Of Rats and Men: A Synoptic Environmental History of the Island Pacific*

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THE Pacific and its islands have long held allure for romantics and scientists alike. The ocean's great size and galaxies of islands make it as appealing to botanists and biogeographers as to beachcombers. It also has seductive charms for those interested in environmental history, in the changing mutual influence of human communities and the earth, air, water, and life forms that sustain them. In the last three years, two books have appeared that emphasize the relevance of the environmental history of Easter Island to that of planet earth.[1] But Easter Island, like most Pacific islands—indeed, most islands anywhere—has had a particularly tumultuous environmental history. Evolution and history have conspired to give island peoples especially unstable environments.

The island world of the Pacific shows the transforming power of intrusive species, including *Homo sapiens,* and of their efforts to secure niches for themselves. In human terms that effort includes economic activity, which is particularly capable of

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[1] Bahn and Flenley 1992; Ponting 1991. Even *The Economist* has succumbed to the charms of Pacific environmental history, printing a story on intrusive species in Hawaii (*The Economist,* 10 April 1993:91–92).

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changing environments when organized on large scales; in the case of the Pacific, this has happened primarily through market integration. The power to transform is greatly amplified by the effects of remoteness from the earth's continental hothouses of biological and cultural evolution. Isolation over millions of years caused Pacific ecosystems to become labile, that is, prone to sudden change.

The pattern of environmental history of the Pacific islands exhibits eras of calm interrupted by spurts of torrential change, like the punctuated equilibrium of evolutionary biology, although in this case equilibria often look more punctured than punctuated. The pace of Pacific environmental history has been governed primarily by the spurts and lulls in human transport and communication throughout the ocean. The chief (but not sole) determinant of these spurts and lulls has been technology, and for this reason I divide the story, once humankind appears on the stage, into ages of the outrigger, the sailing ship, and the steamship. The direction of Pacific environmental history, since humans first intruded, has been toward ecological homogenization, within the limits defined by climate, soils, and the susceptibility of specific ecosystems to change.

The Prehuman Pacific

The Pacific Ocean accounts for one-third of the earth's surface and half of the world's ocean area. It has about 25,000 islands. I will focus on the oceanic islands, not those of the Pacific rim, and still less upon the continental rim itself. There is admittedly a certain arbitrariness in this, and distortion too, for the history of Micronesia, Melanesia, and Polynesia, especially in recent times, is linked to the rim. But delimitations are necessary, and these choices still leave about 7,500 islands to consider.[2]

The great majority of the Pacific islands were born barren of

[2] A second delimitation: my approach here to environmental history is more ecological than chemical or physical. This is less arbitrary, because most of the big changes (exceptions such as nuclear radiation and soil erosion are discussed) have been in biological communities, rather than in pollution or the shape of the earth. See Brodie and Morrison (1984) on the modest problem represented by pollution. I admit further that I have little to say here about pelagic fishing. It seems impossible to ascertain the impact of fishing until about 1970, when clear signs of overfishing appeared.

life, basaltic pimples on the sea's surface. New Zealand is the chief exception: it is among the "continental islands" of the western Pacific, together with Fiji, the Solomons, and others to the west. New Zealand already had life forms when it spun off from Gondwanaland some 80 million years ago and has remained until recently a sanctuary for species of the Cretaceous (Stevens, McGlone, and McCulloch 1988; Anderson and McGlone 1992). Life arrived on most other islands by accident or by drift. Some plants arrived by air transport; seeds carried in the digestive tracts of birds account for nearly 40% of Hawaii's early plants (Carlquist 1980, pp. 4–5). The first invaders were either creatures that could float well enough, in air or water, to cross stretches of ocean, or those whose seeds could survive a voyage in some avian gut. At times of lower sea level (glacial epochs), land bridges linked, or nearly linked, many islands in the far western Pacific, so some species colonized these islands without being notably good floaters or stowaways. In the eastern Pacific—say, Easter Island—only the best floaters and travelers arrived and survived. Consequently, the western islands, especially Melanesia, have far more species, far greater biodiversity, than do the eastern islands of Polynesia. Before European impact, Bougainville in the Solomons had several thousand plant species, while Easter Island had only thirty. Hawaii acquired new species at the modest rate of one every 100,000 years. Newer islands have fewer species, and the atolls that became hospitable to terrestrial life only in the last few thousand years (thanks to the fall in sea level in the late Holocene) are extremely impoverished. Vostok in the Kiribati islands had a prehuman flora of only three species (Nunn 1990, p. 128). Mammals found it hard to get anywhere in the island Pacific; only bats and rats successfully colonized east of New Guinea. Almost all species derive from Asia; the prehuman Pacific was an Asian lake, with only a tiny proportion of species from the Americas. As biogeographers put it, the Pacific had an attenuated Indo-Malayan biota. As a rule of thumb, the farther from Indonesia, the more impoverished the biota and, in consequence, the less stable and resilient in the face of disturbance. This attenuation is strong for land species, less strong for marine species, and nonexistent for oceanic birds, although fairly strong for land birds (Merrill 1954; Fosberg 1963, 1973; Oliver 1989; Salvat 1981; Holdaway 1989).

