ALSO BY DAVID QUAMMEN

NONFICTION

Monster of God

Wild Thoughts from Wild Places

The Flight of the Iguana

Natural Acts

FICTION

Blood Line

The Soul of Viktor Tronko

The Zolta Configuration

To Walk the Line

THE *Song* OF THE *Dodo*

ISLAND BIOGEOGRAPHY IN AN AGE OF EXTINCTIONS

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TO

THOMAS G. SAVAGE, S.J.

1926–1975

VIVID IN MEMORY

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THIRTY-SIX

PERSIAN THROW RUGS

I

LET'S START indoors. Let's start by imagining a fine Persian carpet and a hunting knife. The carpet is twelve feet by eighteen, say. That gives us 216 square feet of continuous woven material. Is the knife razor-sharp? If not, we hone it. We set about cutting the carpet into thirty-six equal pieces, each one a rectangle, two feet by three. Never mind the hardwood floor. The severing fibers release small tweaky noises, like the muted yelps of outraged Persian weavers. Never mind the weavers. When we're finished cutting, we measure the individual pieces, total them up—and find that, lo, there's still nearly 216 square feet of recognizably carpetlike stuff. But what does it amount to? Have we got thirty-six nice Persian throw rugs? No. All we're left with is three dozen ragged fragments, each one worthless and commencing to come apart.

Now take the same logic outdoors and it begins to explain why the tiger, *Panthera tigris*, has disappeared from the island of Bali. It casts light on the fact that the red fox, *Vulpes vulpes*, is missing from Bryce Canyon National Park. It suggests why the jaguar, the puma, and forty-five species of birds have been extirpated from a place called Barro Colorado Island—and why myriad other creatures are mysteriously absent from myriad other sites. An ecosystem is a tapestry of species and relationships. Chop away a section, isolate that section, and there arises the problem of unraveling.

For the past thirty years, professional ecologists have been murmuring about the phenomenon of unraveling ecosystems. Many of these scientists have become mesmerized by the phenomenon and, increasingly with time, worried. They have tried to study it in the field, using mist nets and bird bands, box traps and radio collars, ketamine, methyl bromide, formalin, tweezers. They have tried to predict its course, using elaborate abstractions played out on their computers. A few have blanched at what they saw—or thought they saw—coming. They have disagreed with their colleagues about particulars, arguing fiercely in the scientific journals. Some have issued alarms, directed at governments or the general public, but those alarms have been broadly worded to spare nonscientific audiences the intricate, persuasive details. Others have rebutted the alarmism or, in some cases, issued converse alarms. Mainly these scientists have been talking to one another.

They have invented terms for this phenomenon of unraveling ecosystems. *Relaxation to equilibrium* is one, probably the most euphemistic. In a similar sense your body, with its complicated organization, its apparent defiance of entropy, will relax toward equilibrium in the grave. *Faunal collapse* is another. But that one fails to encompass the category of *floral* collapse, which is also at issue. Thomas E. Lovejoy, a tropical ecologist at the Smithsonian Institution, has earned the right to coin his own term. Lovejoy's is *ecosystem decay*.

His metaphor is more scientific in tone than mine of the sliced-apart Persian carpet. What he means is that an ecosystem—under certain specifiable conditions—loses diversity the way a mass of uranium sheds neutrons. Plink, plink, plink, extinctions occur, steadily but without any evident cause. Species disappear. Whole categories of plants and animals vanish. What are the specifiable conditions? I'll describe them in the course of this book. I'll also lay siege to the illusion that ecosystem decay happens without cause.

Lovejoy's term is loaded with historical resonance. Think of radioactive decay back in the innocent early years of this century, before Hiroshima, before Alamogordo, before Hahn and Strassmann discovered nuclear fission. Radioactive decay, in those years, was just an intriguing phenomenon known to a handful of physicists—the young Robert Oppenheimer, for one. Likewise, until recently, with ecosystem decay. While the scientists have murmured, the general public has heard almost nothing. Faunal collapse? Relaxation to equilibrium? Even well-informed people with some fondness for the natural world have remained unaware that any such dark new idea is forcing itself on the world.

What about you? Maybe you have read something, and maybe cared, about the extinction of species. Passenger pigeon, great auk, Steller's sea cow, Schomburgk's deer, sea mink, Antarctic wolf, Carolina parakeet: all gone. Maybe you know that human proliferation on this planet, and our voracious consumption of resources, and our large-scale transformations of landscape, are causing a cataclysm of extinctions that bodes to be the worst such event since the fall of the dinosaurs. Maybe you are aware, with distant but genuine regret, of the destruction of tropical forests. Maybe you know that the mountain gorilla, the California condor, and the Florida panther are tottering on the threshold of extinction. Maybe you even know that the grizzly bear population of Yellowstone National Park faces a tenuous future. Maybe you stand among those well-informed people for whom the notion of catastrophic worldwide losses of biological diversity is a serious concern. Chances are, still, that you lack a few crucial pieces of the full picture.

Chances are that you haven't caught wind of these scientific murmurs about ecosystem decay. Chances are that you know little or nothing about a seemingly marginal field called island biogeography.

THE MAN WHO KNEW ISLANDS

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BIOGEOGRAPHY is the study of the facts and the patterns of species distribution. It's the science concerned with where animals are, where plants are, and where they are not. On the island of Madagascar, for instance, there once lived an ostrichlike creature that stood ten feet tall, weighed half a ton, and thumped across the landscape on a pair of elephantine legs. Yes, it was a bird. One thousand pounds of bone, flesh, feathers. This is no hypothetical monster, no implausible fantasy of Herodotus or Marco Polo. In a ramshackle museum in Antananarivo, I've seen its skeleton; I've seen its two-gallon egg. Paleontologists know it as *Aepyornis maximus*. The species survived until humans reached Madagascar, just within the last few millennia, and began hunting it, harrying it, transforming the ecosystem it was part of, scrambling those bounteous eggs. A thousand years ago, *Aepyornis maximus* existed only on that single island; now it exists nowhere. To say so is the business of biogeography.

As practiced by thoughtful scientists, biogeography does more than ask *Which species?* and *Where?* It also asks *Why?* and, what is sometimes even more crucial, *Why not?*

Another example. The island of Bali, a small mound of volcanic rock and elaborate rice terraces just off the eastern tip of Java, in Indonesia, once supported a unique subspecies of tiger. *Panthera tigris balica*, it was called. Java itself had a different subspecies, *Panthera tigris sondaica*. Meanwhile the island of Lombok, just east of Bali across a twenty-mile stretch of ocean, had no resident tigers at all. Today the Balinese tiger exists nowhere, not even in zoos. It was driven extinct by an intricate combination of the usual factors. The Javanese tiger is probably also extinct, though some people cherish a feeble hope. Sumatra still has a few tigers, and again those belong to a distinct subspecies. Tigers can also be found in certain regions of mainland Asia, but not in the northwestern part of the continent, nor in Africa, nor in Europe. Once they existed as far west as Turkey. Not anymore. And Lombok, no smaller than Bali, with forests no less inviting, is still as tigerless as ever.

Why, why not, why? These facts, and their explanations, represent biogeography. When the same sort of attention is focused specifically on islands, it becomes island biogeography.

Island biogeography, I'm happy to report, is full of cheap thrills.

Many of the world's gaudiest life forms, both plant and animal, occur on islands. There are giants, dwarfs, crossover artists, nonconformists of every sort. These improbable creatures inhabit the outlands, the detached and remote zones of landscape and imaginability; in fact, they give vivid biological definition to the very word "outlandish." On Madagascar lives a species of chameleon barely more than an inch long, the smallest chameleon (among the smallest land vertebrates of any sort, actually) on the planet. Madagascar was also the home of a pygmy hippopotamus, now extinct. On the island of Komodo lurks that gigantized lizard we've all heard of, hungry for flesh and plausibly nicknamed a dragon. In the Galápagos an ocean-going iguana grazes underwater on seaweed, flouting the usual limits of reptilian physiology and behavior. In the central highlands of New Guinea you can catch sight of the ribbon-tailed bird of paradise, no bigger than a crow but dragging a pair of grossly elongated tail feathers, white streamers like the tail on a kite, as it swims heavily through the air of a clearing. On a tiny coral island called Aldabra, in the Indian Ocean, lives a species of giant tortoise less famous though no less imposing than the Galápagos tortoises. On Saint Helena there existed, at least until recently, a species of giant earwig—the world's largest and no doubt most repulsive dermapteran insect. Java has its own species of rhinoceros, another pygmy. Hawaii has its honeycreepers, a whole group of bizarre birds seen nowhere else. Australia has its kangaroos and other marsupials, of course, while the island state of Tasmania has its devil, its bettong, its pademelon, and its spotted-tailed quoll, marsupials too peculiar even for mainland Australia. The island of Santa Catalina, in the Gulf of California, has a rattleless rattlesnake. New Zealand has the tuatara, the last surviving species of an order of beaky-faced reptiles that flourished in the Triassic period, before the peak of the dinosaurs. Mauritius, until Europe invaded, had the dodo. The list could go on, with no diminution of weirdness. The point is that islands are havens and breeding grounds for the unique and anomalous. They are natural laboratories of extravagant evolutionary experimentation.

That's why island biogeography is a catalogue of quirks and superlatives. And that's why islands, those outlands, have played a central role in the study of evolution. Charles Darwin himself was an island biogeographer before he was a Darwinist.

Some of the other great pioneers of evolutionary biology—notably Alfred Russel Wallace and Joseph Hooker—also gathered their best insights from fieldwork on remote islands. Wallace spent eight years collecting specimens in the Malay Archipelago, the empire of islands (and therefore of biological diversity) that now goes by the name Indonesia. Hooker, like Darwin, was lucky and well connected enough to get a place on board one of Her Majesty's ships. It was the *Erebus*, sent off (like Darwin's *Beagle*) on a round-the-world charting expedition, from which Hooker went ashore on Tasmania, New Zealand, and an interesting little nub called Kerguelen Island, halfway between Antarctica and nowhere. Decades later, Hooker was still publishing studies of the plants of New Zealand and his other island stops.

The trend started by Darwin, Wallace, and Hooker has continued throughout this century, with important studies done in New Guinea, in the southwestern Pacific, in Hawaii, in the West Indies, and on Krakatau after the big eruption. It came to a culmination of sorts—or at least to a turning point—in a dense little volume titled *The Theory of Island Biogeography*, published in 1967. *The Theory of Island Biogeography* was a daring, fruitful, and provocative attempt by two young men to merge biogeography with ecology and transform them into a mathematical science. Wherever we wander in this book, you and I, we'll never be far from that one. The two young men were Robert MacArthur and Edward O. Wilson. They derived their theory in part from the patterns of distribution of ant species that Wilson had found among the islands of Melanesia.

Islands have been especially instructive because their limited area and their inherent isolation combine to make patterns of evolution stand out starkly. It's such an important truth I'll repeat it: Islands give clarity to evolution. On an island you might find those enormous tortoises, those flightless birds weighing half a ton, those pygmy chameleons and hippos. Generally you will also find fewer species, and therefore fewer relationships among species, as well as more cases of species extinction. All these factors result in a simplified ecosystem, almost a caricature of nature's full complexity. Consequently islands have served as the Dick-and-Jane primers of evolutionary biology, helping scientists master enough vocabulary and grammar to begin to comprehend the more complex prose of the mainlands. *The Origin of Species* and *The Theory of Island Biogeography* are only two among many landmarks in biological thought that owe their existence to the contemplation of islands. Another is *Island Life*, the first major compendium of island biogeography, published in 1880 by Wallace.

Alfred Russel Wallace was a modest man from a humble English background, the eighth child of amiable, unfocused parents. His father was trained as a solicitor but never practiced, preferring to work as a librarian, dabble disastrously at business ventures, or grow vegetables. After the senior Wallace lost his inheritance through bad investments, the family as a whole lost its foothold in the middle class. Alfred had to leave school at age fourteen and go to work. He learned the surveying trade. It was an early start toward a life of hard, honest, narrow toil, but Alfred broke clear of it. He educated himself during stolen evening moments at workingmen's institutes and public libraries, then escaped from his niche and from England altogether on a wild youthful adventure, and eventually turned himself into the greatest field biologist of the nineteenth century. Most people know of him, if at all, as the fellow who stumbled upon Darwin's most famous idea just before Darwin himself got around to publishing it.

Charles Darwin was a generation older, and had come back from his eye-opening journey aboard the *Beagle* twenty years earlier. Soon after returning, he had conceived his great theory. But the theory was a heretical notion in its early Victorian context, and Darwin was a cautious man, so he had spent those twenty years nurturing it in secret. The heretical notion, specifically, was this: that species had evolved, one from another, along lineages that were continuous but continuously changing, by a process of competitive struggle and differential survival, which Darwin labeled natural selection. Others before him (including Jean Baptiste Lamarck, Georges Buffon, and his own grandfather, Erasmus Darwin) had entertained the view that species were shaped by some form of evolution. None of those earlier evolutionists, though, had offered a persuasive explanation of *how* species evolved, because none had hit on the concept of natural selection. That concept remained Darwin's secret insight, his carefully guarded intellectual treasure, while he devoted much of two decades to gathering evidence and framing arguments that would support it. Then one day Darwin received a manuscript in the mail from a young, obscure naturalist named Wallace—and the Wallace manuscript, to Darwin's horror, contained his own precious concept. Wallace had found his way to it independently. For a brief heartsick period, Darwin believed that the younger man had eclipsed him and preempted his life's work by staking a just claim to priority. As things developed, however, with Joseph Hooker's collusion, Wallace and Darwin announced the concept simultaneously. For a variety of reasons, some good and some shabby, Darwin received most of the recognition; and Wallace, in consequence, is famous for being obscured.

But that's just the cartoon version of a complicated, troubling story. The cartoon neglects much, including Alfred Russel Wallace's role as the patriarch of biogeography.

