a target for a handful of critics, who used the inexactitude of the numbers to cast doubt on the reality of the problem. Most conspicuous of the naysayers was Julian Simon, an economist at the University of Maryland, who argued bullishly that human resourcefulness would solve all problems worth solving, of which a decline in diversity of tropical insects wasn't one.

In a 1986 issue of *New Scientist*, Simon rebutted Norman Myers, arguing from his own construal of select data that there was "no obvious recent downward trend in world forests--no obvious 'losses' at all, and certainly no 'near catastrophic' loss." He later co-authored an op-ed piece in the *New York Times* under the headline "Facts, Not Species, Are Periled." Again he went after Myers, asserting a complete absence of evidence for the claim that the extinction of species is going up rapidly--or even going up at all." Simon's worst disservice to logic in that statement and others was the denial that *inferential* evidence of wholesale extinction counts for anything. Of inferential evidence there was an abundance--for example, from the Centinela Ridge in a cloud-forest zone of western Ecuador, where in 1978 the botanist Alwyn Gentry and a colleague found thirty-eight species of narrowly endemic plants, including several with mysteriously black leaves. Before Gentry could get back, Centinela Ridge had been completely deforested, the native plants replaced by cacao and other crops. As for inferential evidence generally, we might do well to remember what it contributes to our conviction that approximately 105,000 Japanese civilians died in the atomic bombing of Hiroshima. The city's population fell abruptly on August 6, 1945, but there was no one-by-one identification of 105,000 bodies.

Nowadays a few younger writers have taken Simon's line, pooh-poohing the concern over extinction. As for Simon himself, who died earlier this year, perhaps the truest sentence he left behind was, "We must also try to get more reliable information about the number of species that might be lost with various changes in the forests." No one could argue.

But it isn't easy to get such information. Field biologists tend to avoid investing their precious research time in doomed tracts of forest. Beyond that, our culture offers little institutional support for the study of narrowly endemic species in order to register their existence *before* their habitats are destroyed. Despite these obstacles, recent efforts to quantify rates of extinction have supplanted the old warnings. These new estimates use satellite imaging and improved on-the-ground data about deforestation, records of the many human-caused extinctions on islands, and a branch of ecological theory called island biogeography, which connects documented island cases with the mainland problem of forest fragmentation. These efforts differ in particulars, reflecting how much uncertainty is still involved, but their varied tones form a chorus of consensus. I'll mention three of the most credible.

W.V. Reid, of the World Resources Institute, in 1992 gathered numbers on the average annual deforestation in each of sixty-three tropical countries during the 1980s and from them charted three different scenarios (low, middle, high) of presumable forest loss by the year 2040. He chose a standard mathematical model of the relationship between decreasing habitat area and decreasing species diversity,

made conservative assumptions about the crucial constant, and ran his various deforestation estimates through the model. Reid's calculations suggest that by the year 2040, between 17 and 35 percent of tropical forest species will be extinct or doomed to be. Either at the high or the low end of this range, it would amount to a bad loss, though not as bad as the K-T event. Then again, 2040 won't mark the end of human pressures on biological diversity or landscape.

Robert M. May, an ecologist at Oxford, co-authored a similar effort in 1995. May and his colleagues noted the five causal factors that account for most extinctions: habitat destruction, habitat fragmentation, overkill, invasive species, and secondary effects cascading through an ecosystem from other extinctions. Each of those five is more intricate than it sounds. For instance, habitat fragmentation dooms species by consigning them to small, island-like parcels of habitat surrounded by an ocean of human impact and by then subjecting them to the same jeopardies (small population size, acted upon by environmental fluctuation, catastrophe, inbreeding, bad luck, and cascading effects) that make island species especially vulnerable to extinction. May's team concluded that most extant bird and mammal species can expect average life spans of between 200 and 400 years. That's equivalent to saying that about a third of one percent will go extinct each year until some unimaginable end point is reached. "Much of the diversity we inherited," May and his co-authors wrote, "will be gone before humanity sorts itself out."