Pacific ecosystems evolved in relative (but differential) isolation from the continental crucibles of biological evolution. This meant opportunities for speciation (adaptive radiation): the development of new species occupying niches that elsewhere were already filled. Darwin's finches of the Galapagos Islands are the classic example. On islands that had no mammals, reptiles and birds took their place. Thus the Galapagos have giant tortoises, and New Zealand once had giant birds that functioned more or less like browsing or grazing mammals. Throughout most of the Pacific, the paucity of grazing animals meant that plants developed no defenses, such as spines, poisonous alkaloids, or bitterness (Fosberg 1992, p. 237). The remoter islands had very high proportions of endemism—that is, of species that existed only there. In the case of Hawaii, as many as 99% of the species were endemic (Kirch 1984, p. 23). All this led to a certain biological vulnerability among the (terrestrial) island species, should they ever be obliged to compete for niche space with the winners of the more intense continental competitions for survival. This vulnerability increased toward the east and toward the remoter corners of the Pacific, along a gradient defined chiefly by the degree of isolation.

A second source of vulnerability, perhaps more decisive, arose from the late arrival of humankind in the Pacific. Island animals evolved with no experience of the ways of humankind, or indeed of any large terrestrial predators. As a result, they had no "immunities" to predators or to the effects of human action. Pacific animals were often unwary and easy prey. At the extreme, again the Galapagos, Darwin found many birds almost tame, so naively trusting that they would allow him to get within arm's reach. Pacific plants had little experience of fire, because natural fires were very rare, except in a few places. Thus few plants were well adapted to fire, and most proved vulnerable to it. In contrast, continental species that had evolved in the presence of humankind, or in places where natural fire is much more common, could recover easily after burns, and some could flourish as a result of fire.

In short, Pacific ecosystems were very different from continental ones on account of their isolation. They were well adapted to their prehuman circumstances but very vulnerable to alien invasion and human impact (Holland and Olson 1989; Bates 1963; MacArthur and Wilson 1967; Dodson 1992). This was more true of the eastern Pacific than of the western. The opportunity for speciation and the absence of humankind meant that Pacific island ecosystems tended to diverge over time. Ecological homogenization began with humankind.

The Age of the Outrigger

The biogeographical peculiarities of the island Pacific offered a challenge of the unknown to the first human colonists. Human impact began in New Guinea perhaps 40,000 years ago, but elsewhere in Melanesia not until 11,000 to 12,000 years ago. In Micronesia and Polynesia humankind arrived only about 3,500 years ago (Thorne and Raymond 1989; Spate 1979–88, 3:1–30). New Zealand was the last significant Pacific land to acquire human population. Polynesians first landed there within the lifetime of some trees, about 1,000 years ago—although this conventional wisdom is now under renewed debate (Sutton 1987; Anderson 1991; Anderson and McGlone 1992; Spriggs and Anderson 1993). Nowhere in the world has a single ethnos radiated over such a large space and over such a broad array of environments as has the Polynesian.[3]

The Polynesians most conspicuously, but other islanders as well, changed their islands in two broad phases. Upon first arrival they exploited and depleted the resources that appeared easiest to use. This phase might last for centuries. In the second phase, straitened ecological circumstances obliged them to exploit new resources, to develop new food sources, and to use all their ingenuity-or else to emigrate, colonize, and begin anew in another virgin land.

Island settlers, whether Polynesian, Melanesian, or Micronesian, found no tropical paradise. During the long age of island settlement, conditions were growing worse because of climate warming and sea-level rise. Between 18,000 and 4,000 years ago, sea level rose about 20–30 meters in the southwest Pacific, the most dramatic change in the last 100,000 years. Islands shrank and reefs drowned, creating diminished and impoverished landscapes (Enright and Godsen 1992, pp. 173–79).

Many low islands were (and are) deficient in fresh water and sustained very little in the way of useful plants or animals. The higher islands had more fresh water and more varied biotas, and generally presented fewer constraints. But all islands were sub-

[3] The Polynesian triangle extends from New Zealand to Hawaii to Easter Island. Had these island outposts maintained regular contact, Polynesians would have enjoyed the benefits of ecological complementarity. New Zealand might have been the "ghost acreage" of Polynesia, as the Americas were for Europe. On this concept, see Jones (1981).

ject to environmental disasters of one sort or another: drought, cyclone, tsunami, volcanic eruption, and flood. Further, initial settlers sometimes found their environments unfamiliar on account of the high endemism (and, in the case of New Zealand, a cool climate). Reefs and lagoons (absent in the case of New Zealand) were more familiar, as their life forms showed a greater commonality throughout the tropical Pacific. Agriculture presented many difficulties because soils were often poor and scant on low islands, freshwater was often in short supply, and on all islands the seasonality of production was great and food storage problematic.