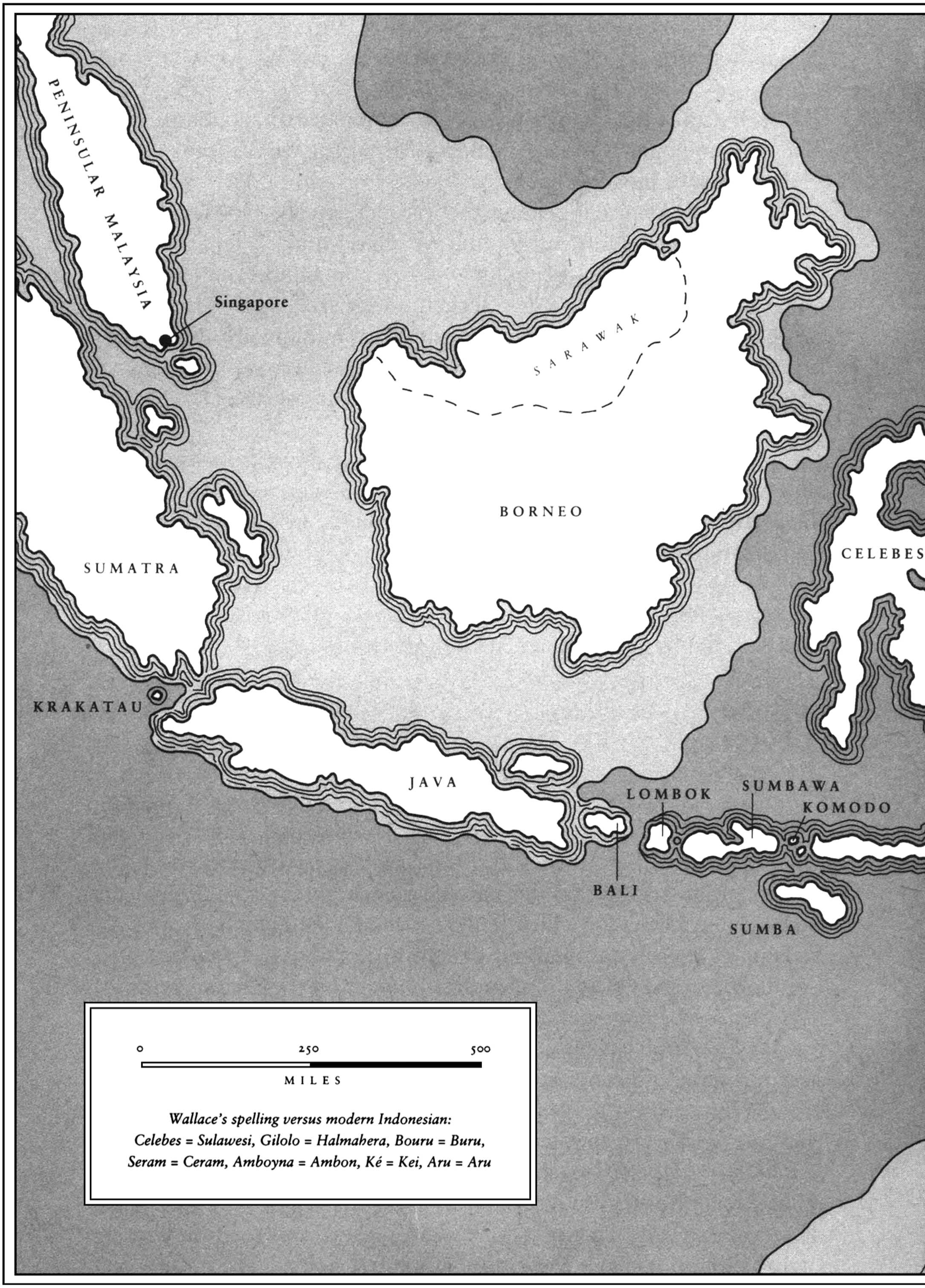
Darwin was a more ingenious theorist, admittedly. Hooker became the preeminent botanist of his time. Wallace, much later in life, involved himself in certain crankish interests (including the Land Nationalization Society, an anti-vaccination crusade, and spiritualism) that have made it easier for historians to treat him unfairly. Still, Wallace remains the most heroically appealing, at least to my crankish taste. No doubt I'm biased by the fact that he, unlike Darwin and Hooker, was an impecunious freelancer.

On June 13, 1856, after a twenty-day passage down from Singapore aboard a schooner called the *Rose of Japan*, Wallace stepped ashore on the island of Bali. He was just passing through, en route east toward Celebes. The layover in Bali lasted two days. Following his normal routine, Wallace collected some birds and insects. He scouted the landscape. Then he rejoined the *Rose of Japan* and crossed the strait to Lombok. In physical distance, it's a short trip.

3

THE GATEWAY to the island of Lombok is Padangbai, a ferry port on the east coast of Bali. It's a scruffy little town, far off track from the glittery destinations of international beach tourism—Sanur, Kuta Beach, Nusa Dua—for which Bali has become lamentably famous. At Padangbai, there's no notable surf. No upscale hotel. From the pier, Lombok shows itself as a blue gray silhouette on the eastern horizon, like a cold morning sun, offering only the dimmest promise. Of all the Western and Japanese travelers who jet into Bali each year, not one in a thousand crosses eastward to Lombok. Not one in a thousand has any reason to. Nobody would claim that the less famous island is dramatic, except in a rarefied biogeographical sense.

The ferry departs at two o'clock, I learn, but it's already full. This unwelcome information comes from Nyoman Wirata, my translator, driver, and friend. I can see that there's more information lurking shyly behind Nyoman's eyes. I accept the bad news, and I wait.


PENINSULAR MALAYSIA
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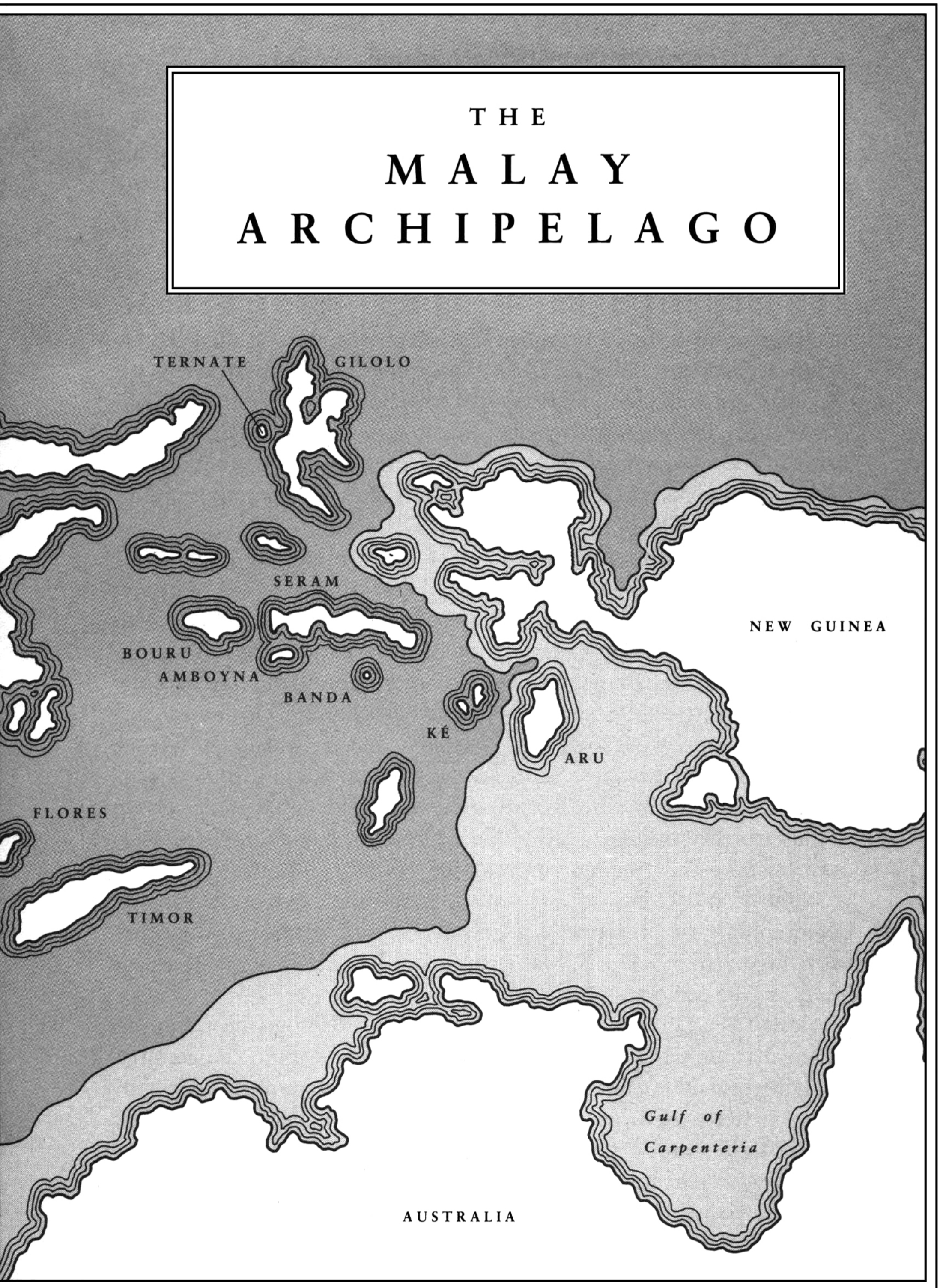
MILES
Wallace's spelling versus modern Indonesian:
Celebes = Sulawesi, Gilolo = Halmahera, Bouru = Buru,
Seram = Ceram, Amboyna = Ambon, Ké = Kei, Aru = Aru


THE
MALAY
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AMBOYNA
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NEW GUINEA
FLORES
TIMOR
Gulf of
Carpenteria
AUSTRALIA

Then again, maybe the ferry he's *not* full, Nyoman says. A five-thousand-rupiah bribe to the ticket agent might open up some space.

Nyoman is a sweet-natured Balinese tailor unaccustomed to brokering waterfront bribes. He's a sterling young man whose real trade is shirtmaking and whom for this expedition I've shanghaied away from his shop. His tailoring business and his home are in Ubud, a little wonderland of a town in the uplands, full of temples and art studios and clever mask carvers and clanging *gamelan* orchestras. Despite the tourism boom that has tarted up its face in recent years, Ubud remains graceful, pious, more spiritual than most towns on the island—damn well more spiritual than Padangbai—and my trusted pal Nyoman is a true Ubudian. He's so excruciatingly polite and ingenuous that if bribing a ticket agent seems to him faintly advisable, in the mind of the agent it's no doubt mandatory. Having made that extrapolation, I give Nyoman a fistful of rupiahs and full discretion, then I go off to find food.

Padangbai has the character of any border town, though the border crossing here happens to be a boat trip. The streets are full of predatory cab drivers and part-time masseuses and aggressive toddlers who offer to change money. There's none of the artistic ethos nor the architectural charm found in the highlands around Ubud, and the Hindu-Animist ceremonial element is absent too. Lombok, just across the strait, is predominantly Moslem, and the Moslem influence seems to begin right here at the point of embarkation. Beer is suddenly harder to come by, for instance. Still, Padangbai has a certain roguish forthrightness. "Hey. Hello. Where are you going?" the sidewalk hustlers holler demandingly at me. "What you want?" Whatever it is, they can deliver. But all I want is to sit down, out of the sun and preferably in the presence of a cold drink. I catch up with my other traveling partner, a Dutch biologist named Bas van Balen, and we investigate the offerings of Padangbai.

Skinny as a Quaker, with a wiry black Smith Brothers beard and an imperturbable digestive tract, Bas has been ten years in the country, studying birds. He's fluent in the Indonesian language and in sixty different patterns of avian song, but this will be his first trip across to Lombok. Bas and I find a *warung* for some *makanan* and inquire whether *ada nasi campur*. In English: We find a café and order the rice-with-today's-leftover-meat. The first night I fell in with him, Bas led me off to a street stall for *rajak cingur*, which turned out to be cow snout and bean sprouts in muddy gravy. The cow snout was accept-able, but the thick orange drink he recommended for washing it down—something called *jamu*, resembling a barium cocktail flavored with buttermilk and garlic—was a onetime experience, thanks. Today, in retreat from Padangbai's midday heat, we quench our thirst with bottles of tepid Temulawak, a peculiar but inoffensive soft drink made from the pulp of a tuber. And then, with time to kill and Lombok on my mind, I reread a certain passage by Wallace.

It comes from *The Malay Archipelago*, the narrative account of his eight-year expedition among the islands.

> During the few days which I stayed on the north coast of Bali on my way to Lombock, I saw several birds highly characteristic of Javan ornithology.

This was in 1856, the third year of his Malay travels, as he was working his way eastward from an earlier base at the town of Malacca on the Malaysian peninsula. Java in that era was a familiar outpost to English and Dutch colonialists, and its resident bird life was well known. Wallace had noted the unsurprising fact that at least some of those Javanese birds occurred also on Bali, to the east across a narrow strait. He mentioned a half-dozen species, including the yellow-headed weaver, the rosy barbet, and the Javanese three-toed woodpecker. Then he added a noteworthy observation:

> On crossing over to Lombock, separated from Bali by a strait less than twenty miles wide, I naturally expected to meet with some of these birds again; but during a stay there of three months I never saw one of them, but found a totally different set of species, most of which were utterly unknown not only in Java, but also in Borneo, Sumatra, and Malacca.

Conspicuous among these other species was the white cockatoo, absent from Bali, absent also from Java, more characteristic of Australia. A mysterious line of some sort had been crossed.

It came to be known as Wallace's Line. As drawn in those days, it split the gap between Borneo and Celebes. Continuing southward, it split also that narrower gap between Bali and Lombok. As far as the pioneer biogeographers were concerned, these two sibling islands, Bali and Lombok, belonged to two different realms. West of the dividing line lived tigers and monkeys, bears and orangutans, barbets and trogons; east of the line were friarbirds and cockatoos, birds of paradise and paradise kingfishers, cuscuses and other marsupials including (farther east in New Guinea and tropical Australia) the ineffable tree kangaroos, doing their clumsy best to fill niches left vacant by missing monkeys. Bali and Lombok were the two little islands—similar in size, similar in topography, similar in climate, nestled shoulder to shoulder—where the zoological differences were most sharply delineated. Wallace himself wrote that "these islands differ far more from each other in their birds and quadrupeds than do England and Japan." And from the earliest moment he had been wondering why.

The secret of Wallace's Line, as eventually discovered and clarified by later biogeographers, is deep water. The sea gap between Bali and Lombok is narrow but deep, because Lombok lies just *off* the continental shelf while Bali, so close, lies just *on* the shelf's southeast edge. Having once been connected by dry land, Bali shares much of its flora and fauna with Java, Borneo, Sumatra, and the Malaysian peninsula, whereas Lombok, and all the other islands to the east in deep water, are truly at sea. Although Alfred Wallace didn't offer this insight himself, he elucidated the pattern that led to it. That pattern leads to much more as well. The narrow strait between Bali and Lombok is one of the sites where biogeography first came into focus.