The most recent estimate comes from Stuart L. Pimm and Thomas M. Brooks, ecologists at the University of Tennessee. Using a combination of published data on bird species lost from forest fragments and field data gathered themselves, Pimm and Brooks concluded that 50 percent of the world's forest-bird species will be doomed to extinction by deforestation occurring over the next half century. And birds won't be the sole victims. "How many species will be lost if current trends continue?" the two scientists asked. "Somewhere between one third and two thirds of all species--easily making this event as large as the previous five mass extinctions the planet has experienced."

Jablonski, who started down this line of thought in 1978, offers me a reminder about the conceptual machinery behind such estimates. "All mathematical models," he says cheerily, "are wrong. They are approximations. And the question is: Are they usefully wrong, or are they meaninglessly wrong?" Models projecting present and future species loss are useful, he suggests, if they help people realize that *Homo sapiens* is perturbing Earth's biosphere to a degree it hasn't often been perturbed before. In other words, that this is a drastic experiment in biological drawdown we're engaged in, not a continuation of routine.

Behind the projections of species loss lurk a number of crucial but hard-to-plot variables, among which two are especially weighty: continuing landscape conversion and the growth curve of human population.

Landscape conversion can mean many things: draining wetlands to build roads and airports, turning tallgrass prairies under the plow, fencing savanna and overgrazing it with domestic stock, cutting second-growth forest in Vermont and consigning the land to ski resorts or vacation suburbs, slash-and-burn clearing of Madagascar's rain forest to grow rice on wet hillsides, industrial logging in Borneo to meet Japanese plywood demands. The ecologist John Terborgh and a colleague, Carel P. van Schaik, have described a four-stage process of landscape conversion that they call the land-use cascade. The successive stages are: 1) *wildlands*, encompassing native floral and faunal communities altered little or not at all by human impact; 2) *extensively used areas*, such as natural grasslands lightly grazed, savanna kept open for prey animals by infrequent human-set fires, or forests sparsely worked by slash-and-burn farmers at low density; 3) *intensively used areas*, meaning crop fields, plantations, village commons, travel corridors, urban and industrial zones; and finally 4) *degraded land*, formerly useful but now abused beyond value to anybody. Madagascar, again, would be a good place to see all four stages, especially the terminal one. Along a thin road that leads inland from a town called Mahajanga, on the west coast, you can gaze out over a vista of degraded land--chalky red hills and gullies, bare of forest, burned too often by grazers wanting a short-term burst of pasturage, sparsely covered in dry grass and scrubby fan palms, eroded starkly, draining red mud into the Betsiboka River, supporting almost no human presence. Another showcase of degraded land--attributable to fuelwood gathering, overgrazing, population density, and decades of apartheid--is the

Ciskei homeland in South Africa. Or you might look at overirrigated crop fields left ruinously salinized in the Central Valley of California.

Among all forms of landscape conversion, pushing tropical forest from the *wildlands* category to the *intensively used* category has the greatest impact on biological diversity. You can see it in western India, where a spectacular deciduous ecosystem known as the Gir forest (home to the last surviving population of the Asiatic lion, *Panthera leo persica*) is yielding along its ragged edges to new mango orchards, peanut fields, and lime quarries for cement. You can see it in the central Amazon, where big tracts of rain forest have been felled and burned, in a largely futile attempt (encouraged by misguided government incentives, now revoked) to pasture cattle on sun-hardened clay. According to the United Nations Food and Agriculture Organization, the rate of deforestation in tropical countries has increased (contrary to Julian Simon's claim) since the 1970s, when Myers made his estimates. During the 1980s, as the FAO reported in 1993, that rate reached 15.4 million hectares (a hectare being the metric equivalent of 2.5 acres) annually. South America was losing 6.2 million hectares a year. Southeast Asia was losing less in area but more proportionally: 1.6 percent of its forests yearly. In terms of cumulative loss, as reported by other observers, the Atlantic coastal forest of Brazil is at least 95 percent gone. The Philippines, once nearly covered with rain forest, has lost 92 percent. Costa Rica has continued to lose forest, despite that country's famous concern for its biological resources. The richest of old-growth lowland forests in West Africa, India, the Greater Antilles, Madagascar, and elsewhere have been reduced to less than a tenth of their original areas. By the middle of the next century, if those trends continue, tropical forest will exist virtually nowhere outside of protected areas--that is, national parks, wildlife refuges, and other official reserves.