The islanders developed ingenious devices to cope with these new environments, such as taro pits that tapped the lens of underground freshwater that floats above the salt groundwater on many atolls. In the Marquesas, especially prone to drought and unreliable food supply, islanders raised ensilage technique to a high art (Kirch 1984, pp. 127–31). In Fiji, Tahiti, and especially Hawaii, islanders developed irrigation systems. Everywhere the settlers needed to exploit more familiar marine resources to compensate for environmental difficulties (Klee 1980). In the atolls this meant reef and lagoon life, often abundant, though occasionally vulnerable to environmental shock; in New Zealand it meant mollusks, seals, dolphins, and whales. Even so, hunger was routine, famine frequent, and life usually short (by modern island standards).[4]

Faced with these robust challenges, the island settlers sought to transform their new homes into familiar and manageable landscapes. They brought notions of suitable landscape with them and, to the best of their abilities, created "transported landscapes" (Anderson 1952) by importing what Crosby, in another context, has called a "portmanteau biota" (Crosby 1986). In so doing, they promoted ecological homogenization, based on a handful of cosmopolitan species. To take one example, the Polynesian portmanteau biota consisted chiefly of three or four animals (the rat, dog, chicken, and pig) and several edible plants (for example, coconut, taro, and breadfruit) now widespread throughout the Pacific. Indeed, almost all the food crops of the islands are

[4] There are four major series of skeletons for prehistoric Polynesia (two from Hawaii, one from Tonga, one from the Marquesas). They show that almost no one lived to age fifty, that death rates increased sharply for those over age thirty-five, and that infant and child mortality was highly variable (Kirch 1984, pp. 114–17).

imports.[5] To assist in the creation of these transported landscapes, Polynesians brought that great labor-saving device, fire, humankind's favorite tool for biota management.

The Polynesians significantly changed the fauna of the islands they settled. In Hawaii, about half the indigenous bird species (some forty of eighty) were eliminated between the Polynesian arrival (ca. A.D. 400) and that of Captain Cook (1778).[6] In New Zealand, about half the avifauna (some thirty species) disappeared, including the great moa, which weighed up to 200 kilograms and could measure almost 2 meters tall. The Marquesas, Cook Islands, and Society Islands had extinction rates similar to those in Hawaii and New Zealand. Widespread extinctions also followed human settlement in the Chatham Islands, Fiji, and elsewhere. Human beings did little of this directly, although they may have hunted the moa to extinction; rather, rats, dogs, and habitat destruction (all brought or brought on by human beings) sealed the fate of the indigenous island birds. They were probably doomed, having been schooled by natural selection into behavior (particularly reproductive behavior) that made them vulnerable to even the modest Polynesian portmanteau biota, which in New Zealand consisted of only six plants and two mammals (Cassels 1984; Anderson 1984; Anderson 1989, pp. 171–87; Trotter and McCulloch 1984; Holdaway 1989; King 1984; Steadman 1989; McGlone and Anderson 1992).

Early settlers relied heavily on marine creatures too and in some cases severely depleted their numbers. On Tikopia, in the Solomons, mollusks, fish, and turtles suffered sharper declines than birds after the arrival of humankind (about 900 B.C.). After 800 years these declines ended, signaling a transition from the first phase of environmental history to a second. Populations of these marine creatures remained rather stable from 100 B.C. to A.D. 1800, recovering slightly around 1500, but never approaching the

[5] Of food crops only the sweet potato, which came from South America, was not an Asian plant. Just how the sweet potato arrived on Pacific islands is the subject of great controversy. The chicken went everywhere with the Polynesians. The dog did not make it to Easter Island, and neither did the pig. Pigs were also absent from Polynesian New Zealand (Oliver 1989, pp. 39–46). Polynesians accidentally introduced a few more animals to Hawaii, such as geckos, skinks, and snails (Cuddihy and Stone 1990, p. 32).

[6] Olson and James 1982 and 1983; Olson and James 1984. Some think Polynesians arrived in Hawaii as early as the first century A.D. Spriggs and Anderson (1993) review the literature and prefer a later date, ca. 600–950.

densities they had achieved before the first people arrived. Mollusks in particular, and lagoon species in general, declined or vanished with human settlement in tropical Polynesia (Kirch 1983, p. 27; Kirch 1982, p. 8; Kirch 1984, p. 148). Elsewhere other species were sharply reduced in number but not eliminated entirely. Polynesian New Zealanders had hunted fur seals to the point of heavy depletion by 1500 and by the 1760s eradicated them on the North Island. Sea elephants vanished as well. Sea lions disappeared from the North Island too, but they were merely shy, not hunted (Smith 1989, p. 92; Caughley 1989).

