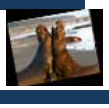

By **Kennedy Warne** Photographs by **Tim Laman**

At the intersection of land and sea, mangrove forests support a wealth of life, from starfish to people, and may be more important to the health of the planet than we ever realized.

Mangroves live life on the edge. With one foot on land and one in the sea, these botanical amphibians occupy a zone of desiccating heat, choking mud, and salt levels that would kill an ordinary plant within hours. Yet the forests mangroves form are among the most productive and biologically complex ecosystems on Earth. Birds roost in the canopy, shellfish attach themselves to the roots, and snakes and crocodiles come to hunt. Mangroves provide nursery grounds for fish; a food source for monkeys, deer, tree-climbing crabs, even kangaroos; and a nectar source for bats and honeybees.

As a group, mangroves can't be defined too closely. There are some 70 species from two dozen families—among them palm, hibiscus, holly, plumbago, acanthus, legumes, and myrtle. They range from prostrate shrubs to 200-foot-high (60 meters) timber trees. Though most prolific in Southeast Asia, where they are thought to have originated, mangroves circle the globe. Most live within 30 degrees of the Equator, but a few hardy types have adapted to temperate climates, and one lives as far from the tropical sun as New Zealand. Wherever they live, they share one thing in common: They're brilliant adapters. Each mangrove has an ultrafiltration system to keep much of the salt out and a complex root system that allows it to survive in the intertidal zone. Some have snorkel-like roots called pneumatophores that stick out of the mud to help them take in air; others use prop roots or buttresses to keep their trunks upright in the soft sediments at tide's edge.

These plants are also landbuilders par excellence. Some Aborigines in northern Australia believe one mangrove species resembles their primal ancestor, Giyapara, who walked across the mudflats and brought the tree into existence. The plants' interlocking roots stop riverborne sediments from coursing out to sea, and their trunks and branches serve as a palisade that diminishes the erosive power of waves.

Despite their strategic importance, mangroves are under threat worldwide. They are sacrificed for salt pans, aquaculture ponds, housing developments, roads, port facilities, hotels, golf courses, and farms. And they die from a thousand indirect cuts: oil spills, chemical pollution, sediment overload, and disruption of their sensitive water and salinity balance. Calls for mangrove conservation gained a brief but significant hearing following the 2004 Indian Ocean tsunami. Where mangrove forests were intact, they served as natural breakwaters, dissipating the energy of the waves, mitigating property damage, perhaps saving lives. Post-tsunami, the logic of allowing a country's mangrove "bioshields" to be bulldozed looked not just flawed but reprehensible.

Bangladesh has not lost sight of that logic, putting a great premium on the ability of mangroves to stabilize shores and trap sediments. A low-lying

country with a long, vulnerable coastline, Bangladesh is also land starved, with a crushing population density of 2,500 persons per square mile (2.6 square kilometers). By planting mangroves on delta sediments washed down from the Himalaya, it has gained over 300,000 acres (120,000 hectares) of new land on the Bay of Bengal. The plantings are relatively new, but there have been mangroves here for as long as the Ganges, Brahmaputra, and Meghna Rivers have been draining into the bay. The vast tidal woodland they form is known as the Sundarbans—literally "beautiful forest." Today, it's the largest surviving single tract of mangroves in the world.

In the forest's most luxuriant sections a dozen mangrove species, from feathery golpata palms to the towering sundri tree, form labyrinthine stands up to 60 feet (18 meters) tall. Beneath the sundri, the glutinous mud bristles with the tree's breathing roots. Twelve inches high (30 centimeters) and as thick as deer antlers, they grow so tightly together there's barely room to squeeze a foot between them. In drier areas, groves of semi-deciduous mangroves blaze red in the months before the monsoon. Spotted deer glide through the filtered shade, stopping abruptly when a troop of macaques shriek an alarm call. Woodpeckers hammer in the high branches, while on the forest floor dry leaves rustle with the scuttling of mud crabs. A butterfly called the Sundarban crow—charcoal with splashes of white—rests on a twig, opening and closing its wings like a prayer book.

Evening falls with the *junk junk junk* sound of nightjars, then all is quiet. Night belongs to the tiger. These forests provide one of the last remaining haunts for the Bengal tiger and its only saltwater habitat. According to local tradition, the tiger's name, *bagh*, must never be uttered. To speak it is to summon it. So people talk of *mamu*, uncle. Uncle tiger, lord of the Sundarbans.

Half a million Bangladeshis risk mamu's displeasure by coming into the Sundarbans each year to harvest its products. They come as fishermen, woodcutters, palm-frond cutters, cutters of thatching grass, harvesters of wild honey. The workers spend weeks at a time in the forest, living off its bounty as they earn a few taka for their labor. Seafood, fruits, medicines, tea, sugar, even the raw materials for beer and cigarettes are to be found in the Sundarbans larder.