How many protected areas will there be? The present worldwide total is about 9,800, encompassing 6.3 percent of the planet's land area. Will those parks and reserves retain their full biological diversity? No. Species with large territorial needs will be unable to maintain viable population levels within small reserves, and as those species die away their absence will affect others. The disappearance of big predators, for instance, can release limits on medium-size predators and scavengers, whose overabundance can drive still other species (such as ground-nesting birds) to extinction. This has already happened in some habitat fragments, such as Panama's Barro Colorado Island, and been well documented in the literature of island biogeography. The lesson of fragmented habitats is Yeatsian: Things fall apart.

Human population growth will make a bad situation worse by putting ever more pressure on all available land.

Population growth rates have declined in many countries within the past several decades, it's true. But world population is still increasing, and even if average fertility suddenly, magically, dropped to 2.0 children per female, population would continue to increase (on the momentum of birth rate exceeding death rate among a generally younger and healthier populace) for some time. The annual increase is now 80 million people, with most of that increment coming in less developed countries. The latest long-range projections from the Population Division of the United Nations, released earlier this year, are slightly down from previous long-term projections in 1992 but still point toward a problematic future. According to the U.N.'s middle estimate (and most probable? hard to know) among seven fertility scenarios, human population will rise from the present 5.9 billion to 9.4 billion by the year 2050, then to 10.8 billion by 2150, before leveling off there at the end of the twenty-second century. If it happens that way, about 9.7 billion people will inhabit the countries included within Africa, Latin America, the Caribbean, and Asia. The total population of those countries--most of which are in the low latitudes, many of which are less developed, and which together encompass a large portion of Earth's remaining tropical forest--will be more than twice what it is today. Those 9.7 billion people, crowded together in hot places, forming the ocean within which tropical nature reserves are insularized, will constitute 90 percent of humanity. Anyone interested in the future of biological diversity needs to think about the pressures these people will face, and the pressures they will exert in return.

We also need to remember that the impact of *Homo sapiens* on the biosphere can't be measured simply in

population figures. As the population expert Paul Harrison pointed out in his book *The Third Revolution*, that impact is a product of three variables: population size, consumption level, and technology. Although population growth is highest in less-developed countries, consumption levels are generally far higher in the developed world (for instance, the average American consumes about ten times as much energy as the average Chilean, and about a hundred times as much as the average Angolan), and also higher among the affluent minority in any country than among the rural poor. High consumption exacerbates the impact of a given population, whereas technological developments may either exacerbate it further (think of the automobile, the air conditioner, the chainsaw) or mitigate it (as when a technological innovation improves efficiency for an established function). All three variables play a role in every case, but a directional change in one form of human impact--upon air pollution from fossil-fuel burning, say, or fish harvest from the seas--can be mainly attributable to a change in one variable, with only minor influence from the other two. Sulfur-dioxide emissions in developed countries fell dramatically during the 1970s and 80s, due to technological improvements in papermaking and other industrial processes; those emissions would have fallen still farther if not for increased population (accounting for 25 percent of the upward vector) and increased consumption (accounting for 75 percent). Deforestation, in contrast, is a directional change that *has* been mostly attributable to population growth.

According to Harrison's calculations, population growth accounted for 79 percent of the deforestation in less-developed countries between 1973 and 1988. Some experts would argue with those calculations, no doubt, and insist on redirecting our concern toward the role that distant consumers, wood-products buyers among slow-growing but affluent populations of the developed nations, play in driving the destruction of Borneo's dipterocarp forests or the hardwoods of West Africa. Still, Harrison's figures point toward an undeniable reality: more total people will need more total land. By his estimate, the minimum land necessary for food growing and other human needs (such as water supply and waste dumping) amounts to one fifth of a hectare per person. Given the U.N.'s projected increase of 4.9 billion souls before the human population finally levels off, that comes to another billion hectares of human-claimed landscape, a billion hectares less forest--even without allowing for any further deforestation by the current human population, or for any further loss of agricultural land to degradation. A billion hectares--in other words, 10 million square kilometers--is, by a conservative estimate, well more than half the remaining forest area in Africa, Latin America, and Asia. This raises the vision of a very exigent human population pressing snugly around whatever patches of natural landscape remain.