Almost everywhere people went in the Pacific they hunted and gathered the local fauna, much of which lacked experience with humankind and had no appropriate defenses. Once the initial obstacles of colonization were surmounted—no easy matter—this made for an abundant supply of fish and game, while it lasted. The supply, in New Zealand, Hawaii, Tikopia, and probably elsewhere, lasted for generations but not indefinitely, resulting in local extinctions and scarcities. This state of affairs amounted to a slow crisis, requiring either adaptation to a second and more sophisticated phase of resource use—or else emigration. In this matter of faunal history and supply of wild fish and game, the Pacific islands differ only in details from other islands after invasion by humankind.

More significant perhaps than animal extinctions and depletions was the settlers' impact on vegetation. Fire allowed them to replace forest with plant communities more to their liking. Most of the larger tropical Pacific islands supported rainforest before human settlement, and New Zealand was perhaps 85–90% forest, mostly evergreen podocarp. Everywhere settlers torched land to clear the way for shifting cultivation and garden crops. Fire gets out of control easily, especially in time of drought, and so the areas burned bore little relation to the actual needs of agriculture. Anthropic fire vastly extended the fern and shrub savannas of the Pacific islands. In Fiji, fire cleared wide areas of forest between 3,000 and 1,500 years ago. In New Zealand, Polynesians burned off between one-third and one-half of the (postglacial) prehuman forest area before Cook arrived in 1769.[7] The elimination

[7] Brookfield and Overton 1988, pp. 92–93, on Fiji. Dodson (1992) has much on Fiji, largely derived from W. Southern, "Environmental History of Fiji" (Ph.D. dissertation, Australian National University, 1986). I have not seen this dissertation. On New Zealand: McGlone 1983, 1989; McGlone and Anderson 1992; Ash 1992; Fosberg

(or reduction) of browsing birds and the introduction of frequent lire amounted to powerful change in selective pressures on plants in New Zealand and throughout the Pacific—a major part of the ecological revolution created by human occupancy of the land.

In Hawaii little lowland forest vegetation remained when Cook first saw it; Tahiti, Fiji, and most other high islands had been similarly affected by human settlement. Crops replaced the forest trees, but so did weeds that throve on disturbed ground or were compatible with fire. In prehuman Hawaii, most areas burned only once every 700–1,000 years, so few native Hawaiian plants withstood fire well (an exception is pili grass). Hence human-caused fire opened the field for intruders. Polynesians introduced about thirty-two new plants to Hawaii (Nagata 1985; Cuddihy and Stone 1990, pp. 31–32). The irrigation works extended the domain of cultivation and new plants to dry leeward zones. Wherever they settled, the early Hawaiians, with their fire and their portmanteau biota, transformed stable (that is, slowly evolving) ecosystems, the fruit of millions of years of evolution, into a kaleidoscopic "cultural mosaic" of gardens, swidden fields, tree crops, weeds, and second-growth scrub.[8]

Burning often led to soil degradation. Slopes shorn of their protective cover and root mass quickly lose their soil in heavy rains. High rates of erosion, related to forest clearance, affected Fiji in the second to the fourth centuries A.D. Upland cultivation suffered, but swamps created in lowlands helped compensate when converted to taro pits.[9] Hawaii suffered from accelerated erosion, especially from the fourteenth to sixteenth centuries, an era of growing population and extension of arable land. In New

1992. Most of the forest destruction in New Zealand took place between the thirteenth and fifteenth centuries A.D. These forests had grown up between 15,000 and 9,000 years ago with the retreat of glaciers and climate warming.

[8] Kirch and Sahlins 1992, 2:45–47, 2:168–69. Kirch (1982, p. 5) says Polynesians used all land below 500 meters that was neither arid nor cliffs. Kirch (1984, p. 123) states that "the Polynesians actively manipulated, modified, and at times degraded their island habitats, producing ecological changes which were fraught with major consequences." Olson and James (1984, p. 777) say, "By removing [lowland forest] habitats from the Hawaiian Islands, the Polynesians wrought a greater change in the total biota of the archipelago than has been accomplished by all post-European inroads in the wet montane forests."

[9] Brookfield and Overton 1988, pp. 92–93. These swamps may also have improved conditions for anopheline mosquitoes, the vector for malaria. I know of no evidence concerning the vicissitudes of malaria in prehistoric Melanesia. But it is possible that its role varied with landscape changes effected by humankind. This was true on another frontier of the malarial domain, the Mediterranean world.