I leave Bas drinking coffee in the *warung* and go off to buy water and bananas. On a lark I buy also some unfamiliar fruit, scaly brown globes the size of golf balls, and later ask Bas to identify them. Ah yes, *salak*, he tells me. They're more commonly known as lizard-skin fruit; they grow on a tree that resembles a date palm. Peeling one, I find the flesh cream-colored and squeaky firm. It tastes like a cross between pineapple and garlic. In passing I wonder whether this might be the secret ingredient of *jamu*, the nasty orange drink. If not, then how many different Balinese foods taste like a cross between garlic and something? I'm still puzzling over that one when Nyoman appears, his innocent Balinese face split with a guilty grin, to announce that he has bribed us onto the ferry.

As the boat pulls away I get a last glance at Padangbai. The shining silver turret of a mosque stands above the *warungs*, the shops, the beached praus, and a big cheesy billboard for Bintang beer. Bintang is the Budweiser of Indonesia, cheap, democratic, ubiquitous, the main difference being that (thanks to the Dutch influence and a Heineken recipe, I gather) Bintang tastes good. On this island, even Moslem restaurants will serve it to you, provided that you're obviously an infidel. On the next island, things will be different. *Selamat datang*, says the Bintang sign. Welcome, it tells us, as we leave.

The crossing takes three hours. The upper deck is crowded with Indonesians on holiday, on pilgrimage, on business, on journeys to see family. A traveling salesman is working the crowd, trying to sell false teeth from a cardboard display box. He carries molars, incisors, canines, a half-dozen different specimens of each type, shrink-wrapped individually like antihistamine tablets—a nice selection, though no one is buying. Like any good salesman, he appears undaunted by failure and rejection. Probably he's just amusing himself on his way to a promising circuit of the dentists of Lombok.

Two miles out of Padangbai I see a small white butterfly, beating its way eastward on the wind. The butterfly is a suggestive datum. Here in the sea gap between Bali and Lombok, making its reckless attempt to cross Wallace's Line, it stands as an emblem for larger topics—isolation, speciation, dispersal, all connected within the still larger subject of island biogeography. Isolation is the most obvious of those three, since of course islands are inherently isolated. Their isolation fosters speciation, the process in which one species splits into several. But the isolation of islands isn't absolute, and some creatures always manage to breach it—that's dispersal. Maybe the white butterfly from Bali will make landfall in Lombok and play some genetic role there among a population of similar butterflies . . . though most likely, no, it will fall short. The arduousness of dispersal across stretches of ocean is part of what gives island biogeography its special clarity. Many creatures set out, few arrive. The failure and death of potential dispersers enforces isolation long enough for speciation to occur.

Speciation, let's remember, is a modern word. Within the Victorian world from which Darwin and Wallace went off on their journeys, it had never been spoken or written. Most people hadn't even thought it. Most people believed in a God who had created all species from scratch and put them on Earth in elaborately illogical arrangements—tigers here but not there, cockatoos only as far as this or that point, rhinos on this or that tropical island but not on the neighboring one, white butterflies in some places and blue butterflies in others. Those arrangements, it was assumed, somehow suited divine whimsy. Biogeography until the mid-nineteenth century served to prove nothing except that the deity had a disjointed and inscrutable sense of pattern.

I lose sight of the sea-crossing butterfly. I gape at the horizon. Halfway to Lombok, with folks lying asleep on the benches and on the rusty iron floor, with even the tooth salesman at rest, stewards appear smartly on deck to administer our lifejacket demonstration. In crisp Indonesian the stewards recite a program of safety procedures. I listen attentively, enjoying the lilt of the language, comprehending zilch. Later I discover a bilingual sign; the English half says:

> IN AN EMERGENCY, KEEP YOUR HEAD AND FOLLOW THE CREWS INDUCEMENTS CONFUSION MAKES THE SITUATION WORSE. ON LEAVING SHIP, GIVE PREFERENCE TO LADIES, CHILDREN AND OLDS AND TIDY UP YOURSELF TO HAVE YOUR HANDS FREE WITH ONLY VALUABLES AS POSSIBLE. THE LIFE JACKETS ARE STOWED IN EACH CABIN KINDLY CONFIRM THE STORED PLACE AND HOW TO WEAR IT BY "HOW TO PUT ON THE LIFE JACKET" AND CHECK THE LEAVING ROUTE BY THE MAP OF LEAVING ROUTE.

No doubt it sounds more reassuring in Indonesian.

At sunset, as we glide into a well-sheltered harbor on the northwestern coast of Lombok, the ship's loudspeaker croons out a Moslem chant. It's the evening prayer, nasal and soothing. The volcanic cone of Gunung Rinjani, Lombok's highest mountain, rises over us to darken the twilight. Menacing gray clouds are coming in from the east, from Komodo and Timor, but the water of this bay is preternaturally slick. Offshore, a small prau with a blue sail cruises weightlessly. A pair of beefy Australian tourists appear on deck, ruddy-faced from Bintang and armed with video cameras to film their arrival for later experiencing. And I think of Alfred Russel Wallace during his years of lonely travel.

4

In February of 1855, the year before he reached Bali and Lombok, Wallace was holed up in Sarawak, one of the states on the island of Borneo. He had the use of a little house at the mouth of a river. It was the wet season. "I was quite alone," he would recount fifty years later in his autobiography, "with one Malay boy as cook, and during the evenings and wet days I had nothing to do but to look over my books and ponder over the problem which was rarely absent from my thoughts." The problem to which he alluded was: What is the origin of species? Unlike Charles Darwin two decades earlier, Wallace had started off on his travels with that question already in mind. The interlude in Sarawak is important because there, for the first time, he attempted an answer.

His answer derived from biogeography. "Having always been interested in the geographical distribution of animals and plants," he would recall—and having boned up particularly on Malayan insects and reptiles, at the British Museum, before he embarked on this trip—he realized that "these facts had never been properly utilized as indications of the way in which species had come into existence." The data of plant and animal distribution were simply accepted as mysterious givens. Charles Darwin himself had offered many of those data for sheer entertainment value in his narrative account of the *Beagle* voyage, first published in 1839. (In this original edition the book was catchily titled *Journal of Researches into the Geology and Natural History of the Various Countries Visited by H.M.S.* Beagle, *under the Command of Captain Fitzroy, R.N. from 1832 to 1836.* To us it's more familiar in later editions as *The Voyage of the "Beagle."*) But even Darwin's *Journal* was just a scientific travelogue, a pageant of colorful creatures and places, propounding no evolutionary theory. The theory would come later. Wallace was correct in his recollection, looking back on the 1855 circumstances, that the biogeographical data had never been properly utilized.

Charles Darwin in 1855 was a patient, sedulous forty-six-year-old. He knew that the notion of evolution by natural selection was going to incite a shitstorm of resentment in Victoria's England, and not just from rock-headed clergy. Most of Darwin's own friends among the scientific elite and the comfortable gentry were also disposed toward loathing that notion. For Alfred Wallace, the situation was slightly different. He knew, as Darwin did, that a cogent theory of evolution would rattle tea carts in the rectories, raise eyebrows in the country mansions, and put solid chaps off their sherry at the better clubs. But Wallace, unlike Darwin, didn't care. He was a hungry young man with nothing to lose.

5

THOSE UNUTILIZED facts of biogeography were a byproduct of the great age of discovery. They had piled up in libraries and museums during the previous four centuries as the more remote regions of sea and land had surrendered to exploration by adventurous Europeans who kept their eyes open and later told tales. From all over the planet, travelers had been bringing home reports of wondrous, unexpected beasts. In 1444, for instance, a Venetian named Nicolo de Conti wrote an account of his travels, in which he mentioned the white cockatoo. De Conti had just returned from the Malay Archipelago.

The first voyage of Christopher Columbus yielded eyewitness accounts of macaws, caimans, manatees, and iguanas, none of which had a place in the belief structure of an orthodox European. The later Columbian voyages added South American monkeys, peccaries, and the Hispaniolan hutias, a group of tree-climbing rodents that were ratlike without quite being rats. Antonio Pigafetta, who sailed with Magellan, published a journal that mentioned the golden lion marmosets of eastern Brazil, dainty monkeys that do look like lions, as Pigafetta claimed, "only yellow and very beautiful." Pigafetta also described rheas, which he may have mistaken for ostriches, and penguins, which he could hardly have mistaken for anything. About that time, also from the Americas, the first report of a hummingbird reached Europe; the first accurate report of an armadillo; the first report of a toucan; the first reports of giant anteaters and sloths and vicunas and one useful bird that was quickly welcomed to the Old World as a domestic, the turkey; the first report of the American bison, a giant-headed animal almost too majestic to be real. Imagine how these prodigies must have unnerved a complacently pious sixteenth-century European. Imagine it this way: You think you know every bird in the world, and then someone shows you a curl-crested aracari.

God had supposedly stopped creating after the sixth day. But now, as the wider world opened to the taking of a more thorough biological inventory, it seemed that God had stayed busier than anybody had dreamed.

One theological tenet threatened by the more thorough inventory was the Genesis account of Noah's ark. A boat that was literal rather than symbolic, and therefore finite rather than infinite, could have carried only so many passengers—even if it did measure three hundred cubits by fifty cubits. If the ark had previously been full, with the roster of new animals it became hopelessly crowded.

Was there room aboard that boat for a pair of capybaras? Around the year 1540 Juan de Ayolas sighted this giant South American rodent, "a sort of waterboar, half hog, half hare." Was there room for a pair of sloths? About the same time Gonzalez Fernando de Oviedo described this creature as "one of the slowest beastes in the worlde, and so heavy and dull in mowynge that it cannot scarcely go fyftie pases in a hole day." Was there room for possums? From a forest in Venezuela, Vicente Pinzón brought back a live one to Spain. It was a furred animal like none seen before. It carried its young in a pouch.

The American voyages, the American fauna, were just a beginning. The African continent had its own share of novelties. Elephants, rhinos, lions, and hippopotamuses had been known since the years of the Roman empire, but slightly less spectacular animals, such as warthogs and civets, still seemed remarkable to travelers in the sixteenth century. Toward the end of that century, during a visit to eastern Africa, Friar Joanno dos Sanctos caught sight of an aardvark. He was impressed by the extensible tongue, so useful for slurping up ants, and by certain other incongruous features, such as "the snout very long and slender, long eares like a mule, without haire, the taile thick and straight of a spanne long, fashioned at the end lyke a dystaffe." In India, about the same time, a Dutchman named Jan Huygen van Linschoten saw a pangolin. It was the size of a dog, he reported, with the snout of a hog, small eyes, two holes where its ears should have been, and its whole body "covered with scales of a thumb breadth," which Linschoten took to be "harder than iron or Steele."

From the exotic East came reports of exotic birds. There had been de Conti's account of the cockatoo and of several other parrotlike species that he had seen on one of the islands of the Banda cluster, in the far southeastern corner of the Malay Archipelago. There was the testimony of a Portuguese diplomat named Tomé Pires, who around 1512 stopped at the Aru Islands, still farther east, and laid eyes on the gaudy skins of another unimagined group of birds. The Aru Islands, considerably more remote even than Banda, were richly endowed with biological oddities. The specimens that Pires saw, presumably in a small trading settlement where they had been offered by native hunters, were "birds which they bring over dead, called birds of paradise, and they say they come from heaven and that they do not know how they are bred." This seems to have been the first European report of an especially decorative and significant avian family. Besides the two species native to Aru, another forty-some species of bird of paradise remained to be found in the forests of New Guinea, northeastern Australia, and other small offshore islands of the vicinity.

Actual specimens reached Europe slowly and in mangled form—as dried skins, with the feet (sometimes also the wings and the head) chopped away in the process of preservation. Van Linschoten, the Dutch traveler who had seen a live pangolin but never a live bird of paradise, offered his readers the unreliable assurance that *no one* had ever seen these birds alive, because they spent all their lifetimes in the upper atmosphere. They were footless and wingless, according to him, ethereal creatures of unearthly beauty and unearthly habits that fell to the ground only at death. That misapprehension remained strong through the mid-eighteenth century, when the systematizing Swedish biologist Carl von Linné (known more commonly, through his writings, as Carolus Linnaeus) gave a formal scientific description and a Latin name to the larger of the two Aru species. Linnaeus called it *Paradisea apoda*, the footless. We shouldn't judge Linnaeus's credulousness too harshly, since such a bird wasn't much more implausible than other aspects of the new zoological reality that people were forced to assimilate. If the giant bird *Aepyornis maximus* could exist without wings, why not a modest-sized *Paradisea apoda* without feet?

Fruit bats, dingoes, and cassowaries were also reported. Gradually the European surge of discovery and conquest was extending itself toward the Antipodes. In 1629 a Dutchman shipwrecked on an island off western Australia caught sight of a wallaby and lived to tell. Some people found it too much to believe. A large pouched mammal in upright posture, bouncing around on two oversized feet, with a face like a deer and ears like a rabbit? Right. Skepticism about Australian marsupials lasted more than a century. Then in 1770 the British ship *Endeavour*, commanded by Captain James Cook, landed along the northeastern coast in what is now tropical Queensland. Aboard the *Endeavour* was Joseph Banks, a wealthy amateur naturalist who had bought himself a place on the trip in order to add to his collections.

Joseph Banks was arguably the prototype of the shipboard naturalist on the voyage of exploration, a role that became more important when it was later filled by Darwin, Hooker, and T. H. Huxley, among others. Banks himself, unlike the best of those later shipboard naturalists, was no theorist. But he played his part. One day a whomping big beast was sighted, tracked with greyhounds, and shot. Having examined the carcass, Banks wrote: "To compare it to any European animal would be impossible, as it had not the least resemblance to any one that I have seen." The native people thereabouts, dark-skinned and peaceable folk who hadn't yet been given reason to want to murder Cook's party and feed the bodies to currawongs, explained that their name for the leaping animal was *kanguru*. Banks took the specimen back to England and commissioned George Stubbs to do a painting. From Stubbs's oil someone did an engraving, eventually published with Cook's journal. The kangaroo became famous.

So did *Raphus cucullatus*, the giant flightless pigeon from a little island called Mauritius in the Indian Ocean. This bird reached Europe during the early seventeenth century, initially in the tales of returned travelers and then probably in the form of several live specimens. It was such a ridiculous creature—round and ungainly, gawkish and risible—that its renown spread by hearsay and cartoon. It seemed to burlesque the very essence of birdness. Its anatomical components appeared badly matched—short legs, big body, tiny wing stubs, huge beak, with no harmony to the whole. Who could resist being amused by such an ornithological joke? From the memoirs of an English theologian, Sir Hamon L'Estrange:

> About 1638, as I walked London streets, I saw the picture of a strange fowle hung out upon a clothe and myselfe with one or two more then in company went in to see it. It was kept in a chamber, and was a great fowle somewhat bigger than the largest Turky Cock, and so legged and footed, but stouter and thicker and of a more erect shape, coloured before like the breast of a young cock fesan, and on the back of dunn or dearc colour. The keeper called it a Dodo.