Add to that vision the extra, incendiary aggravation of poverty. According to a recent World Bank estimate, about 30 percent of the total population of less-developed countries lives in poverty. Alan Durning, in his 1992 book *How Much Is Enough? The Consumer Society and the Fate of the Earth*, puts it in a broader perspective when he says that the world's human population is divided among three "ecological classes": the consumers, the middle-income, and the poor. His consumer class includes those 1.1 billion fortunate people whose annual income per family member is more than \$7,500. At the other extreme, the world's poor also number about 1.1 billion people--all from households with less than \$700 annually per member. "They are mostly rural Africans, Indians, and other South Asians," Durning writes. "They eat almost exclusively grains, root crops, beans, and other legumes, and they drink mostly unclean water. They live in huts and shanties, they travel by foot, and most of their possessions are constructed of stone, wood, and other substances available from the local environment." He calls them the "absolute poor." It's only reasonable to assume that another billion people will be added to that class, mostly in what are now the less-developed countries, before population growth stabilizes. How will those additional billion, deprived of education and other advantages, interact with the tropical landscape? Not likely by entering information-intensive jobs in the service sector of the new global economy. Julian Simon argued that human ingenuity--and by extension, human population itself--is "the ultimate resource" for solving Earth's problems, transcending Earth's limits, and turning scarcity into abundance. But if all the bright ideas generated by a human population of 5.9 billion haven't yet relieved the desperate needfulness of 1.1 billion absolute poor, why should we expect that human ingenuity will do any better for roughly 2 billion poor in the future?

Other writers besides Durning have warned about this deepening class rift. Tom Athanasiou, in *Divided Planet: The Ecology of Rich and Poor*, sees population growth only exacerbating the division, and notes that governments often promote destructive schemes of transmigration and rain-forest colonization as safety valves for the pressures of land hunger and discontent. A young Canadian policy analyst named Thomas F. Homer-Dixon, author of several calm-voiced but frightening articles on the linkage between what he terms "environmental scarcity" and global sociopolitical instability, reports that the amount of cropland available per person is falling in the less-developed countries because of population growth and because millions of hectares "are being lost each year to a combination of problems, including encroachment by cities, erosion, depletion of nutrients, acidification, compacting and salinization and waterlogging from overirrigation." In the cropland pinch and other forms of environmental scarcity, Homer-Dixon foresees potential for "a widening gap" of two sorts--between demands on the state and its ability to deliver, and more basically between rich and poor. In conversation with the journalist Robert D. Kaplan, as quoted in Kaplan's book *The Ends of the Earth*, Homer-Dixon said it more vividly: "Think of a stretch limo in the potholed streets of New York City, where homeless beggars live. Inside the limo are the air-conditioned post-industrial regions of North America, Europe, the merging Pacific Rim, and a few other isolated places, with their trade summitry and computer information highways. Outside is the rest of mankind, going in a completely different direction."

That direction, necessarily, will be toward ever more desperate exploitation of landscape. When you think of Homer-Dixon's stretch limo on those potholed urban streets, don't assume there will be room inside for tropical forests. Even Noah's ark only managed to rescue paired animals, not large parcels of habitat. The jeopardy of the ecological fragments that we presently cherish as parks, refuges, and reserves is already severe, due to both internal and external forces: internal, because insularity itself leads to ecological unraveling; and external, because those areas are still under siege by needy and covetous people. Projected forward into a future of 10.8 billion humans, of which perhaps 2 billion are starving at the periphery of those areas, while another 2 billion are living in a fool's paradise maintained by unremitting exploitation of whatever resources remain, that jeopardy increases to the point of impossibility. In addition, any form of climate change in the mid-term future, whether caused by greenhouse gases or by a natural flip-flop of climatic forces, is liable to change habitat conditions within a given protected area beyond the tolerance range for many species. If such creatures can't migrate beyond the park or reserve boundaries in order to chase their habitat needs, they may be "protected" from guns and chainsaws within their little island, but they'll still die.

We shouldn't take comfort in assuming that at least Yellowstone National Park will still harbor grizzly bears in the year 2150, that at least Royal Chitwan in Nepal will still harbor tigers, that at least Serengeti in Tanzania and Gir in India will still harbor lions. Those predator populations, and other species down the cascade, are likely to disappear. "Wildness" will be a word applicable only to urban turmoil. Lions, tigers, and bears will exist in zoos, period. Nature won't come to an end, but it will look very different.