Throughout the tropical world it's the same: Mangrove forests are the supermarkets, lumberyards, fuel depots, and pharmacies of the coastal poor. Yet these forests are being destroyed daily. One of the greatest threats to mangrove survival comes from shrimp farming. At first glance, shrimp might seem the perfect export for a poor country in a hot climate. Rich countries have an insatiable appetite for it (shrimp has overtaken tuna to become America's favorite seafood), and the developing world has the available land and right climate to farm it.

A prime location for shrimp ponds, though, happens to be the shore zone occupied by mangroves, an unhappy conflict of interests that has a predictable outcome: The irresistible force of commerce trumps the all-too-removable mangrove. To compound matters, shrimp farmers typically abandon their ponds after a few crop cycles (to avoid disease outbreaks and declining productivity) and move to new sites, destroying more mangroves as they go.

Mangrove-rich Brazil was slow to stake its claim in the bonanza. By the time shrimp fever hit Brazil's northeastern states, around the turn of the millennium, shrimp-farming pioneers such as Thailand, the Philippines, and Ecuador had been uprooting their mangroves for decades. Today, in the Brazilian port city of Fortaleza ponds the size of football fields crowd the landscape like rice fields. Paddle wheel aerators froth the water, and workers in kayaks fill feeding trays with fish meal. Even where mangroves have been spared, access to them is often blocked by the shrimp farms.

At the riverside settlement of Porto do Céu— "the gates of paradise"—an electrified fence shuts out villagers from their traditional harvesting grounds. But there is worse. The shrimp ponds have no lining, so salt water has percolated through the sandy soil and contaminated the aquifer beneath. The villagers have been forced to abandon wells that until recently drew sweet fresh water to the surface. The water is no longer sweet; it is *salgada*, saline, undrinkable.

At Curral Velho, a community to the west of Fortaleza, people have been finding a voice to oppose Big Shrimp. Demonstrations have been organized, land deals challenged, a public education center set up. Sister Mary Alice McCabe, an American nun who is helping the community in its struggle, says that one of the difficulties in raising awareness about *carcinicultura*—shrimp farming—is that most Brazilians aren't aware of the environmental damage it causes. "'Where does it happen, out at sea?' they ask. 'No, no, no,' we tell them, 'they're digging up your mangroves, they're destroying your coastline.' "

As serious as the threat from shrimp farming is to the world's remaining mangroves, there looms a potentially more disastrous problem: rising sea levels. Standing as they do at the land's frontiers, mangroves will be the first terrestrial forests to face the encroaching tides.

Loss of mangrove forests could prove catastrophic in ways only now becoming apparent. For more than 25 years Jin Eong Ong, a retired professor of marine and coastal studies in Penang, Malaysia, has been exploring a less obvious mangrove contribution: What role might these forests play in climate change? Ong and his colleagues have been studying the carbon budget of mangroves—the balance sheet that compares all the carbon inputs and outputs of the mangrove ecosystem—and they've found that these forests are highly effective carbon sinks. They absorb carbon dioxide, taking carbon out of circulation and reducing the amount of greenhouse gas.

By measuring photosynthesis, sap flow, and other processes in the leaves of the forest canopy, Ong and his team can tell how much carbon is assimilated into mangrove leaves, how much is stored in living trees, and how much eventually makes its way into nearby waterways. The measurements suggest that mangroves may have the highest net productivity of carbon of any

natural ecosystem (about a hundred pounds per acre [45 kilograms per 0.4 hectares] per day) and that as much as a third of this may be exported in the form of organic compounds to mudflats. Mangroves, it seems, are carbon factories, and their demolition robs the marine environment of a vital element.

Ong's team has also shown that a significant portion of the carbon ends up in forest sediments, remaining sequestered there for thousands of years. Conversion of a mangrove forest to a shrimp pond changes a carbon sink into a carbon source, liberating the accumulated carbon back into the atmosphere—but 50 times faster than it was sequestered.

If mangroves were to become recognized as carbon-storage assets, that could radically alter the way these forests are valued, says Ong. If carbon trading becomes a reality—that is, if forest-rich, carbon-absorbing countries are able to sell so-called emissions credits to more industrialized, carbon-emitting countries—it could, at the least, provide a stay of execution for mangroves.

But Ong notes that the financial incentives have to be great enough to make forest preservation economically viable. "Take Indonesia, which has the largest total area of mangroves of any country in the world. It can't afford to save them for nothing," he says. "But if the Indonesians could trade the carbon-storage potential of their mangroves as a commodity, that would create a great incentive to stop bulldozing them for shrimp ponds or chipping them for the production of rayon."

Countries that have squandered their mangroves could also replant them, gaining both a tradable asset and coastline protection. At Ong's research site small boys stuff their pockets with cigarillo-shaped mangrove seeds, or propagules. The boys will sell them for a few cents. Ong says that throughout Asia there's a run on propagules, as countries replant their mangrove defenses in the wake of the 2004 tsunami.