Zealand erosion accelerated to three or four times previous rates after human settlement, probably as a consequence of Polynesian burning and deforestation, although possibly—but doubtfully—as a result of climate change (Anderson and McGlone 1992, pp. 221–22). In many landscapes, sheetwash erosion exposed lateritic soils on which only ferns could flourish (Nunn 1990, p. 131). Thus the biological productivity, and probably the carrying capacity, of many of the larger islands eventually shrank under the impact of settlement and fire.[10] The high and steep islands felt these effects much more than the low islands, most of which have always been uninhabited. Even on inhabited ones, or those which islanders visited regularly, forest clearing on low islands provoked less erosion than on high islands.

Lagoons and reefs probably felt the human touch even less, although they made a large contribution to island sustenance. Fire did not affect them except indirectly through sedimentation increases, and human cultural constraints often operated to preserve them. Pacific islanders moderated their impact on many ecosystems through restraints and restrictions on resource use. In many societies taboos or other prohibitions limited the exploitation of reefs, lagoons, and the sea. These taboos often had social or political purposes, but among their effects was a reduction in pressures on local ecosystems. Decisions about when and where harvesting might take place were made by men who had encyclopedic knowledge of the local marine biota, "master fishery ecologists" (Klee 1980, p. 255).

Cultural constraints limited human impact on other elements of island ecosystems too, but to a much lesser degree. Terrestrial hunting, generally of turtles and birds, was often subject to magico-religious taboos, or to royal or chiefly privilege. Some societies also protected forests and trees (Klee 1980, pp. 253–63; Fosberg 1973; Akimichi 1986; Burrows 1989).

Island peoples with very limited resource bases had strong and stark incentives to practice conservation in one form or

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[10] Kirch 1982; Kirch 1984, p. 139; Fosberg 1992, p. 236. In French Polynesia, the forest service is planting pines on these fernlands. In some cases, such as Aneityum Island in Vanuatu, erosion carried little or no cost to humans, because it transported soil from high ground to allluvial flats where it could be put to better use (Spriggs 1985). Kirch (1983) found the same happy situation on Tikopia. McGlone (1989) suggests much the same for Polynesian New Zealand: that deforestation and erosion constituted improvement, given Maori land-use patterns and capabilities.

another. This was especially true on small islands, and perhaps it is no accident that Micronesians developed firm and fully conscious taboos against overuse of reefs and lagoons, and maintained turtle and bird sanctuaries. In Darwinian terms one might say that Pacific island environments selected for societies with such cultural characteristics, and much more rigorously than did continental environments. Societies that did not develop conservation practices sooner or later suffered for it, as did the Easter Islanders who appear to have brought themselves to the brink of ruin through ecological degradation of their island home.

All the ecological restraints developed in Pacific island societies were woven into religious and magical belief systems and political structures. When and where those systems and structures changed, eroded, or disappeared, so too did useful if imperfect constraints on environmental overexploitation. This may have happened on Easter Island before Europeans arrived; it certainly happened broadly in the Pacific after their arrival.

Some people fondly maintain that islanders lived in harmony with their environments. The weight of the evidence suggests that this is romantic exaggeration. Even the rigorous pressures and conservationist incentives of small island ecosystems could not consistently prevail against ordinary human tendencies. Pacific islanders, wherever they were numerous, strongly shaped their environments and frequently degraded them. Their conservationist taboos, which in any case affected the sea much more than the land, often existed to buttress the power of elite groups, and enforcement could lapse when convenient (Klee 1980, pp. 266–67). Their reverence for nature must not be confused with a conservation ethic. Under the pressure of population growth or the instructions of their rulers, islanders used the tools at hand to shape their environments and inevitably damaged parts of them in the process. They were human beings, not ecological angels (Kirch 1982; Kirch and Sahlins 1992, 1:53–56; King 1984, p. 54; and Diamond 1986, for a general critique of the myth of the ecologically noble savage).

On small islands, even ecological angels would have found it hard to keep their numbers in balance with resources. On most islands, people tried to regulate their numbers and to moderate population pressures. They were more successful in some times and places—such as the precontact Society Islands—than others (Fosberg 1992, p. 237; Klee 1980, pp. 263–66). The practice of seaborne colonization, a very perilous business even for the best of navigators, strongly suggests that population sometimes did put intolerable strains on limited island resources.