The most obvious differences will be those I've already mentioned: tropical forests and other terrestrial ecosystems will be drastically reduced in area, and the fragmented remnants will stand tiny and isolated. Because of those two factors, plus the cascading secondary effects, plus an additional dire factor I'll mention in a moment, much of Earth's biological diversity will be gone. How much? That's impossible to predict confidently, but the careful guesses of Robert May, Stuart Pimm, and other biologists suggest losses reaching half to two thirds of all species. In the oceans, deepwater fish and shellfish populations will be drastically depleted by overharvesting, if not to the point of extinction then at least enough to cause more cascading consequences. Coral reefs and other shallow-water ecosystems will be badly stressed, if not devastated, by erosion and chemical runoff from the land. The additional dire factor is invasive species, fifth of the five factors contributing to our current experiment in mass extinction.

That factor, even more than habitat destruction and fragmentation, is a symptom of modernity. Maybe you haven't heard much about invasive species, but in coming years you will. The ecologist Daniel Simberloff takes it so seriously that he recently committed himself to founding an institute on invasive biology at the

University of Tennessee, and Interior Secretary Bruce Babbitt sounded the alarm last April in a speech to a weed-management symposium in Denver. The spectacle of a cabinet secretary denouncing an alien plant called purple loosestrife struck some observers as droll, but it wasn't as silly as it seemed. Forty years ago, the British ecologist Charles Elton warned prophetically in a little book titled *The Ecology of Invasions by Animals and Plants* that "we are living in a period of the world's history when the mingling of thousands of kinds of organisms from different parts of the world is setting up terrific dislocations in nature." Elton's word "dislocations" was nicely chosen to ring with a double meaning: species are being moved from one location to another, and as a result ecosystems are being thrown into disorder.

The problem dates back to when people began using ingenious new modes of conveyance (the horse, the camel, the canoe) to travel quickly across mountains, deserts and oceans, bringing with them rats, lice, disease microbes, burrs, dogs, pigs, goats, cats, cows, and other forms of parasitic, commensal, or domesticated creature. One immediate result of those travels was a wave of island-bird extinctions, claiming more than a thousand species, that followed oceangoing canoes across the Pacific and elsewhere. Having evolved in insular ecosystems free of predators, many of those species were flightless, unequipped to defend themselves or their eggs against ravenous mammals. *Raphus cucullatus*, a giant cousin of the pigeon lineage, endemic to Mauritius in the Indian Ocean and better known as the dodo, was only the most easily caricatured representative of this much larger pattern. Dutch sailors killed and ate dodos during the seventeenth century, but probably what guaranteed the extinction of *Raphus cucullatus* is that the European ships put ashore rats, pigs, and *Macaca fascicularis*, an opportunistic species of Asian monkey. Although commonly known as the crab-eating macaque, *M. fascicularis* will eat almost anything. The monkeys are still pestilential on Mauritius, hungry and daring and always ready to grab what they can, including raw eggs. But the dodo hasn't been seen since 1662.

The European age of discovery and conquest was also the great age of biogeography--that is the study of what creatures live where, a branch of biology practiced by attentive travelers such as Carolus Linnaeus, Alexander von Humboldt, Charles Darwin, and Alfred Russel Wallace. Darwin and Wallace even made biogeography the basis of their discovery that species, rather than being created and plopped onto Earth by divine magic, evolve in particular locales by the process of natural selection. Ironically, the same trend of far-flung human travel that gave biogeographers their data also began to muddle and nullify those data, by transplanting the most ready and roguish species to new places and thereby delivering misery unto death for many other species. Rats and cats went everywhere, causing havoc in what for millions of years had been sheltered, less competitive ecosystems. The Asiatic chestnut blight and the European starling came to America; the American muskrat and the Chinese mitten crab got to Europe. Sometimes these human-mediated transfers were unintentional, sometimes merely shortsighted. Nostalgic sportsmen in New Zealand imported British red deer; European brown trout and Coastal rainbows were planted in disregard of the native cutthroats of Rocky Mountain rivers. Prickly-pear cactus, rabbits, and cane toads were inadvisedly welcomed to Australia. Goats went wild in the Galapagos. The bacterium that causes bubonic plague journeyed from China to California by way of a flea, a rat, and a ship. The Atlantic sea lamprey found its own way up into Lake Erie, but only after the Welland Canal gave it a bypass around Niagara Falls. Unintentional or otherwise, all these transfers had unforeseen consequences, which in many cases included the extinction of less competitive, less opportunistic native species. The rosy wolfsnail, a small creature introduced onto Oahu for the purpose of controlling a larger and more obviously noxious species of snail, which was itself invasive, proved to be medicine worse than the disease; it became a fearsome predator upon native snails, of which twenty species are now gone. The Nile perch, a big predatory fish introduced into Lake Victoria in 1962 because it promised good eating, seems to have exterminated at least eighty species of smaller cichlid fishes that were native to the lake's Mwanza Gulf.