Some historians suspect that the captive animal seen by L'Estrange was actually a Réunion solitaire, another largish bird that might have been casually mistaken for a dodo. The solitaire was slightly more gracile but also flightless, and found only on the island of Réunion, not far from Mauritius. Dodo or solitaire, it was a novelty to Europe.

An interesting sidelight to this wave of biological discovery is that some of the more vivid animals were adopted for map illustrations. As early as 1502 a Portuguese mapmaker drew red and blue macaws into place in Brazil, counterpointing the green and gray parrots with which he decorated Africa. Monkeys also showed up on maps of South America almost as soon as the roughest outlines of that continent could be drawn. A pangolin appeared on the world map done by Pierre Descelliers in 1546. In 1551 Sancho Guttierrez portrayed a bison in North America on his map of the world. Toward the end of the century, another artist drew a bird of paradise—footless—on a map of southeastern Asia. Offering a few splashy pictures to enliven their charts, whether accurately or misleadingly, these Renaissance mapmakers were committing biogeography.

As the inventory increased, so did the difficulty for biblical literalists. Noah's ark was getting too full. Some of the pious scholars haggled desperately about how to interpret the word "cubit." No no, not the *little* cubit, they said—those measurements in Genesis 6 must refer to *big* cubits, six times as large. It was a way of stretching the ark and of buying time, but meanwhile there came ever more species of monkey and pigeon and kangaroo. Other scholars offered ingenious suggestions for retroactive improvement of Noachian boat design. A German Jesuit named Athanasius Kircher published *Arca Noë in Tres Libros Digesta*, containing much learned argument from historical and philological sources as well as an engraving of the ark as he fancied it. Kircher's ship is a boxy, three-story structure resembling a Super 8 motel, beneath which appears no trace of a hull. Unquestionably it would have allowed efficient division of space into many stalls and cages, but it doesn't look seaworthy. Maybe seaworthiness, like creation itself, was the province of miracles. In the Kircher engraving, a pair of lions, a pair of snakes, a pair of spoonbills, a pair of ostriches, a pair of horses, a pair of donkeys, a pair of camels, a pair of dogs, a pair of pigs, a pair of peafowl, a pair of rabbits (Noah, watch out!), and a pair of turtles are waiting their turns to climb the gangplank. It's a crowded scene, though the level of biological diversity is relatively minuscule.

As described by Janet Browne in *The Secular Ark*, her excellent history of the foundations of biogeography, Father Kircher's ark included just 150 kinds of birds and about the same number of other vertebrate animals. Fish, naturally, didn't need a boat. Neither did those reptiles and insects that arose by spontaneous generation. With such cleverly rigorous exclusions, Kircher pared down the total of species requiring rescue and got them all aboard, thereby keeping the good ship of biblical literalism afloat just a while longer.

But his passenger manifest was too small to accord with reality. By the end of the seventeenth century, naturalists were aware of 500 bird species, 150 quadruped species, and about 10,000 species of invertebrates. Fifty years later, when Linnaeus began putting things in order, those numbers were still growing quickly. Linnaeus himself named and catalogued almost 6,000 species. The ark was overbooked.

6

THE ARK as a physical vessel was only one tenet of scriptural orthodoxy under threat. Another was that mountaintop where the boat had made landfall and unloaded. Conventional belief had fixed on a mountain in eastern Turkey as the site—Mount Ararat, as we know it—though Genesis itself gives no geographic coordinates. Grounding Noah's menagerie in eastern Turkey left the distributional anomalies of the world's fauna unexplained. If all the surviving animals disembarked at Ararat after the deluge, how did various species end up where they did?

At the simplest level, this was a problem of dispersal. How did the rheas, being flightless, get from Turkey to South America? Did they walk? How did the polar bears get to the Arctic, given their need for cold temperatures, frozen oceans, and toothsome seals? It must have been a long, hungry, hot trudge across the Caucasus. How did those troublesome kangaroos get to Australia? Exactly how far could the bloody things jump?

At a more intricate level, the problem also encompassed discontinuities in distributional patterns. If the kangaroos hopped from Ararat to Australia, why had none lingered in Asia? If the cockatoos had flown out from the ark (as the raven and the dove had done earlier, on their scouting missions for dry land) and headed southeast, why did they fly all the way to Lombok before choosing to stop and establish a presence? Why had they spurned all the intermediate terrain? What had been so off-putting about, say, Bali?

Linnaeus himself was among the first to see the story of Ararat and the ark as irreconcilable with biological reality. He doubted that a pair from each species of land animal could have fit on a single boat, no matter how Noah had calibrated cubits. Linnaeus also doubted the vision of those animals disembarking onto a mountaintop. Instead he offered a symbolic interpretation, differing slightly from the literalistic one. He suggested that Ararat must represent a primordial island, from which all created species had dispersed: "If we therefore enquire into the original appearance of the earth, we shall find reason to conclude, that instead of the present wide-extended regions, one small island only was in the beginning raised above the surface of the waters." This island, as Linnaeus saw it, was the site of Eden and the original home of all God's creatures. It was "a kind of living museum, so furnished with plants and animals, that nothing was wanting of all the present produce of the earth." The island was mountain-shaped, encompassing a stratified spectrum of climatic zones—a tropical zone near the base, a temperate zone farther up, a polar zone surrounding the summit. Each type of animal was matched to its "proper soil" and its "proper climate" within one of the stratified zones. As the primeval waters subsided, allowing steadily more land surface to emerge, the different zones became enlarged across the world's landscape and the distribution of animals expanded accordingly. Each type of animal was dependent upon its own zone, and each type had a physical form suiting it snugly—and immutably—to that zone.

Linnaeus had hit upon a richly ambivalent line of thought, leading in one direction toward insight, in another direction toward a new kind of confusion. Toward insight: The talk about "proper soil" and "proper climate" sounds like the ecological concept of a species adapted to its niche. But that concept wouldn't be developed until much later. Toward confusion: The immutable linkage that Linnaeus imagined between the form of an animal and its "proper" place enticed some eighteenth-century thinkers to embrace the idea of *special creation.*

This idea implied divine involvement in every picayune aspect of floral and faunal origination. It swept aside all those quibbles (big cubits versus little cubits, for instance) that afflicted literalistic interpretations of the ark story, allowing Noah's flood to be accepted again as a true but nonliteral parable. What did not relax into parable, in light of special creation, was the deity's direct role. That bit was still literal and historic. And now He appeared busier than ever.

According to the idea of special creation, God had functioned both as almighty creator and as chief zoological usher, designing particular beasts for particular places and seeing to it that they got to those places. He had made the polar bears in just such a way as to suit them for the Arctic—and so that's where He had put them. He had shaped the kangaroos and set them down in precisely the location where they belonged—Australia. He had personally adapted the capybara to its life in South American swamps. He had divided His attention among a number of distinct geographical realms and flattered each of those realms as a center of creation. He had invented whole floras and faunas, integral communities, every one appropriate to its physiographic context. He had decreed into existence mature ecosystems. Let there be neotropical moist forest, He had said, and lo. Let there be sclerophyllous chaparral, He had said, and it was so. Let there be taiga, and let it be graced with great herds of antlered ungulates, with a few snow-hardy predators, with wildflowers that bloom hurriedly in midsummer, with fast-reproducing small mammals whose population sizes fluctuate drastically, and with more mosquitoes than even I can count, He had said, et cetera. This newly imagined God of the late eighteenth century was a hands-on, follow-through sort of guy who committed himself to details and showed no knack for delegating power. He made himself immanent and manifest the laborious way, with one little intervention after another. It was a thorough ontological vision, the theory of special creation. It solved everything and nothing. Misconceived but beguiling, it became the new orthodoxy. It reigned long enough for Darwin and Wallace to confront it.

Linnaeus had meanwhile exerted still another form of influence. As a teacher in Uppsala, he had nurtured and energized students. Many of those students became scientific travelers, wandering out across the planet to fulfill their mentor's intellectual program by studying groups of living species in varied places. Janet Browne mentions some of these far-flung Linnaean protégés: Osbeck sailed to China, Solander was on board the *Endeavour* with Captain Cook and Joseph Banks, Gmelin went to Siberia, Koenig to Tranquebar (wherever that is), and Carl Peter Thunberg got into imperial Japan, after which he published his *Flora Japonica*, by definition a work of island biogeography. What sets this school of biological chroniclers apart from the earlier voices—such as Pigafetta, de Conti, and Columbus—is that Carl Peter Thunberg and his peers were traveling for the express purpose of collecting biogeographical observations, not just blundering upon them in the course of imperial exploration.

Flora Japonica is only one item in the bounteous bibliography that resulted. A friend of Linnaeus named J. F. Gronovius had already published *Flora Virginica*, presumably based on fieldwork in Virginia, and Linnaeus had launched his own career with *Flora Lapponica*, derived from his adventurous youthful trek across Lapland. Gmelin's botanical journeying across Asia yielded *Flora Sibirica* and later *Flora Orientalis*. Whether from the example set by Linnaeus (who had held the chair in botany at Uppsala) or for other reasons, most eighteenth-century biologists devoted themselves to the identification and mapping of plants, in preference to animals. Von Jacquin produced *Flora Austriacae*, Lightfoot produced *Flora Scotica*, Oder produced *Flora Danicae*, and Richard Weston, with no fetish for scientific Latin, bless his soul, published *English Flora* in 1775. That was just four years after a notable fellow named Johann Reinhold Forster had offered his *Flora Americae Septentrionalis* (the title means "North American Plants"), undeterred by the disadvantage of never having seen North America. Eighty years later, as Alfred Wallace sat in Sarawak waiting for the wet season to end and pondering the great mass of facts that had "never been properly utilized," these books were among what he had in mind.

Johann Reinhold Forster, of the North American flora, comes forward through time more vividly than the rest. Born in Prussia, he trained as a minister in order to placate his father, though his own real interest was natural history. For some years he held a pastorate near Danzig, but ultimately the pastorate didn't hold him. In 1765 he visited Russia, and the following year he emigrated to England, hoping to establish himself as a scholar. He was a scrambler, like Wallace himself, living on whatever odd employments he could find, whatever opportunities he could manufacture. He published a *Catalogue of British Insects* in 1770. For a while he taught languages and natural history at an institution wonderfully named the Dissenters' Academy, in Lancashire. He became known for translating and editing some of the works by Kalm, Osbeck, and other scientific travelers, as well as for his own writings, and in 1772 he was elected to the Royal Society. Later that year, by a stroke of luck, Forster was picked to replace Joseph Banks as naturalist on James Cook's second voyage.

The voyage would eventually last three years, taking Forster to some of the more spectacular biological provinces of the southern hemisphere, but it was a troubled journey for him in personal terms. He didn't get along with the sailors, and Captain Cook seems to have found him insufferable. Forster lacked Joseph Banks's easygoing, sybaritic charm. He was part Prussian and part taxonomist, after all. One historian has called him "a tiresome, rather mean-spirited pedant and a prude." Another has derided, wrongly, his "miscellaneous low-powered scientific writing." The prudishness must have stood out badly on a voyage that alternated grim weeks of exploration along the edge of the Antarctic ice with rest-and-recuperation layovers back up in Tahiti, where Cook's men needed only red parrot feathers to buy sex with Tahitian girls. Forster disliked what he witnessed in Tahiti, and he said so. His impolitic moralism had consequences. James Cook took umbrage at Forster's sour company and, when they arrived back in England, urged the British Admiralty to for-

Forster to publish. Cook published his own account of the voyage. Forster's son, who had gone along as an illustrator, slid around the ban on his father and also published. Forster himself finally beat the ban too, publishing *Observations Made During a Voyage Round the World, on Physical Geography, Natural History, and Ethic Philosophy.* Whatever he meant by "ethic philosophy," it certainly didn't encompass the Tahitian trade in red parrot feathers.

A round-the-world journey wasn't possible in those years without stops for provisions at some interesting islands. Cook had seen New Zealand and Tahiti, among others, and the same logistical imperatives had made the Azores, the Madeiras, the Canaries, and the Mascarenes familiar to European mariners (therefore also to European science) at an early stage. Although each of those island groups was itself in the middle of nowhere, each sat on a sailing route between somewhere and somewhere. The faunas of Tasmania, Kerguelen Island, and Hawaii also received attention. Nautical explorers and the naturalists who sailed with them had occasion to see more of the world's biological marvels than did landlubbers—even well-traveled landlubbers—in Europe and Asia, because so many of those biological marvels were unique to remote islands. But Forster was more percipient than most seagoing naturalists of his time. He noticed something that the others had missed, seemingly obvious but vastly significant. He wrote:

> Islands only produce a greater or less number of species, as their circumference is more or less extensive.

Big islands harbor greater diversity than little ones. Johann Reinhold Forster had discerned the relationship between species and area. It was just two logical steps, and two hundred years, from that insight to ecosystem decay.

7

DURING THOSE wet days in Sarawak at the start of 1855, Alfred Wallace wrote a scientific paper, "On the Law Which Has Regulated the Introduction of New Species." Little known now and little read in his own time, it merits recognition as one of the historical landmarks of evolutionary biology. The word "Introduction" in the title, sounding bland and noncommittal, was actually packed full of subversive meanings.

He sent the manuscript to London on a mail steamer, and by September it had been published in a good journal, *The Annals and Magazine of Natural History*. Wallace was proud of this paper, his first major attempt at conceptual biology. As months passed he waited expectantly, as a young writer or scientist will do, for reactions. From one friend he got a letter congratulating him lefthandedly on how "simple and obvious" the central idea seemed now that Wallace had stated it, and misquoting the paper's title. Otherwise, silence. Back in England, Charles Darwin read the paper in his own copy of the *Annals*, made some marginal scratches, took some notes. But Darwin was a clerkish reader by habit, making scratches and notes on virtually everything; despite his programmatic attentiveness, he seems to have missed the paper's point. Wallace had used the word "creation" as well as "introduction" in discussing the origin of new species, and Darwin evidently dismissed him as a believer in special creation. Several years later, Darwin would reread the paper with keener perception and a jealous sense of panic.