Recent research and compelling interpretations of the history of Easter Island support this notion (Bahn and Flenley 1992). If anyone had incentive to limit population growth and the depletion of resources, it was Easter Islanders. They first arrived around A.D. 400, but lost all contact with other people.[11] They were so isolated that they believed theirs was the only land left in the world. Conspicuous forest clearance (visible in pollen diagrams) began about A.D. 800. By 1400 they had cut down almost all their trees at one corner of the island, and by 1600 had probably cut down almost all trees throughout the island. The island is small enough that whoever cut the last palm surely knew it was the last one. The population of Easter Island mounted while resources lasted, slowly at first, but perhaps doubling every generation after about A.D. 1100. It reached a maximum of about 7,000 around 1600, then crashed late in the seventeenth century. In the eighteenth century, apparently after paroxysms of violence and decades of food shortage, the inhabitants numbered only 1,000–2,000. Other Pacific islanders, who felt no compulsion to cut logs to roll giant statuary from quarries to pedestals, were more cautious about resource depletion and more inclined, like the Tahitians, to resort to infanticide, abortion, and other methods of population control (Bahn and Flenley 1992, pp. 164–80).

Population pressure was the only powerful driving force behind environmental degradation before European impact. Pacific islanders did not engage in much long-distance trade. Inter-island trade was often a matter of gift exchange with political motives, and the distances (except around Yap in the Caroline Islands and in the archipelagos just east of New Guinea) and numbers of people involved were small. Hence there was none of the furious and large-scale environmental change motivated by trade that became so pronounced in later centuries. Pacific islanders developed no powerful new technologies that could radically change their environments; their tool kit consisted of stone implements, domestic animals, and fire. Warfare may have exacerbated burning, but it also may have checked population pressure, and according to Rappoport it may even have reduced burning (Oliver 1989, pp. 76–85; Rappoport 1963, p. 167). The strong probability is

[11] This is conventional wisdom. Spriggs and Anderson (1993) suggest A.D. 650–900.

that the extent of human impact on the environment was governed by population and by the inherent potential for disturbance of the islands—greater in the east than the west, and greater in the high islands than the low ones. Population history most probably followed the familiar logistic curve of populations exploiting new but finite ecosystems: slow but accelerating growth from first arrival, which eventually tapers off and approximates some equilibrium when carrying capacity is approached.

This pattern apparently describes the New Zealand experience, among others. There population seems to have grown slowly until about A.D. 1200, after which it burgeoned for three centuries (an era of forest clearance and bird extinction), before slowing down (an era of dietary change and increased violent conflict). Not surprisingly, population history reflects the two phases of environmental history, as the two were everywhere intertwined. Human numbers grew quickly in the first phase of comparatively easy resource exploitation, then slowed during the transition to the second phase. On Easter Island the transition came only at a high cost. In the cases of Easter Island, Tonga, and perhaps Hawaii, carrying capacity was reached before external shocks rocked the Pacific world. Elsewhere limits were approached but not exceeded, which had consequences for social hierarchy, political structures, and the likelihood of war, but without the ecological crash that marked Easter Island and that may have been afoot in Hawaii before Captain Cook stepped ashore.[12]

Throughout the centuries or millennia of pre-European settlement of the island Pacific, anthropic environmental change took place against a shifting background of climatic, tectonic, and evolutionary change. On the low islands, where coastline change mattered most, tectonic shifts and climate change played a larger role than on high islands. In some cases "natural" environmental change may have overshadowed anthropic change; on an island that stands only a few meters above the sea, subsidence or rise in sea level could make the difference between a habitable island and a wasteland, or no island at all. Even on high islands, such as New Zealand, climate change in the shape of stormier epochs may have led to the conspicuous accelerated erosion of Polynesian

[12] See the argument and data in Kirch 1984, p. 98; Bushnell 1993, pp. 5–6; Stannard 1989; and the symposium in *Pacific Studies* 13 (1990): 255–301. Estimates for Hawaiian population in 1778 vary from 100,000 to 1 million. For New Zealand, see McGlone 1989.

times. Disentangling "natural" and human causes in erosion and other sorts of environmental change is often a difficult matter that defies consensus among experts.[13]

Whatever the state of population pressure and its ecological implications, whatever the proportions of anthropic and "natural" causes in pre-European environmental change, when Cook entered the Pacific in 1769 he heralded a second surge of change in Pacific environments. In the age of Cook change was more sudden than anything that had gone before, and probably more thorough. Human impact in Melanesia had taken place over 40 millennia and in Micronesia and Polynesia over anywhere from eight to 35 centuries. Thus, environmental change, while sudden from the evolutionary viewpoint and in places very thorough, was rarely sudden on human timescales. It had proceeded around the Pacific, island by island, rather than enveloping the whole oceanic region at once. Thus environmental change at any given time was spatially concentrated in one or a few islands. From the pan-Pacific viewpoint, it was chronologically dispersed over 40,000 years. This pattern changed with Cook. Henceforth, environmental change was chronologically concentrated and geographically dispersed over the entire oceanic region.