The problem is vastly amplified by modern shipping and air transport, which are quick and capacious enough to allow many more kinds of organism to get themselves transplanted into zones of habitat they never could have reached on their own. The brown tree snake, having hitchhiked aboard military planes from the New Guinea region near the end of World War II, has eaten most of the native forest birds of Guam. Hanta virus, first identified in Korea, burbles quietly in the deer mice of Arizona. Ebola will next



appear who knows where. Apart from the frightening epidemiological possibilities, agricultural damages are the most conspicuous form of impact. One study, by the congressional Office of Technology Assessment, reports that in the United States 4,500 nonnative species have established free-living populations, of which about 15 percent cause severe harm; looking at just 79 of those species, the OTA documented \$97 billion in damages. The lost value in Hawaiian snail species or cichlid diversity is harder to measure. But another report, from the U.N. Environmental Program, declares that almost 20 percent of the world's endangered vertebrates suffer from pressures (competition, predation, habitat transformation) created by exotic interlopers. Michael Soule, a biologist much respected for his work on landscape conversion and extinction, has said that invasive species may soon surpass habitat loss and fragmentation as the major cause of "ecological disintegration." Having exterminated Guam's avifauna, the brown tree snake has lately been spotted in Hawaii.

Is there a larger pattern to these invasions? What do fire ants, zebra mussels, Asian gypsy moths, tamarisk trees, maleleuca trees, kudzu, Mediterranean fruit flies, boll weevils and water hyacinths have in common with crab-eating macaques or Nile perch? Answer: They're *weedy* species, in the sense that animals as well as plants can be weedy. What that implies is a constellation of characteristics: They reproduce quickly, disperse widely when given a chance, tolerate a fairly broad range of habitat conditions, take hold in strange places, succeed especially in disturbed ecosystems, and resist eradication once they're established. They are scrappers, generalists, opportunists. They tend to thrive in human-dominated terrain because in crucial ways they resemble *Homo sapiens*: aggressive, versatile, prolific, and ready to travel. The city pigeon, a cosmopolitan creature derived from wild ancestry as a Eurasian rock dove (*Columba livia*) by way of centuries of pigeon fanciers whose coop-bred birds occasionally went AWOL, is a weed. So are those species that, benefiting from human impacts upon landscape, have increased grossly in abundance or expanded in their geographical scope without having to cross an ocean by plane or by boat--for instance, the coyote in New York, the raccoon in Montana, the white-tailed deer in northern Wisconsin or western Connecticut. The brown-headed cowbird, also weedy, has enlarged its range from the eastern United States into the agricultural Midwest at the expense of migratory songbirds. In gardening usage the word "weed" may be utterly subjective, indicating any plant you don't happen to like, but in ecological usage it has these firmer meanings. Biologists frequently talk of weedy species, meaning animals as well as plants.

Paleontologists, too, embrace the idea and even the term. Jablonski himself, in a 1991 paper published in *Science*, extrapolated from past mass extinctions to our current one and suggested that human activities are likely to take their heaviest toll on narrowly endemic species, while causing fewer extinctions among those species that are broadly adapted and broadly distributed. "In the face of ongoing habitat alteration and fragmentation," he wrote, "this implies a biota increasingly enriched in widespread, weedy species--rats, ragweed, and cockroaches--relative to the larger number of species that are more vulnerable and potentially more useful to humans as food, medicines, and genetic resources." Now, as we sit in his office, he repeats: "It's just a question of how much the world becomes enriched in these weedy species." Both in print and in talk he uses "enriched" somewhat caustically, knowing that the actual direction of the trend is toward impoverishment.