A few other scientists had taken notice of Wallace's paper, and two even said so to Darwin. One of these was Sir Charles Lyell, England's preeminent geologist. The other was Edward Blyth, an Englishman stationed in India with whom Darwin corresponded. But neither Lyell nor Blyth communicated appreciation to the author. To them, this fellow Wallace was an unknown, a commercial collector and trader, a purveyor of stuffed birds and mounted insects for the curio market. Collection was crucial to the advancement of biology, but if the collector sold specimens (as Wallace did, in order to live), he was liable to be looked on as déclassé. Furthermore, Wallace was still tramping his way from one island to the next all-hell-and-gone out in the Malay Archipelago. He had no social standing and no fixed address. Did anyone know how to reach him? Did anyone care? Having attended some meetings of the Entomological Society during his last sojourn in London, he was not quite a total outsider, but he stood more out than in. And though the discipline of biology had not yet in those years become a profession, regulated by academic credentials and protocols, it was at least a semi-exclusive club. The club's membership consisted largely of gentlemen with inherited wealth, such as Darwin, and of country clergy, who performed their clerical chores mainly on Sunday and were free to watch birds or collect beetles during the week. The club met in London, in Paris, in Edinburgh, in Cambridge, in Berlin, in a few other places, while Alfred Wallace on the far side of the world coped with malaria and rotting feet.

Wallace's sales agent, back in London, heard mutterings from some naturalists that young Mr. Wallace ought to quit theorizing and stick to gathering facts. Besides expressing their condescension toward him in particular, that criticism also reflected a common attitude that fact-gathering, not theory, was the proper business of *all* naturalists. Those few clubbable scientists who did find merit in Wallace's theorizing acknowledged it quietly, if at all. Two months after the Sarawak paper appeared, Charles Lyell himself started a notebook on the subject of species transmutation, putting Wallace's name at the top of the first page. Lyell recognized what Darwin still didn't: that Alfred Wallace, whoever he was, stood on the threshold of something big.

The punchline of Wallace's paper was:

> Every species has come into existence coincident both in space and time with a pre-existing closely allied species.

Though he called it a law, it was really a description—but a provocative description, with a cargo of radical implications. He stated it near the start of his manuscript and repeated it near the end, each time in italics so no one could miss it. *Every species has come into existence coincident both in space and time with a pre-existing closely allied species.* Description or law, it challenged the theory of special creation and bruited the idea of evolution in a tone of thunderous innuendo.

8

THE TENRECS, for example, are closely allied species, coincident both in space and time.

The tenrecs are a family of extraordinary mammals—about thirty living species, spanning roughly the same size range as mice and rats but showing their own remarkable spectrum of physiological adaptations. Although a related subfamily of mammals (known as the otter shrews) occurs in western and central Africa, all other tenrecs are unique to the island of Madagascar. Wallace in his years of travel never reached Madagascar. Luckier, less intrepid, I do. At the Parc

Botanique et Zoologique de Tsimbazaza, in a suburb of Antananarivo, I find a young Englishman who is happy to share his tenrecs.

The Englishman's name is P. J. Stephenson. He is a doctoral student from the University of Aberdeen, transplanted to Madagascar for his research. He wears a white lab coat, which is no longer white, and a deceptively sleepy grin. He has just been building terraria so his hands are glopped with glue, P.J. explains. He rubs one hand through his hair. It's long, feral blond hair, suitable for a drummer in a band. P.J. blinks. Maybe he's dazed to be speaking English again suddenly; maybe I've interrupted a chain of tenrecoid thoughts. Maybe, glue or no, he was just catching a nap before I arrived. His lab area is a pair of stony gray chambers in a garage behind one of the Parc buildings, where not many visitors intrude. Tenrecs, he says, you're interested in tenrecs? Come.

I follow him to the back.

"Look here." P.J. lifts the lid off a terrarium. "This little guy is really freaky." We gaze down. The terrarium contains a substrate of wood shavings and some items of furniture. Otherwise it seems to be empty.

P.J. turns over a small piece of wood. No tenrec beneath that. He snatches up a cardboard tube and peeks down its bore, seeing only daylight. Then another tube, and another. Nothing. He checks the wood again, still nothing there, and the tubes again, his hand moving fast. "Hold on. He's hiding," says P.J. "Or else we've just had an escape. I hope not. Wait a minute, here he is." P.J. scoops up a handful of wood shavings. He cradles them toward his nose. He spreads his fingers. Wood shavings fall. "No. Wait. Here now." He scoops again. Finally, success and relief: In his palm is a tiny mammal.

Face like a carrot, dark little eyes, gray fur; it resembles a shrew. It isn't a shrew. It's a member of the species *Geogale aurita*, otherwise known as the large-eared tenrec. "He's a termite specialist," P.J. says fondly. "Hides in rotting wood. That's how I found him, actually—busting apart pieces of rotting wood."

P.J. intends to spend two years in Madagascar, busting apart more pieces of rotting wood, collecting more tenrecs, studying the peculiarities of their physiology. They embody some interesting questions. Why, for instance, do some tenrecs mature so quickly? One species reaches sexual maturity at the age of about forty days. Then again, certain other species mature rather slowly. And why do some of them produce such large litters? One species can carry as many as thirty-two fetuses, which is unusual among mammals. Then again, certain other species produce litters as small as one or two. Some of them have exceptionally low metabolic rates, and some don't. Some are capable of going into a state of torpor—turning their metabolism way down, saving energy—and some aren't. They're very diverse. What sort of mechanism controls the shift to torpor? And how can they have such a high reproductive rate, some of them, yet such a low metabolic rate? And what's the relationship between metabolic rate and body temperature? Between metabolic rate and diet? Why is this little termite eater so similar to a shrew in its anatomy and its ecology, yet so drastically different in how its body burns fuel? Why?

Having heard P.J. rattle off these questions, I'm ready to hear answers. I'll gladly surrender myself to the premise—for an hour or two, anyway—that tenrec physiology is the most intriguing of all branches of biological inquiry. What then, exactly, does it teach us? But P.J. doesn't have answers, not yet. What he has is a head full of curiosity, a lab full of animals, sticky hands, and two years to think. He sets the little termite eater back into its cage, where it instantly disappears.

P.J. is maintaining quite a number of different species, but even his menagerie is just a modest sample of tenrec diversity. That diversity is part of what makes the group notable—they aren't only peculiar, they're peculiar in a profusion of different ways. Experts on tenrec taxonomy note that a single genus, *Microgale*, encompasses at least sixteen species: *M. cowani*, *M. dobsoni*, *M. gracilis*, *M. principula*, *M. brevicaudata*, and so on. The experts sort all these microgales into four categories, based on anatomical and ecological factors. There are burrowing, short-tailed microgales without much talent for leaping; there are surface-foraging microgales, also short-tailed, also nonleaping, that have some marginal talent for climbing; there are long-tailed surface-foragers that are good climbers; and there are very long tailed microgales that merit description as "climbers and ricochettors among branches," which sounds fantastic even for Madagascar. There's a *Microgale longicaudata*, whose name signals its membership among the very long tailed. None of this will be on the quiz at the end of the book.

The other genera include tenrecs that resemble moles, tenrecs that resemble hedgehogs (or, to an American eye, miniature porcupines), and an elusive aquatic tenrec named *Limnogale mergulus*, which lives the life of a small river otter. P. J. Stephenson himself is one of very few scientists who have ever glimpsed *Limnogale mergulus* in the wild.

He and another bloke sat on a riverbank all of one night for that privilege, he tells me, being savaged by mosquitoes and holding their foolish damn flashlights.

P.J. shows me more tenrecs in more terraria. He shows me tenrecs in cardboard boxes, housed there temporarily while he cobbles together still more terraria. In another shed, he says, he's got larger tenrecs in wooden cages. And here's a tenrec in its own little submarine—that is, a sealed gas-monitor chamber suspended inside a tank of water—where P.J. can measure its oxygen use. Alongside the tank sit an electronic console and a needle-graph printer. Suddenly a thunderclap jars the sky above Antananarivo and the lights flicker in P.J.'s lab. The needle-graph printer emits a disconsolate click. It has turned itself off.

"Weather. Hold on." He resets the machine. "That could be a problem. We get a storm and everything's liable to shut down. Not good for the flow of data." The flow of data is lifeblood to a doctoral student. Breathing deeply, P.J. stirs a hand through his unruly yellow hair.

Tomorrow he will go off to collect more tenrecs from the wild. Having mentioned that, he remembers: "I've got to send a fellow out to get me some food." He moves for the door.

What kind of food, I wonder aloud, thinking I might cadge an invitation to join his field trip.

"Crickets," says P.J.

The tenrec family belongs to the order Insectivora—nominally the insect eaters, though not every species confines its diet to true insects such as crickets and termites. The streaked tenrec *Hemicentetes nigriceps* eats earthworms. The aquatic *Limnogale mergulus* eats frogs and crustaceans.

The Insectivora are sometimes considered to be among the most primitive mammals surviving today, and the tenrecs to be the most primitive of the Insectivora. Although "primitive" is an invidious word that raises objections from some biologists, the intended point is that tenrecs preserve certain traits that have been dispensed with by other mammal groups in the course of evolution. A tenrec commonly has bad eyesight. Its body temperature fluctuates. It possesses a cloaca, as birds do, instead of two separate openings for the reproductive and the digestive tracts, like other mammals. The male tenrec has no scrotum, instead retaining its testes inside its abdomen. The female gives birth to helpless young with their eyes and ears closed.

The slow development of those young, in some species, prolongs their dependence on the mother and their vulnerability to enemies. Bad eyesight, unsteady temperature, cloacal plumbing, internal testes, blind and deaf newborns—each of these represents a disadvantage in the struggle against competitor species and predators. The question arises, then, how the tenrecs have survived at all.

The answer is simple. They have survived by getting to Madagascar, where competition and predation are not nearly so intense as on the mainland.

Every species of tenrec (except for those anomalous African otter-shrew forms) is endemic to Madagascar—meaning, native to this island and nowhere else. Their ancestors probably arrived sixty or seventy million years ago, near the end of the age of dinosaurs, at a time when mammalian evolution was still in its earliest stages. As the island became isolated from Africa (by geological splitting that widened and deepened what we now call the Mozambique Channel), only a few other mammal lineages got aboard: lemurs, rodents, viverrids, and the ancestors of that pygmy hippopotamus you've already heard about. An African aardvark reached Madagascar within the last few million years, somehow, but it didn't last. And an occasional small flock of wayward bats has come in on the winds. Compared with what exists on mainland Africa, Madagascar's list is dramatically short. The mammalian fauna is meager. Among the African mammal groups *not* present on the island (at least until humans began arriving by boat, bringing livestock and pets, causing extinctions, and otherwise muddling the biogeographical record) were these: the cat family, the dog family, elephants, zebras, rhinos, buffalo, antelopes, camels, and rabbits. Also, there was no Madagascan giraffe. There was no bear. There were no monkeys or apes, no otters or hyraxes, no porcupines. Within this gentle world of reduced competition and reduced predation, during the long eons of unbreached isolation, the tenrecs not only survived but prospered.

They multiplied. They spread all over the island. They took hold in the rainforests on the eastern slope of Madagascar, in the drier forests of the central plateau and the west, in the thorny desert of the south. They adapted to fill ecological niches that were otherwise empty. They diverged variously from their original type and were variously transmogrified into those thirty-some distinct species. They mitigated competition between one species and another by diverging still further. The scientific term for this process is *adaptive radiation.*

P.J. remembers a moment, earlier in his studies, when he picked up a volume of symposium papers and "there was this talk about adaptive radiation. I was reading it, and I just thought, 'Tenrecs. You're waiting to say tenrecs, that's what you're trying to say.' As an example. And it cited half a dozen things, but it didn't mention tenrecs. Whereas I think it's probably the most classic adaptive radiation I've ever seen in my life. Where you've got ancestral stock, it arrives on an island, finds all the niches available. Evolution takes its course. And it adapts to fill all the niches. I mean, you can't *get* something better." Blessed is the doctoral student who so loves his beasts. "You've got shrews, you've got hedgehogs, you've got moles. You've got things you can't possibly even describe. That have just evolved. It's absolutely unbelievable." Again he rubs at his hair, ever vigilant against the possibility that it has somehow gotten itself combed.

In the scientific literature, the tenrecs of Madagascar have been divided into two subfamilies, the Oryzorictinae and the Tenrecinae. Included among the Tenrecinae are all the larger, prickly-haired species that resemble hedgehogs. The Oryzorictinae include all the smaller species resembling moles and shrews. Somewhere between these two groups stands a missing link, a species called *Cryptogale australis*—in English, "the secretive southern tenrec." It has a skull like the Tenrecinae, body size and teeth like the Oryzorictinae. It's missing in the sense that it's apparently extinct, known only from remnant bones.

Now let's recall again what Wallace wrote in Sarawak: *Every species has come into existence coincident both in space and time with a pre-existing closely allied species.* No matter that he had never reached Madagascar or studied tenrecs. He was finding the same pattern among the Borneo butterflies, among the cockatoos and the macaws, as well as in published reports of plant and animal distribution gathered from all over the world. The unstated point behind Wallace's "law" was that closely allied species come into existence not only *near* one another but *from* one another. The theory of special creation could not account for such patterns persuasively. A theory of evolution could.

Wallace's Sarawak paper was an overture. It hinted toward evolution but stopped short of explaining how the process might work. At that point in time, he had no theory to offer. Charles Darwin did have a theory but wasn't yet ready to offer it.

"Let me show you something," says P. J. Stephenson. "Here. This fellow's *really* freaky."

He lifts another lid to reveal a tenrec as hefty as a muskrat. It's a garish thing with black-and-white stripes like a skunk, sharp quills like a porcupine, a nose like an anteater. This is *Hemicentetes nigriceps*, P.J. says, the famous earthworm specialist. It lives at the edge of the central plateau and in the rainforest of the eastern slope, and it does pretty well around rice paddies also. The quills are barbed and detachable so that they can come away in the muzzle of an enemy. Under attack, it erects those quills and makes bucking motions that threaten the attacker with a muzzle-load of painful regret. The black-and-white stripes, as with a skunk, offer a conspicuous form of visual warning: Mess with me and you'll wish you hadn't. Predators may be scarce on Madagascar, but they aren't nonexistent. The viverrids in particular, those mongoosey carnivores, are capable of forcing a tenrec to defend itself. Another nice little adaptive feature of *H. nigriceps* is that some of the quills have become modified into an organ of stridulation. They can be scraped together, like a bow on the strings of a fiddle, to produce a ratchety squeak by which a female signals her young. Having advanced so far along its own odd evolutionary path, *H. nigriceps* strains the meaning of the word "primitive."

P.J. reaches down dotingly and gives the tenrec a gentle rub.

So I reach down too. P.J.'s appreciation is contagious. The quills are benign when laid flat to the body. I pay my respects to *H. nigriceps* with a cordial little nudge.

"They're rather nasty biters, actually," P.J. says.

9

YOU MUST READ the paper by this fellow Wallace, Charles Lyell told his friend Darwin. Well, Darwin already *had* read it. He had even written his few notes on a piece of blue paper and pinned that into the back of the journal: "Wallace's paper: Laws of Geograph. Distrib. Nothing very new." Lyell disagreed.