The Age of Cook, Part I: Sailing Ships and Extraction, 1769–1880

The 1760s were to the Pacific what the 1490s were to Atlantic America. Europeans brought to the Pacific new tools, a new portmanteau biota, and new economic principles and possibilities, all of which eventually combined to disrupt biotic communities, not least human ones. The Indian historian K. M. Panikkar saw an age of Vasco da Gama in the Indian Ocean world beginning in 1498. In Pacific environmental history there is an age of Cook, beginning in 1769 and still in train. I divide it into two parts, the first lasting until about 1880, the second from 1880 to the present.

The two parts parallel the two phases visible in the environmental history of the pre-European Pacific. The first was characterized by quick exploitation of the most easily available resources; the second represents an adaptation to an impoverished

[13] On "natural" environmental change, see Nunn 1990, 1991. On New Zealand erosion, see McGlone 1989; McFadden 1989; Grant 1989; McSaveny and Whitehouse 1989. I put *natural* in quotation marks because of the conflict between the conventional (and useful) distinction between human and nonhuman agency, and the fact that human beings are part of nature.

environment that required more work and ingenuity to exploit. The integration of the Pacific into broader flows of goods and people meant that the first phase was much briefer in the age of Cook than in the age of the outrigger, only a century or more rather than several centuries. It also allowed the greater labor requirements of the second phase to be met through migration rather than exclusively by local populations.

Europeans had sailed the Pacific long before Cook's day, and so had Japanese, Chinese, Malay, and other mariners. From 1520 to 1760, Spanish, Dutch, French, and British sailors traded and fought around the Pacific rim. In the 1760s two circumnavigators, Byron and Bougainville, crossed the Pacific before Cook. Perhaps 450 European ships had crossed the Pacific by 1769, but their impact on the oceanic islands—like the impact of Columbus's predecessors on the Americas—came to little. The Spanish Manila galleons (1565–1815), probably the most durable shipping line in world history, account for the vast majority of the 450. They did pass through Micronesia, and after 1668 they usually paused in Guam, but what effect they may have had on oceanic islands is hard to detect outside of Guam. There Spanish Jesuits inaugurated a mission in 1668 and in converting the population to Christianity communicated to them influenza and smallpox. Disease, combined with egregious violence on the part of Spanish soldiers, soon reduced the population by about 90%. Elsewhere in the Pacific, Europeans had seen perhaps a hundred of the islands east of New Guinea, but had landed at only about thirty. No mariners dallied outside of Guam except for Mendaña and Quires in 1595. They stopped for nine weeks at a small island in the Solomons and in the Marquesas tried (and failed) to grow maize.[14] There was no great and sudden "Magellan exchange" across the Pacific, let alone one involving the islands. A few American species became established in the Philippines thanks to the Manila galleons. But in general the ecological isolation of Oceania (Guam aside) endured until Cook.[15]

[14] Prieto 1975, p. 93–97; Spate 1979–88; 1:128–29, 3:56–58, 3:208, and passim; Merrill 1954, p. 239. Guam had perhaps 50,000 people before the Jesuit mission, about 4,000 in 1710. By 1786 only 1,318 Chamorros remained, but 2,626 were counted in 1810. After that counts did not distinguish Chamorros from others in Guam (Spate 1979–88, 2:115–18).

[15] Guzman-Rivas (1960, pp. 92–133, 195–208) discusses the biological exchange between the Americas and the Philippines. Many American plants, including maize, potato, and cassava, were transported westward across the ocean, while very few went the other way. Not until Cook suggested the idea to the British

Cook made the difference because he always knew where he was. Earlier European mariners, once far from land, knew their latitude but could only guess how far east or west they might be. Armed with chronometers. Cook and his contemporaries could fix longitude as well as latitude. They could describe any location with precision and return to it directly if desired. With the chronometer, European exploration of the Pacific became more a matter of science and less a dangerous venture. In this lay great peril for the island populations.

The greatest disruption brought on by the arrival of European mariners was human depopulation. The evidence concerning Pacific island populations in the eighteenth and nineteenth centuries is far from ideal, and estimates have lately taken on political shades. Fortunately, there is now an authoritative guide to modern population history in the Pacific from European contact to 1945, the work of the French demographer Jean-Louis Rallu (1990). He uses all imaginable evidence and all the tricks of Gallic historical demography, including family reconstitution, and arrives at a grim picture. Depopulation ratios of 10:1 or 12:1 were not rare and 20:1 not unknown (the Marquesas). This means that the Pacific's encounter with the Eurasian disease pool was roughly as disastrous as that of the Americas (Stannard 1989; Crosby 1992). Declines of 2–3% a year were sustained over decades in many cases, due in part to high sterility (a consequence of sexually transmitted diseases), but more to heightened mortality. In Hawaii between 1834 and 1841, the birth rate attained only 19 per 1,000, while the death rate soared to 77 per 1,000 (Bushnell 1993, p. 295). As in the Americas, populations began to stabilize 120–150 years after