On the east coast of Africa, a very different kind of mangrove experimentation is going on. In Hirgigo, Eritrea, a few miles down the coast from the port of Massawa, two men sit on planks on the hot desert sand. With a knife for a chisel and a rock for a hammer, they knock the bottoms out of empty tomato sauce cans—discards from the Eritrean Navy. Nearby, on the shores of the Red Sea, a group of women push the hollow cans into the soft sediment, forming long alleys on the mudflats. Into each can, the women press mangrove propagules.

This is the planting of the Red Sea, the brainchild of cell biologist, cancer-drug pioneer, and humanitarian Gordon Sato. In the early 1980s, Sato's laboratory at the University of California at San Diego developed Erbitux, a breakthrough drug for colorectal cancer. These days 79-year-old Sato works to cure a different disease—poverty—attacking the problem not by culturing cells but by cultivating mangroves.

Eritrea was reeling from war and famine when Sato first traveled there in the mid-1980s. Since water is such a scarce resource in this arid country, Sato wondered if he could develop some form of salt water–based agriculture on Eritrea's long coastline, to help provide food for the hungry. Mangroves seemed a logical, if unconventional, choice. They occurred naturally, though patchily, along the Red Sea shore, they flourished in salt water, and camels were known to eat the leaves. If camels ate them, why not feed the foliage to sheep and goats? Grow enough mangroves, Sato reasoned, and you could provide food security for thousands.

So, like a maritime Johnny Appleseed, he began planting—and failed. All the saplings died. Undaunted, Sato looked closely at places on the Eritrean coast where mangroves were growing naturally, and he noticed they occurred only where fresh water was channeled during the brief rains that fall on this desert coast. Sato reasoned it was not fresh water the trees needed but minerals the water was bringing from inland—specifically nitrogen, phosphorus, and iron, elements in which seawater is deficient.

By conducting a few simple trials, Sato and a small team of helpers from the Eritrean Ministry of Fisheries assessed how much of the three elements mangrove seedlings needed and devised a low-tech method of supplying them. When the propagules are planted, a small piece of iron is buried alongside. So, too, is a small plastic bag with holes punched in it containing a fertilizer rich in nitrogen and phosphorus.

Now, six years on, 700,000 mangroves are growing on the formerly treeless shore of Hirgigo. Sato calls the project Manzanar, after the World War II internment camp in the California desert where, during his teens, he and his family were relocated, along with thousands of other Japanese Americans. It was the memory of older internees there coaxing crops from the arid soil that inspired him all these years later.

At Sato's Manzanar many of the mangrove trees are now well above head height, and the yellow-green coats of ripe propagules are beginning to split open, showing the plump green leaves within. The mangrove mud is sprouting pneumatophores, as if someone had sown a crop of pencils. Barnacles and oysters have started to settle on them, and crab and winkle trails crisscross the sediment. Plant a few trees, and you usher in an ecosystem. Build nature a house, and she makes it her home.

That home extends its influence out to sea. At the end of a long rock jetty, Ibrahim Moham-med Ibrahim peels off his shirt, winds it around his head, then steps into the water to check his net. He wades chest deep along it, feeling the mesh for fish and turning up a nice barracuda and a jack. He cleans them on the rocks, plunging them repeatedly, almost reverently, in the water.

Since planting began, Hirgigo's fishermen have started to catch small species such as mullet. Ibrahim put the equation simply: "No mangroves, no mullet." And the little fish that make the mangroves their home attract bigger, predatory fish—the kind that snag in Ibrahim's net and sell for good prices in the Massawa market.

In a pen on the outskirts of the village, a flock of sheep crunches mangrove propagules as if they were apples. Sato is using these animals to fine-tune the livestock-rearing side of the project. He has found that mangrove leaves and propagules, though highly nutritious, are not a complete stock food. Fish meal, which Sato is having made locally from fish processing, seems to provide the missing nutrients.

Outside the pen, donkeys nibble in the dust. The stubble of grass is so miserable and sparse it doesn't provide even the faintest green tinge to the parched earth. The nearby houses are nothing more than dusty improvisations of flattened iron, bits of cloth, and scraps of wood. Sato dreams of seeing a livestock pen beside every house. "In this country, a few goats can be the beginning of an empire," he says. "I want to give everyone this chance." Who would have imagined it: The mangrove, foundation of empires.

The town of Massawa recently celebrated the 15th anniversary of its liberation from Ethiopian forces—a David-and-Goliath struggle (as Eritreans tell it) in which the pride of the Ethiopian Navy was bested by a ragtag band of Eritreans in speedboats. A sign on a café shows a soldier in heroic pose and the slogan "Able to do what can't be done."

Out on the mudflats another old soldier is attempting the impossible: turning the tide of poverty by growing mangroves. The gardeners of Manzanar would be proud.

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