Regarding impoverishment, let's note another dark, interesting irony: that the two converse trends I've described--partitioning the world's landscape by habitat fragmentation, and unifying the world's landscape by global transport of weedy species--produce not converse results but one redoubled result, the further loss of biological diversity. Immersing myself in the literature of extinctions, and making dilettantish excursions across India, Madagascar, New Guinea, Indonesia, Brazil, Guam, Australia, New Zealand, Wyoming, the hills of Burbank, and other semi-wild places over the past decade, I've seen those redoubling trends everywhere, portending a near-term future in which Earth's landscape is threadbare, leached of diversity, heavy with humans, and "enriched" in weedy species. That's an ugly vision, but I find it vivid. Wildlife will consist of the pigeons and the coyotes and the white-tails, the black rats (*Rattus rattus*) and the brown rats (*Rattus norvegicus*) and a few other species of worldly rodent, the crab-eating macaques and the cockroaches (though, as with the rats, not *every* species--some are narrowly endemic, like the giant Madagascar hissing cockroach) and the mongooses, the house sparrows and the house geckos and the

houseflies and the barn cats and the skinny brown feral dogs and a short list of additional species that play by our rules. Forests will be tiny insular patches existing on bare sufferance, much of their biological diversity (the big predators, the migratory birds, the shy creatures that can't tolerate edges, and many other species linked inextricably with those) long since decayed away. They'll essentially be tall woody gardens, not forests in the richer sense. Elsewhere the landscape will have its strips and swatches of green, but except on much-poisoned lawns and golf courses the foliage will be infested with cheatgrass and European buckthorn and spotted knapweed and Russian thistle and leafy spurge and salt meadow cordgrass and Bruce Babbitt's purple loosestrife. Having recently passed the great age of biogeography, we will have entered the age *after* biogeography, in that virtually everything will live virtually everywhere, though the list of species that constitute "everything" will be small. I see this world implicitly foretold in the U.N. population projections, the FAO reports on deforestation, the northward advance into Texas of Africanized honeybees, the rhesus monkeys that haunt the parapets of public buildings in New Delhi, and every fat gray squirrel on a bird feeder in England. Earth will be a different sort of place--soon, in just five or six human generations. My label for that place, that time, that apparently unavoidable prospect, is the Planet of Weeds. Its main consoling felicity, as far as I can imagine, is that there will be no shortage of crows.

Now we come to the question of human survival, a matter of some interest to many. We come to a certain fretful leap of logic that otherwise thoughtful observers seem willing, even eager to make: that the ultimate consequence will be the extinction of us. By seizing such a huge share of Earth's landscape, by imposing so wantonly on its providence and presuming so recklessly on its forgivingness, by killing off so many species, they say, we will doom our own species to extinction. This is a commonplace among the environmentally exercised. My quibbles with the idea are that it seems ecologically improbable and too optimistic. But it bears examining, because it's frequently offered as the ultimate argument against proceeding as we are.

Jablonski also has his doubts. Do you see *Homo sapiens* as a likely survivor, I ask him or as a casualty? "Oh, we've got to be one of the most bomb-proof species on the planet," he says. "We're geographically widespread, we have a pretty remarkable reproductive rate, we're incredibly good at co-opting and monopolizing resources. I think it would take really serious, concerted effort to wipe out the human species." The point he's making is one that has probably already dawned on you: *Homo sapiens* itself is the consummate weed. Why shouldn't we survive, then, on the Planet of Weeds? But there's a wide range of possible circumstances, Jablonski reminds me, between the extinction of our species and the continued growth of human population, consumption, and comfort. "I think we'll be one of the survivors," he says, "sort of picking through the rubble." Besides losing all the pharmaceutical and genetic resources that lay hidden within those extinguished species, and all the spiritual and aesthetic values they offered, he foresees unpredictable levels of loss in many physical and biochemical functions that ordinarily come as benefits from diverse, robust ecosystems--functions such as cleaning and recirculating air and water, mitigating droughts and floods, decomposing wastes, controlling erosion, creating new soil, pollinating crops, capturing and transporting nutrients, damping short-term temperature extremes and longer-term fluctuations of climate, restraining outbreaks of pestiferous species, and shielding Earth's surface from the full brunt of ultraviolet radiation. Strip away the ecosystems that perform those services, Jablonski says, and you can expect grievous detriment to the reality we inhabit. "A lot of things are going to happen that will make this a crummier place to live--a more stressful place to live, a more difficult place to live, a less resilient place to live--before the human species is at any risk at all." And maybe some of the new difficulties, he adds will serve as incentive for major changes in the trajectory along which we pursue our aggregate self-interests. Maybe we'll pull back before our current episode matches the Triassic extinction or the K-T event. Maybe it will turn out to be no worse than the Eocene extinction, with a 35 percent loss of species. "Are you hopeful?" I ask. Given that hope is a duty from which paleontologists are exempt, I'm surprised when he answers, "Yes, I am."