Although his own work in geology was revolutionary and had been a strong influence on both Darwin and Wallace, Charles Lyell in 1855 held no revolutionary view of the origin of species. He still subscribed to the theory of special creation. Wallace's paper unsettled him. Lyell began his species notebook in November of that year under the heading "Wallace, Index Book 1," and the early entries look like an energized private rebuttal to the Sarawak paper. Focusing particularly on the subject of islands, Lyell made more than a hundred pages of notes about the distribution of animals and plants on the Azores, the Madeiras, the Canaries, Saint Helena, New Zealand, and other places, including the Galápagos. He asked himself how closely the species of land snails found in Britain might resemble the species in mainland Europe. And what about the land snails of the Madeiras, four hundred miles off the coast of Morocco? How many of those species were found also in Europe? How many were uniquely Madeiran? How many turned up on one of the two Madeiran islands but not on the other, just twenty-five miles away? Did the larger Madeiran island support more endemic species than the smaller island? What did it mean, what did it mean?

Around the same time, Lyell started discussing island patterns with Darwin. They shared facts. To a lesser degree they shared thoughts. But it was Alfred Wallace who had set Lyell going.

Wallace's paper had made the interesting point that if God indeed performed special creation, producing custom-designed species to occupy each zone of landscape, then God had shown a strong bias toward geologically *old* islands. That is, old islands had received far more endemic species than young islands. Old islands had even received more endemic species—in proportion to area, anyway—than had continents. Of course, some of the more obdurate of special creationists still didn't believe that any island was significantly older than any other, since by their biblical chronology the Earth itself had been created just six thousand years earlier. But Charles Lyell, whose whole geological vision was premised on the immensity of past time, certainly did distinguish young from old. The old-island pattern caught his interest.

Wallace had cited Saint Helena as one case of "a very ancient island having obtained an entirely peculiar, though limited, flora." He had added: "On the other hand, no example is known of an island which can be proved geologically to be of very recent origin (late in the Tertiary, for instance), and yet possesses generic or family groups, or even many species peculiar to itself." This pattern could be explained two ways. The first possible explanation was that in the very distant past, God so loved islands that He graced them inordinately with wondrous forms of plant and animal, whereas in more recent epochs, either God's fondness for islands has flagged or else His creativity has. If He's not a diminished God of inconstant powers, then, He's a capricious God of inconstant tastes. The second possible explanation was less blasphemous: Species evolve.

The necessary conditions for evolution, as proposed in the second explanation, are isolation and long stretches of time. Since old islands have offered prolonged isolation, they have produced a larger share of evolutionary novelties.

Sir Charles Lyell was an honest scientist as well as an orthodox Victorian creationist. For months, within the privacy of his notebook, he sorted data on the distribution of land snails and the correlations with geologic history. This species appeared here but not there. This island was old, that one young. Lyell could see dimly where it all pointed, but he wrote: "The origin of the organic world, like that of the planet, is beyond the reach of human ken. The changes of both may perhaps eventually be within our ken but ages of accumulation of facts & of speculation may be required." Behind the scientific calm, behind the reserved judgment, behind the litany of snails, he was desperate.

10

MADAGASCAR, home of the tenrecs and so many other bizarre species, is an old island. It's so old that even geologists can't agree how old, not even to the nearest thirty million years.

Once it was part of Gondwanaland, the huge southern continent that also included Africa, India, Australia, South America, and Antarctica before tectonic forces split them and they drifted apart. As the splitting progressed, Madagascar may have remained temporarily connected to the east coast of Africa—possibly snugged in beside Mozambique, or else farther north, adjacent to Kenya. Or maybe it separated early from the African mainland but remained connected to India. By that second view, India and Madagascar eventually came unlinked, India rumbled off like a runaway beer truck toward its collision with southern Asia, and Madagascar stayed parked where it was. Meanwhile the sea floor between Madagascar and Africa subsided. At first the sea was still shallow enough that a moderate lowering of its level (caused by global cooling and glaciation near the poles, sucking away water from the oceans) would have exposed a land bridge between Madagascar and the mainland. Episodes of connection and separation, reflecting climate and sea level, may have alternated throughout many millions of years. But as the sea bottom continued subsiding—sinking deeper and deeper—the channel finally became a permanent ocean gap. Severed irretrievably from the mainland, Madagascar was launched on its voyage of insularity.

Evidence for the various hypotheses comes from deep-sea drilling cores, bathymetry, sediment comparisons, paleomagnetic data. The bones of lemurs are also suggestive. Regardless of uncertainties about Gondwanaland, regardless of India, and regardless of glaciology, we can safely assume that by about sixty million years ago Madagascar was isolated. From then on, it stayed isolated.

Bali, by contrast, is a young island, with a young island's geological and biological characteristics.

The strait between Bali and Java is only a few hundred feet deep. The strait between Java and Sumatra is roughly the same. Two hundred feet of sea depth might sound considerable if you're a bad swimmer aboard an old wooden boat, but in the great movements of land, water, and time it's trifling and transient. The Strait of Malacca, between Sumatra and peninsular Malaysia, is also shallow. These three little straits are the only water gaps separating Bali from the Malaysian mainland. Lower the sea level by a few hundred feet and Bali becomes a province of Asia.

It has happened. Probably it has happened many times, once for each ice age since the landmasses of the Indonesian archipelago took their present shape. The most recent occurrence seems to have ended about twelve thousand years ago, with the last major freeze of the Pleistocene epoch. What we now call Bali is just one promontory in a zone of shallow ocean and volcanic rock known as the Sunda Shelf, which includes also Java, Sumatra, Borneo, the Java Sea, and the Gulf of Thailand. During that last episode of low sea level, it would have been the Sunda Peninsula, a vast region of tropical forests and swamps. *Panthera tigris*, the tiger, was among the animals that roamed the region.

Elephants roamed there too. Orangutans. Rhinos and tapirs and wild pigs and leopards, sun bears and moon rats and pangolins. Many of those animals presumably extended their distributional ranges into the southeasternmost reach of the peninsula—that is, down to and including Bali. After the sea rose again, some remained. We know that *P. tigris*, for one, persisted on Bali, because it was present there at the start of the twentieth century. The Balinese population of tigers had diverged just enough, as I've mentioned, to be considered a distinct subspecies, *Panthera tigris balica*.

If Bali were an older island, its tiger population might have diverged more, enough to constitute a fully distinct species. Let's imagine that species with its own imaginary name, *Panthera balica.* Given still more time, there might have been still more divergence—to the genus level, say, making Bali's beast as different from the original tiger as a tiger is different from a cheetah. Maybe the Balinese species would have changed color, or acquired a different pattern of striping, or developed a special aptitude for stalking wild banteng cattle on the island's volcanic slopes. And probably, owing to certain island-specific factors I'll describe later, the Balinese tiger would have been smaller, maybe as small as a leopard or a cougar. Let's call it *Micropanthera balica*, the Balinese dwarf tigeroid. A hypothetical beast, but quite plausible within the context of evolution on islands.

We can push this hypothetical scenario still farther. During a subsequent glaciation, when the sea level again fell, some individuals of *Micropanthera balica* might have roamed back across the muddy isthmus to Java. By this time, let's say, those Balinese tigeroids would have been incapable of interbreeding with Javanese tigers. They would have feared and avoided the bigger cats. But maybe they would have found ways to survive in Javanese forests, and then multiplied, coexisting discreetly with the native species. Now again we bring the sea level up, renewing the disjunction between Java and Bali. Imagine another million years of isolation and divergence, during which the Javanese population of *Micropanthera* becomes a new species, distinct from its ancestral population on Bali as well as from the more distant relatives with which it shares Java. Are you with me? Call that new species *Micropanthera javanica.*

Let's take stock. In place of a single species represented by two subspecies, there would now be three distinct species: *Panthera tigris*, *Micropanthera balica*, and *Micropanthera javanica*. Isolation plus time yields divergence. This is how insularity contributes to the origin of species.

Evolution happens slowly. Twelve thousand years is just a hiccup in the evolutionary scale of time. Extinction happens faster, and insularity contributes to that process too. Twelve thousand years ago Bali was the big toe of the Sunda Peninsula, an outpost of fertile land that may have supported small populations of pangolins, rhinoceroses, sun bears, orangutans, and elephants. None of those animals, nor the tiger, is native on Bali today. Why not?

The answer is complicated. But we're getting there.

II

OLD VERSUS young is just one crucial dichotomy that affects the biological richness of an island. Small versus large is another. Continental versus oceanic, in the sense that biogeographers use the terms, is a third. These three dichotomies give pattern to a world of spectacular confusion.

Madagascar is a large island, fourth largest on the planet, behind only Greenland, New Guinea, and Borneo. It measures 230,000 square miles, roughly the size of Montana and Wyoming together. Like Montana and Wyoming, Madagascar is psychologically distant from the rest of the world and burdened with a culture that venerates cows. Bali is a small island. It measures 2,100 square miles, just a hundredth the size of Madagascar or Montana-Wyoming. Bali is roughly the size of Yellowstone National Park, though in Bali you see fewer Winnebagos.

Large islands harbor more species than small islands, as a general rule. To be specific, Madagascar harbors more species than Bali—many more birds, many more plants, many more reptiles, many more insects, and (though Madagascar itself isn't rich in this category) significantly more mammals. Among primates, for instance, Madagascar has about thirty living species of lemur and a dozen others recently extinct. Bali has a leaf monkey and a long-tailed macaque.

Most of the Madagascan species are endemic; they evolved there and occur nowhere else. Eighty percent of the plant species are unique to the island. Among trees alone, more than ninety percent. More than ninety percent of Madagascar's reptiles, nearly all of the amphibians, all of the tenrecs, and (if several small offshore islands are counted as part of the Madagascan region) all of the lemurs are endemic. Even among birds, with their greater powers of dispersal, half are special to Madagascar.

Most of the Balinese species, on the other hand, aren't endemic to Bali. Many of those species occur also on Java, and some on Sumatra and mainland Asia. Bali does have *Leucopsar rothschildi*, informally known as the Bali starling, a gorgeous and nearly extinct bird with gleaming white plumage and a mask of turquoise. But aside from the starling and the extinct subspecies of tiger, there are few other creatures that Bali can claim exclusively.

This difference in endemism derives from several causes. The size of the two islands has played a role. So has the difference in elapsed time since each became insular. One other factor is the difference in distance of isolation. Madagascar is much more remote, sitting 250 miles off the African coast. Bali is just a long downwind spit from Java. The remoteness of Madagascar, along with its size and its ancientness, has made it more conducive to speciation and the maintenance of endemism.

But these two very different islands, Bali and Madagascar, do share one essential trait: They are both *continental* islands, as distinct from *oceanic* islands. That is, each was formerly connected to its neighboring continent.

Continental islands tend to be close to the mainland, whereas oceanic islands are more remote. A continental island generally lies on a continental shelf, surrounded by shallow water and therefore subject to reconnection with the mainland by a land bridge during episodes of lowered sea level. Continental islands, for that reason, are known also as land-bridge islands.

An oceanic island is one that never has been and never will be connected to a mainland. It comes into existence as a rising welt off the deep ocean floor, elevated into daylight by some geological process—most commonly, volcanic eruption. After a relatively short lifetime it gets eroded by waves and disappears again below the surface of the sea. The Galápagos are volcanic islands in midocean. The Hawaiian Islands are volcanic. Mauritius and Réunion are volcanic. Among the planet's newest volcanic islands is one called Surtsey, which came steaming up near the southeastern coast of Iceland in 1963. The land-building action of coral is sometimes also involved in erecting oceanic islands. Coralline limestone is laid down just beneath the water's surface and then elevated by volcanic or tectonic pressures. Guam, part limestone and part lava, is a case in point.

Whether built from elevated coral or from extruded lava, every oceanic island comes up from below, like a gasping whale. It starts its terrestrial existence, therefore, completely devoid of terrestrial forms of life. This is the most fundamental distinction between the oceanic and the continental categories. Every terrestrial animal on an oceanic island, and every plant, is descended from an animal or plant that arrived there by cross-water dispersal after the island was formed. A continental island like either Bali or Madagascar, in contrast, already contains a full community of terrestrial species at the moment of its isolation.

A continental island begins with everything, and everything to lose. An oceanic island begins with nothing, and everything to gain. Island biogeography, over the past century and a half, has been the scientific record of those gains and losses.

12

"FROGS ARE NOT found in volcanic islands," Charles Lyell told his notebook in April of 1856. What did it mean, what did it mean?

He added that "Darwin finds frogs' spawn to be very easily killed by salt water." Darwin for years had been conducting quiet little experiments on the question of whether various animals and plants could disperse across a wide stretch of sea. Would the seeds of a given terrestrial plant survive weeks of immersion in salt water? In some cases the answer was yes. Would the eggs of a frog survive that treatment? No. Would an adult frog survive? No. Was it a coincidence that the creator, whoever He was, however He worked, had neglected to put frogs on remote islands? Maybe not. Lyell's faith was weakening.

The subject of islands had begun to occupy Lyell's attention several years earlier, when he and Lady Lyell took a cruise to the Canaries and the Madeiras. These two island groups, standing not far apart in the eastern Atlantic, were regular stops on the oceanic trade route of those years, salubrious and civilized getaways where a Victorian gentleman and his wife could check into a decent hotel. Lyell's main purpose there was to study the volcanic geology. But he couldn't help noticing some remarkable species and some remarkable patterns among the fauna and flora. Many of the Madeiran beetles were endemic; a good number of those endemic species occurred on one Madeiran island but were absent from the other. The land snails of the Canaries caught his eye too. And at least one island of the Canary group, Grand Canary, was strangely empty of wild mammals. Also with reference to Grand Canary, he noted: "I never was in a country where the vegetation was so exclusively . . . unEuropean & so peculiar."

When he got back to England, Lyell sorted through his biological collections and notes, trying to make sense. Late in the autumn of 1855 he confided to his sister in a letter: "It seems to me that many species have been created, as it were expressly for each island since they were disconnected & isolated in the sea. But I can show that the origin of the islands, which are of volcanic formation, dates back to a time when"—and then, instead of dilating on the evidence, he cut himself short. Although in a letter to Darwin, say, he might follow that line out relentlessly, in a letter to his sister he wouldn't. "But I must not run on as it would take me too long to point out how all these bear on one & the same theory—of the mode of the first coming in of species."

A week later he picked up *The Annals and Magazine of Natural History* and read Alfred Wallace's paper, the one written in Sarawak, about "closely allied species." Immediately he started his new species notebook. He began filling it with data from the Canaries, from the Madeiras, from his readings and correspondence about island biogeography; packing it with insular snails, insular beetles, insular plants, and other closely allied species coincident in space and time. Lyell was just realizing what Wallace had lately grasped and what Darwin had known for two decades: that the answer to the riddle of evolution was best sought by a study of islands.