I'm not. My own guess about the mid-term future, excused by no exemption, is that our Planet of Weeds will indeed be a crummier place, a lonelier and uglier place, and a particularly wretched place for the 2 billion people comprising Alan Durning's absolute poor. What will increase most dramatically as time

proceeds, I suspect, won't be generalized misery or futuristic modes of consumption but the gulf between two global classes experiencing those extremes. Progressive failure of ecosystem functions? Yes, but human resourcefulness of the sort Julian Simon so admired will probably find stopgap technological remedies, to be available for a price. So the world's privileged class--that's your class and my class--will probably still manage to maintain themselves inside Homer-Dixon's stretch limo, drinking bottled water and breathing bottled air and eating reasonably healthy food that has become incredibly precious, while the potholes on the road outside grow ever deeper. Eventually the limo will look more like a lunar rover. Ragtag mobs of desperate souls will cling to its bumpers, like groupies on Elvis's final Cadillac. The absolute poor will suffer their lack of ecological privilege in the form of lowered life expectancy, bad health, absence of education, corrosive want, and anger. Maybe in time they'll find ways to gather themselves in localized revolt against the affluent class. Not likely, though, as long as affluence buys guns. In any case, well before that they will have burned the last stick of Bornean dipterocarp for firewood and roasted the last lemur, the last grizzly bear, the last elephant left unprotected outside a zoo.

Jablonski has a hundred things to do before leaving for Alaska, so after two hours I clear out. The heat on the sidewalk is fierce, though not nearly as fierce as this summer's heat in New Delhi or Dallas, where people are dying. Since my flight doesn't leave until early evening, I cab downtown and take refuge in a nouveau-Cajun restaurant near the river. Over a beer and jambalaya, I glance again at Jablonski's *Science* paper, titled "Extinctions: A Paleontological Perspective." I also play back the tape of our conversation, pressing my ear against the little recorder to hear it over the lunch-crowd noise.

Among the last questions I asked Jablonski was, What will happen *after* this mass extinction, assuming it proceeds to a worst-case scenario? If we destroy half or two thirds of all living species, how long will it take for evolution to fill the planet back up? "I don't know the answer to that," he said. "I'd rather not bottom out and see what happens next." In the journal paper he had hazarded that, based on fossil evidence in rock laid down atop the K-T event and others, the time required for full recovery might be 5 or 10 million years. From a paleontological perspective, that's fast. "Biotic recoveries after mass extinctions are geologically rapid but immensely prolonged on human time scales," he wrote. There was also the proviso, cited from another expert, that recovery might not begin until *after* the extinction-causing circumstances have disappeared. But in this case, of course, the circumstances won't likely disappear until *we* do.

Still, evolution never rests. It's happening right now, in weed patches all over the planet. I'm not presuming to alert you to the end of the world, the end of evolution, or the end of nature. What I've tried to describe here is not an absolute end but a very deep dip, a repeat point within a long, violent cycle. Species die, species arise. The relative pace of those two processes is what matters. Even rats and cockroaches are capable--given the requisite conditions; namely, habitat diversity and time--of speciation. And speciation brings new diversity. So we might reasonably imagine an Earth upon which, 10 million years after the extinction (or, alternatively, the drastic transformation) of *Homo sapiens*, wondrous forests are again filled with wondrous beasts. That's the good news.

[David Quammen, *The weeds shall inherit the Earth*, The Independent (London), 11-22-1998, pp 30-39.]