13

In the Sarawak paper, published that autumn in London for all to see and most to ignore, Wallace wrote: "Such phenomena as are exhibited by the Galapagos Islands, which contain little groups of plants and animals peculiar to themselves, but most nearly allied to those of South America, have not hitherto received any, even a conjectural explanation." It was a polite way of saying that the one man in England who had famously described the Galápagos flora and fauna, namely Charles Darwin, had apparently failed to appreciate their significance.

At the time, 1855, Darwin was still chiefly known for his *Journal of Researches* from the *Beagle* expedition, which despite the ungainliness of the full title had done rather well as a travel book. The Galápagos stopover had occupied only a very small fraction of the *Beagle*'s five-year voyage, but Darwin's literary treatment of the islands was vivid, forming one of the *Journal*'s most memorable sections. And besides bringing home a written account, he had also brought a great trove of Galápagos specimens—bird skins and pickled reptiles and insects and plants—which various specialists subsequently worked on for years. His *Journal* had been reissued in a revised and less expensive edition in 1845, with some additional description of the Galápagos fauna, based on what the specialists had done in the meantime with his specimens. "The natural history of these islands is eminently curious, and well deserves attention," he had written. "Most of the organic productions are aboriginal creations, found nowhere else; there is even a difference between the inhabitants of the different islands; yet all show a marked relationship with those of America, though separated from that continent by an open space of ocean, between 500 and 600 miles in width." Darwin had celebrated the archipelago as "a little world within itself," and had hinted cautiously that in this little world "we seem to be brought somewhat near to that great fact—that mystery of mysteries—the first appearance of new beings on this earth." As much as any biologist could lay claim to a piece of turf, Darwin had laid claim to the Galápagos. But his commentary on their implications had been limited and coy. So when he read Wallace's statement about the Galápagos phenomena having "not hitherto received any, even a conjectural explanation," he probably had to bite on a knuckle. It was too true.

Darwin still hadn't explained how that "mystery of mysteries" might be solved. After twenty years, his big evolution book was unfinished. Now this younger fellow, this collector and seller of Malayan beetles, this self-educated nobody who had not spent even one term in a Cambridge or Oxford college, was threatening impertinently to do the explaining himself.

"The Galapagos are a volcanic group of high antiquity," wrote Wallace, who hadn't laid eyes on them, "and have probably never been more closely connected with the continent than they are at present." Many literate Victorians had read Darwin's *Journal*, but few had pondered its Galápagos chapter as minutely as Wallace. "They must have been first peopled," he continued in the Sarawak paper, "like other newly-formed islands, by the action of winds and currents, and at a period sufficiently remote to have had the original species die out, and the modified prototypes only remain."

These "modified prototypes" were the endemic species that Darwin had reported—the tortoises, finches, mockingbirds, iguanas, and others. The finches in particular represented an instance of Wallace's "law," a whole cluster of closely allied species coincident both in space and in time. Wallace was using Darwin's facts to suggest an idea that

Darwin himself hadn't dared mention: that isolation plus time yields new species, by a natural process of evolution. Wallace couldn't say what made the process proceed. But the Sarawak paper announced plainly that he was working on it.

Around this time Wallace and Darwin became correspondents. Wallace wrote the first letter, hoping to strike up a long-distance conversation about the wild idea hinted at in his paper. Though he was a diffident young man, Wallace wasn't too shy to fish for a reaction from an eminent stranger. That first letter is lost. Darwin received it but didn't save it. All we know is that it was dated October 10, 1856, and mailed from the island of Celebes, where Wallace's island hopping had by now taken him.

Seven months later Darwin replied. "By your letter & even still more by your paper in Annals, a year or more ago, I can plainly see that we have thought much alike & to a certain extent have come to similar conclusions." In fact, Darwin said, it was unusual for two scientists to agree so closely on a point of theory.

By now Darwin had evidently reread the Sarawak paper more carefully. He no longer dismissed it as a rehash of creationist arguments. Wallace's percipient approach toward the mystery of mysteries had made him nervous. Sounding just a bit jealous, and tossing in a self-pitying exclamation point, Darwin told Wallace: "This summer will mark the 20th year (!) since I opened my first note-book, on the question how & in what way do species & varieties differ from each other.—I am now preparing my work for publication, but I find the subject so very large, that though I have written many chapters, I do not suppose I shall go to press for two years." It was a halfhearted way of claiming proprietorship of an idea without saying what that idea was. If you'll only be patient, Darwin implied, I'll presently solve this scientific puzzle for both of us. Two paragraphs later he wrote: "It is really *impossible* to explain my views in the compass of a letter on the causes & means of variation in a state of nature; but I have slowly adopted a distinct & tangible idea.—Whether true or false others must judge." Distinct and tangible, maybe it was; but that idea couldn't be judged, not by Wallace or by anyone else, until Darwin finally deigned to unveil it.

If he had no intention of sharing his thoughts, why did Darwin reply to Wallace's letter at all? Well, Charles Darwin was a polite man. He was a tireless correspondent, and having received a letter from a scientific colleague (even an obscure junior colleague), he would characteristically reply.

Beyond that, there was an ulterior reason. "I have never heard how long you intend staying in the Malay archipelago," Darwin wrote. "I wish I might profit by the publication of your Travels there before my work appears, for no doubt you will reap a large harvest of facts." And if Wallace's foreseeable travel book was still years from publication, maybe he would loan Darwin some facts in the meantime. Darwin was especially interested, he allowed, in the distribution of species on oceanic islands.

14

CHANCE HAD PLAYED a large role in bringing both Wallace and Darwin to the study of islands. Since chance is part of the whole story—an important component of both the process of evolution and the process of extinction, as you'll eventually see—let's take a peek at its contributions to these two scientific careers.

Charles Darwin hadn't left England aboard the *Beagle*, back in 1831, with biogeography on his mind or the Galápagos Islands in his sights. His seizure of that subject, his arrival in that place, reflected a fortuitous convergence of circumstance and whim on a feckless young man. He had signed on for the voyage largely to cure himself of boredom and indecision, to postpone the dreaded but seemingly inescapable prospect of becoming a country clergyman, and to escape from a parental glower—roughly the way some twenty-year-old American lad of a later era might have filled a backpack and flown Icelandic to Europe. After four years of surveying the South American coast, the *Beagle* headed westward around the world, and the Galápagos were a convenient port of call. Until then, Darwin had concerned himself as much with geology as with biology, and the Galápagos, being volcanic, may have interested him first as a good place to continue that study.

Alfred Wallace as a young man was more single-mindedly devoted to biology. He started traveling not to elude oppressive expectations or to "find himself," but to find something larger and more interesting—a solution to the mystery of origins. Despite that early clarity, he came to scientific fulfillment on a roundabout path. When he left England on his first international expedition, in 1848, he didn't set out for the Malay Archipelago. He didn't even set out in a different direction and arrive in the Malay Archipelago by accident. He went purposefully to the Amazon.

The saga of Wallace's Amazon journey is a high point in science history for anyone who relishes disaster, perseverance, high adventure, stiffness of lip, and black irony. It began in the circumstances of his adolescence. Forced to leave school at age fourteen by his family's financial troubles, young Alfred spent a short time in London, shadowing after a brother who was apprenticing as a joiner. Then for six years, throughout his middle and late teens, Alfred himself served an informal apprenticeship under another older brother, who had set himself up as a surveyor. Surveying was fine, it was agreeable, because it put him outside on the landscape (especially in Wales, which he loved) and allowed him to learn a bit of math and geology. At the time he wasn't ambitious for more. Then the surveying business slumped and his brother laid him off. Briefly he taught school—reading, writing, arithmetic, a little surveying and drawing—in the town of Leicester. Leicester was where his life veered.

In the town's public library he read Alexander von Humboldt's *Personal Narrative of Travels in South America*, which spoiled him forever against living a life bounded within Britain. He read Prescott's *History of the Conquests of Mexico and Peru* and Robertson's *History of America*. He read Malthus's essay on population, which was fated years later to go off like a detonator in his brain, as it did in Darwin's. Also at the Leicester library he made a friend, a fellow his own age, named Henry Walter Bates. Bates had a hobby that Alfred found intriguing: He collected beetles.

Beetle collecting was common in those days among boys and men with a fancy for nature. Beetles were pretty, highly diverse, and easy to preserve. To an ambitious or competitive naturalist, they were tokens for keeping score. Darwin himself had started with beetles. For Alfred Wallace, at this stage in his development, the collection of beetles was a wonderful new game. He had never imagined that there were so many different kinds—hundreds of beetle species within just the Leicester vicinity and three thousand within the British Isles. His new friend, Bates, owned a hefty reference book that cited such numbers. "I also learnt from him in what an infinite variety of places beetles may be found, while some may be collected all the year round, so I at once determined to begin collecting," Wallace would write in his autobiography, looking back across a sixty-year gap. He spent part of what he made as a schoolmaster, a few hard-earned shillings, on his own *Manual of British Coleoptera*. He and Bates became thick, a pair of demented young coleopterists scrabbling across the Leicester meadows. "This new pursuit gave a fresh interest to my Wednesday and Saturday afternoon walks into the country," he wrote. But it didn't remain just a passionate hobby. Other ideas were getting inside Alfred's head, by way of other books, and causing too much excitement.

One of those books was Charles Darwin's *Journal*. Another was William Swainson's *A Treatise on the Geography and Classification of Animals*. Swainson described patterns of species distribution and mentioned some of the theories that had been offered to explain them; like Charles Lyell, though, he took refuge in a pious agnosticism about underlying processes. "The primary causes which have led to different regions of the earth being peopled by different races of animals, and the laws by which their dispersion is regulated," wrote Swainson, "must be forever hid from human research." Alfred wasn't so sure.

Probably the strongest influence on him was a notorious book, *Vestiges of the Natural History of Creation*, that had been published anonymously in 1844 and later attributed to a man named Robert Chambers. *Vestiges* was a mixed piece of work that drew a mixed public response. It proposed the general idea of biological evolution, and it supported that idea with some provocative facts and arguments; but it offered no reasonable theory of how evolution might work, and it was tainted with a good bit of credulous nonsense. For instance, Chambers described experiments in which insects had supposedly been spontaneously generated by sending an electrical current through a solution of silicate of potash. He claimed that the larvae of a creature called *Oinopota cellaris* live nowhere but in wine and beer, suggesting that the species must have arisen sometime after humans invented fermentation. He asserted that habitual lying in parents can become an inherent (essentially genetic) predisposition toward lying in children, especially notable among the poor classes, and that the Chinese language is a primitive form of communication because it consists of ideographs. Besides, Chambers noted, if the Chinese people were more advanced, they wouldn't have so much trouble pronouncing the letter *r*.

Vestiges was a big success among uncritical readers, turning evolution into a blurred, titillating topic for parlor chatter, like a Victorian version of UFOs. But among rock-steady creationists, on the one hand, and among many careful scientists, on the other, *Vestiges* was dismissed as a piece of sensationalistic junk. Charles Darwin considered it worse than useless, because it gave the whole subject of evolution an aura of lurid implausibility and made his own task that much harder. To young Alfred Wallace, though, *Vestiges* was a catalyst. His thinking at that point was much less developed than Darwin's, and Chambers's reckless book helped him focus on a single crucial question. If species had arisen by natural transformations, one from another, as *Vestiges* argued, then what was the mechanism by which it happened?

By now Alfred Wallace had left the schoolmaster job in Leicester and resumed surveying. He wrote to Henry Bates:

> I have rather a more favourable opinion of the "Vestiges" than you appear to have. I do not consider it a hasty generalization, but rather as an ingenious hypothesis strongly supported by some striking facts and analogies, but which remains to be proved by more facts and the additional light which more research may throw upon the problem. It furnishes a subject for every observer of nature to attend to; every fact he observes will make either for or against it, and it thus serves both as an incitement to the collection of facts, and an object to which they can be applied when collected.

He spoke for himself. An incitement it was.

Big-eyed with youth and energy, Alfred and Henry began plotting an audacious enterprise. They would go out to the tropics as biological collectors. They would finance the trip by collecting not just for themselves but also for the commercial market. They would ship bird skins and mounted insects back to a dealer in London, for sale to museums and to the affluent private collectors who, in that era, bought and displayed natural-history specimens as others bought and displayed Pre-Raphaelite art. Selling off their own surplus specimens as curios for the idle toffs, Alfred and Henry would use their field studies and their personal collections to solve the mystery of mysteries. Yes, by God, they would discover the origin of species—or anyway, they'd try.

But where exactly should they go? To the Malay Archipelago? No, the attractions of that region don't seem to have grabbed Alfred's notice until several years later. To the Galápagos? No, that was too far away for a pair of unsponsored amateurs, and besides, it had already been done. The decision was settled by another book. Near the end of 1847, Alfred read *A Voyage up the Amazon*, just published, by an American named W. H. Edwards. Bates read it too and they both were enthralled. They moved quickly to patch together their arrangements, which included an understanding with a well-connected London agent, Samuel Stevens, who would receive and broker their specimens. Within just four months they sailed from Liverpool on board a ship bound for Pará, at the mouth of the Amazon.

They arrived in Brazil on May 26, 1848. Wallace would stay four years. Bates would stay longer. Neither of them foresaw the length of time or the depth of troubles ahead.

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Soon after reaching Brazil, Wallace and Bates found a house on the outskirts of Pará, hired a cook, started learning Portuguese, and made some preliminary excursions into the forest.

Wallace later recalled the "fever-heat of expectation" he felt. "On my first walk into the forest I looked about, expecting to see monkeys as plentiful as at the Zoological Gardens, with humming-birds and parrots in profusion." But after several days of seeing no monkeys and hardly any birds, he "began to think that these and other productions of the South American forests are much scarcer than they are represented to be by travellers." Anyone who has ever stepped into a rainforest, head full of images from glossy nature photography, has had roughly the same disappointment, which derives from confusing diversity with abundance. Wallace discovered at once that it wasn't easy to collect insects and birds in the tropics. The biological diversity was great, true enough, but the abundance of each species was not great, and most animals didn't offer themselves readily to the eye, let alone to the net or the gun. He was surprised by how empty the forest seemed. The insects weren't so numerous as he'd expected. He saw no rhinoceros beetles. He had to be satisfied with some butterflies (including a few big metallic-blue specimens of the genus *Morpho*, reassuringly gorgeous and Amazonian), some mantids, and some giant bird-catching spiders of the genus *Mygale*. Mosquitoes and ticks were finding him more successfully than he was finding collectable arthropods. The birds likewise seemed sparse and unspectacular. Within a month, though, when he had gotten the knack of looking more carefully and more knowledgeably, Wallace began to see what was actually there. Other problems didn't evaporate so quickly.

After two months of collecting in the vicinity of Pará, he and Bates sent a first batch of specimens back to Samuel Stevens. The shipment reached London safely, and Mr. Stevens, a reliable man who would continue serving Wallace for some years, began the task of marketing. That first shipment consisted largely of insects: about 450 species of beetles and almost as many of butterflies. By October, after a trip up the Rio Tocantins, which flows northward into the mainstem Amazon not far upstream from Pará, they had packed off another batch—again mostly insects, but now also including a few bird skins and shells. This batch was accompanied by a letter, in which Wallace described the logistics of the trip:

> We hired one of the heavy iron boats with two sails for the voyage, with a crew of four Indians and a black cook. We had the usual difficulties of travellers in this country in the desertion of our crew, which delayed us six or seven days in going up; the voyage took us three weeks to Guaribas and two weeks returning. We reached a point about twenty miles below Arroya, beyond which a large canoe cannot pass in the dry season, from the rapids, falls and whirlpools which here commence and obstruct the navigation of this magnificent river more or less to its source; here we were obliged to leave our vessel and continue in an open boat, in which we were exposed for two days, amply repaid however by the beauty of the scenery, the river (here a mile wide) being studded with rocky and sandy islets of all sizes, and richly clad with vegetation; the shores high and undulating, covered with a dense but picturesque forest; the waters dark and clear as crystal; and the excitement in shooting fearful rapids, &c. acted as a necessary stimulant under the heat of an equatorial sun, and thermometer 95° in the shade.

With the Amazon venture still in its early months, Wallace could afford to find compensation for physical hassles in the scenic grandeur and the thrill of running rapids. "Our collections were chiefly made lower down the river," he added. Samuel Stevens did his best to generate interest in those collections by forwarding Wallace's letter to *The Annals and Magazine of Natural History*, which obligingly published an excerpt.

That seems to have been Wallace's first appearance in the *Annals*, which would later carry his Sarawak paper to the attention of Lyell and Darwin. In the same issue, Samuel Stevens placed his own advertisement as "Natural History Agent," offering specimens from New Zealand, India, the Cape, and, most prominently, "*Two* beautiful Consignments of INSECTS of all orders in very fine Condition, collected in the province of Pará" by Messrs. Bates and Wallace.

After he and Bates parted ways (amicably, so that they could collect different species in different parts of the Amazon), Wallace left Pará and moved upriver, spending much of the next four years on a series of arduous canoe expeditions along various tributaries. First he ascended the mainstem as far as the city of Santarém, about five hundred miles inland, where the huge Rio Tapajós drains in from the south. "I have got thus far up the river, and take the opportunity of sending you a few lines," he wrote Stevens on September 12, 1849. "To come here, though such a short distance, took me a month." Now he was waiting to go on, "but the difficulties of getting men even for a few days are very great." Although the landscape around Santarém was dry and scrubby, he did find some lush patches of forest, "and in these, Lepidoptera are rather abundant; there are several lovely *Erycinidae* new to me, and many common insects, such as *Heliconia Melpomene* and *Agraulis Dido*, abundant, which we hardly ever saw at Pará: Coleoptera I am sorry to find as scarce as ever." The butterflies kept him cheerful despite the scarcity of beetles. And maybe, he guessed, on the thousand-foot hills farther upriver near Montalegre, the beetles might also be abundant.

He was even contemplating a push up into Bolivia, or possibly toward Bogotá or Quito. He asked Stevens to advise him: Were those places still untapped, so far as the trade in natural-history novelties was concerned? Throughout all the scientific travels of his early career, Wallace was a market-driven collector. He couldn't afford not to be. "Pray write whenever you can, and give me all the information you may be able to obtain, both as to what things are wanted in any class or order and as to localities." Darwin, a son of wealth, had never faced the necessity of such grubbing. But to Wallace that necessity would eventually prove a blessing because of the particular way it forced him to collect, gathering numerous individual specimens of the showiest and most marketable species.

At Santarém he appreciated the local felicities. "The Tapajoz here is clear water with a sandy beach, and the bathing is luxurious; we bathe here in the middle of the day, when dripping with perspiration, and you can have no idea of the excessive luxury of it." Oranges were cheap in the Santarém markets, only fourpence a bushel, and good. Pineapples were also available. Wallace had come a long way from Leicester, and he was accustoming himself to this new world. "The more I see of the country, *the more I want to*," he told Stevens. The diversity of butterflies seemed endless. He was living out his dream, and he was finding it satisfactory, though also a bit scary and lonely. Remember me to all friends, he wrote.

Five hundred miles above Santarém he reached the trading capital of Barra, a town of mud streets and little red-roofed houses at the junction with the Rio Negro. From there he ascended the Rio Negro to its source in Venezuela. Crossing over a divide in those swampy Venezuelan uplands, he visited an area that Alexander von Humboldt had explored fifty years earlier. Wallace also made two ascents of the Rio Uaupés, a tributary of the Negro that was blocked by a chain of cascades, falls, and steep rapids, which required portaging. He reached places where no other European had ever waved a butterfly net. He learned to subsist on *farinha* (a crunchy flour made from manioc), fish, and coffee. Sometimes there was nothing but *farinha* and salt. For preservative fluid he carried *cachaça*, a famed moonshine brandy distilled from sugar cane, but his sometime crewmen from the local villages tended to view the use of *cachaça* for pickling snake specimens as a perverse misappropriation, and on occasion they drank up what Wallace had carefully hoarded. When *cachaça* was unavailable, the crewmen could drink home-brewed *caxiri*, a sort of beer fermented from manioc. Wallace had less flexibility; he doesn't report ever preserving a specimen in beer.

He adjusted to sleeping in a hammock. He became a gourmet of turtle. In wholesome Victorian moderation, he shared the *cachaça* at village ceremonies. Once in a while he admired the shape of a young Indian girl as she bathed in a stream, and that's all his later account ever said about romantic longing and horniness. The chigoe fleas burrowed holes in his feet, which festered and made him limp. At one point he thought he might die of dysentery. Another time he went down with malarial fever. The cure for the first was to stop eating manioc gruel, go hungry, and wait it out; for the second, quinine. His younger brother Herbert, who came over from England to join him and learn the life of a biological collector, turned out to have less appetite than Alfred for the tropical wilds and a less hardy constitution. Herbert returned downriver to Pará, unhappy with jungle life and eager to escape back to England on the next boat. Before he could sail home, yellow fever killed him. Alfred was a thousand miles away when it happened. Much later in life, he would still carry some weight of guilt about Herbert. At the time, far up the Rio Negro and unaware of what was happening at Pará, he suffered his own bouts of homesickness.

He thought about the long summer evenings of England and the long winter nights with the family gathered around a blazing hearth. He ate roasted plantains and spoke almost nothing but Portuguese. The worst fits of loneliness came and went. Once every year or so he went downriver as far as Barra and hoped for a packet of mail. Herbert is very sick, he learned from a letter one year. Herbert died from his sickness last year, he learned later. He endured the sand flies and the biting gnats and the vampire bats that fluttered quietly into a hut to nip a sleeping person on the nose or the toe. He slept with his toes covered and once woke with a painless but bloody wound on the tip of his nose. He collected and sketched 160 species of fish.

One day in the forest he saw a black jaguar—that is, a melanistic aberration from the spotted pattern of ordinary jaguars—and gaped at it without raising his gun. "This encounter pleased me much," he remembered afterward. "I was too much surprised, and occupied too much with admiration, to feel fear. I had at length had a full view, in his native wilds, of the rarest variety of the most powerful and dangerous animal inhabiting the American continent." In that melanistic jaguar, he caught a vivid glimpse of how certain individuals within one species could vary from the norm. The word "variety" itself, as he and others used it, would later take on new meaning.

He went back up the Rio Uaupés, portaging past dozens of cataracts to a point where the river traders didn't go, in search of a bird he had heard rumors about: a stunning white version of the black umbrella-bird, *Cephalopterus ornatus*. Was the white umbrella-bird an undiscovered species, or was it just a variant individual, an anomaly, a sport, like the occasional black jaguar born to a pair of normally spotted parents? Or was it, perhaps, only legendary? He never did see a white umbrella-bird. In lieu of collecting a specimen, he collected testimony. Some of the local Uaupés people had no knowledge of any such creature; others told him that it was real but rare. Wallace came away frustrated and "inclined to think it is a mere white variety, such as occurs at times with our blackbirds and starlings at home, and as are sometimes found among the curassow-birds and agoutis." But the episode wasn't fruitless. It helped expand his awareness of variation within species.

We all recognize that *Homo sapiens* encompasses variation among individuals, but it is easy to forget that *Cephalopterus ornatus*, *Panthera onca* (the jaguar), and other species routinely encompass variation too. It was easier still to forget in Wallace's day, when the typological view—the assumption that a species consists of one ideal model, represented by exact copies—predominated. The typological view is neat but fallacious. Every species comprises a spectrum of actualities. Just as some humans are taller than others, some ravens are blacker than others. Some giraffes' necks are not quite so long as the giraffic average. Some blue-footed boobies find themselves cursed with feet that aren't quite so resplendently blue as the feet of their relatives, neighbors, and sexual rivals. These small increments of intraspecific variation, these minor individual differences, became immensely important to Alfred Wallace as he continued to think about evolution.

Wallace had reason to notice such variation more clearly than most other naturalists. As a commercial collector, he collected redundantly—taking not just one specimen each of this parrot and that butterfly but sometimes a dozen or more individuals of a single species. Lovely dead creatures were his stock-in-trade, literally, and he grabbed what he could for the market. But after grabbing, he preserved, inspected, and packed his creatures with a keen eye, so he saw intraspecific variation laid out before him in a way that other field biologists (including even the best of the wealthy ones, like Darwin) generally didn't. It was a trail of clues that Wallace would follow to great profit.

There were continual problems with preserving and protecting all these specimens. During the wet season, Wallace found it nearly impossible to dry a bird skin or an insect. If a fleshy specimen was left on a floor, on a table, anywhere within reach, it would quickly draw ants. Tucked away into Wallace's drying box, it would grow mold. Exposed to the sun, it would attract egg-laying flies and then be gobbled by the maggots when they hatched. The only way he could preserve a skin, Wallace found, was to hang it above his fire every morning and evening, like smoking a ham. The smoked specimens were sealed into wooden crates.

Another problem was shipping. While he was working the lower Amazon it had been possible, if not easy, to send batches of specimens back to Stevens in England. Now it wasn't. While Wallace was upstream on the Rio Negro, his specimens from that phase of work accumulated at Barra. Those boxed collections didn't go downriver, they didn't precede him to England, because customs officials wouldn't allow it—not until Wallace himself filed declarations and paid duty. At the time Wallace was able to cover his expenses without additional revenue from Stevens, so the delay didn't seem to matter. Later it would prove to have mattered grievously.

Finally he'd had enough. Stay in the Amazon longer, he figured, and he would probably die. Stored down at Barra were six precious crates of his specimens. He also had four years' worth of journals and drawings and notes, equally precious. And now he was coming down from the upper Uaupés with an ungainly assortment of live animals, including monkeys, parrots, and other large and small birds. His concern was to get as many as possible of these animals, and himself, back to England in good health.

Descending the Uaupés with that cargo was a challenge. He had been delayed by the difficulty of finding an Indian crew, men who knew the river well enough to paddle those rapids yet were willing to be hired for a white man's foolish enterprise on a white man's foolish schedule. Almost everyone had something better to do: repair a house, attend a ceremonial dance, stay home with a young wife. Wallace was tormented by the sense, not uncommon among impatient adventurers in that age and later, that he just couldn't get good help. But he settled for the men who offered themselves, and together they did survive the river. "On April 1st we passed a host of falls, shooting most of them amidst fearful waves and roaring breakers," he wrote. During an earlier descent of the upper Uaupés he had felt "some little fear of the passage of the falls, which was not diminished by my pilot's being completely stupefied with his parting libations of caxirí," but his pilot in this case was evidently sober. Among other small mishaps, he reported that two of his captive birds were eaten by a captive monkey, and that "one of my most valuable and beautiful parrots (a single specimen) was lost in passing the falls." The losses still left him with thirty-four live animals, both furred and feathered, "which, in a small canoe, were no little trouble and annoyance." The menagerie now comprised five monkeys, two macaws, twenty parrots and parakeets of twelve different species, five small birds, a white-crested Brazilian pheasant, and a toucan. From Barra, with the customs officials placated, he continued downriver in a larger canoe. It was June of 1852. Not far out of Barra, his tame toucan went overboard and drowned. Wallace and the rest of his treasures reached Pará safely. He was back at the mouth of the Amazon, where he had started in 1848.

On July 12 he took a last look at the white houses and feathery palm trees of Pará, then boarded a brig called the *Helen*, bound for England. Commanded by a Captain John Turner, the *Helen* held a cargo of rubber, cocoa, broom fiber, and resinous balsam from the capivi tree. The balsam was packed in small kegs. As a precaution against shifting and breakage, some of the kegs were stowed in sand; others were stowed in rice chaff—a very bad idea, given the possibility of spontaneous combustion. Wallace knew nothing about the balsam-in-chaff situation when he stepped aboard. His crates of specimens, his journals and sketches, and his menagerie all went onto the *Helen*.

For three weeks they had light winds but otherwise good weather. Wallace suffered a fever. He thought at first that it might be the same disease that had killed Herbert, now finally claiming him too. He recovered but, still weak, spent his time reading and resting below deck.

By August 6 they had reached mid-Atlantic, somewhere about seven hundred miles east of Bermuda. Captain Turner walked into the cabin and told Wallace, "I'm afraid the ship's on fire; come and see what you think of it." Smoke was oozing from that part of the hold where the balsam casks sat in the rice chaff.

The crew chopped an opening in order to douse the area with water. This was another bad idea, since it gave the smoldering balsam a better draft of oxygen. Hours passed, with the crew throwing buckets of water and the situation still being misread. The ship's carpenter cut a hole in the cabin floor, no doubt further improving the draw, and the calm but incompetent Captain Turner grew pessimistic. Eventually came a moment when Turner went looking for his chronometer, sextant, compasses, charts. Wallace watched all this in some sort of numb paralysis. Turner ordered down the lifeboats. The cabin by now was full of smoke, intolerably hot, close to breaking into flame, but Wallace groped his way in and grabbed a small tin box that held a few of his shirts. Not many feet away, kegs of balsam were burbling like lava. Monkeys and parrots were screeching and flailing and dying.