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Admiralty did Pacific island breadfruit make its famous voyage to the Caribbean in the care of Captain Bligh. Merrill (1954, p. 230 and passim) argues that most exotic Philippine weeds were introduced from Mexico and Brazil to the East Indies, via the Portuguese routes from Brazil to Goa, and that this happened in the sixteenth century. This might have meant an early introduction of American plants to Guam, but that is by no means clear. Traffic from the Philippines to Guam (as opposed to the reverse route) was very light. By 1914, 20–21% of Guam's flora were American species, mostly from Mexico and Brazil (Merrill 1954, p. 237). An exception to the rule of ecological stability before Cook's arrival is the uninhabited Juan Fernández Islands off the Chilean shore, in the eastern Pacific. Spanish mariners introduced alien species and effected a biotic revolution there between 1574 and 1750 (Wester 1991). In this respect these islands parallel the career of the Madeiras of the eastern Atlantic, uninhabited before the fifteenth century and profoundly altered by species (and fire) brought by Portuguese mariners. Daniel Defoe's prototype for Robinson Crusoe, one Alexander Selkirk, was marooned in the Juan Fernández Islands early in the eighteenth century.

initial contact (roughly 1880–1920 in the Pacific) and then to grow. Most islands have more people today than ever before, but not all; the Marquesas, for example, have only about one-quarter of the population of two centuries ago.[16]

New Zealand represents almost the other pole from the Marquesas, experiencing a depopulation of about 2.7:1. Estimates of Maori numbers in 1769 vary from a few thousand to 2 million. The most detailed and sophisticated work, that of Ian Pool, suggests something in the range of 100,000—just what Cook guessed. The Maori declined until the 1890s, reeling under the impact of new diseases and dispossession from their lands (Pool 1991).

Taking the Pacific as a whole, diseases surely did the most damage (Rallu 1990; Bushnell 1993). New infections ran amok among island populations with no inherited or conferred immunities. While epidemics raged, traditional taboos and hygienic practices were abandoned. Migration to new and growing ports undermined sanitation, promoting gastrointestinal infections on top of tuberculosis, smallpox, measles, and other highly contagious diseases.

Simultaneously the islands lost people through enslavement, "blackbirding" (as forced labor recruitment was known), and labor migration. Many island men joined whaling ships in the early nineteenth century and never came home again. In 1850 some 4,000 Polynesian Hawaiians were sailing the seven seas, a considerable proportion of the young male population of the time (Bushnell 1993, p. 211). Peruvian labor recruiters (read slavers) took 3,500 Polynesians, mostly Easter Islanders, to work Peru's coastal guano and sugar in 1862 and 1863; by 1866 almost all were dead. About 100,000 men left Melanesia to work the canefields of Queensland (Australia) and Fiji between 1860 and 1900; about one-third of them never returned (Campbell 1989, pp. 110–15; Howe 1984, pp. 328–40; McCall 1976). The depopulation occasioned by labor exodus in Melanesia reached about 0.5% each year at its height, accounting for about one-quarter or one-fifth of the general demographic decline (Rallu 1990, p. 336). Labor migration on this scale directly lowered population in many places and also promoted

[16] A historian who considers the depopulation of the Pacific Islands a myth, or at least a wild exaggeration is K. R. Howe (1984). This, I think, is a mistake, born of Howe's sympathetic effort to portray Pacific Islanders not as mere playthings of fate but as actors deciding their own destinies. Howe was perhaps reacting to the "Fatal Impact" school of Pacific historiography, well exemplified in Alan Moorehead's popular book of that title.

the circulation of diseases around the Pacific, contributing to higher death rates. Epidemics following upon the slave raids on Easter Island in 1862 and 1863 nearly exterminated the remaining population. Labor migration presumably increased traffic of a variety of other organisms as well, such as food crops, weeds, small animals, and insect pests, and contributed to the ecological homogenization of the islands.

The human demographic catastrophe indirectly affected other creatures on land and at sea. However variable from island to island, depopulation everywhere destabilized anthropic landscapes and opened niches for other species. At sea, it probably permitted reef and lagoon life a chance to recover where human pressures had depleted it. But on land the collapse had consequences more complex than a simple return to more "natural" conditions. If agricultural area diminished in proportion to population, then perhaps 90% of cultivated land fell out of use, creating huge gashes on almost every inhabited landscape. In 1840 cultivation on Tonga appeared "entirely neglected" to an American visitor (Wilkes 1970 [1845], 3:32). Where horticulture had relied on terraces or irrigation, as in Hawaii, labor shortage brought these to ruin, promoting soil erosion. Population decline and land abandonment opened the way for forest recovery—a massive fallowing. In Fiji, for example, the bush reclaimed land from villages abandoned around 1860 (Brookfield and Overton 1988, p. 91). Second-growth forest must have spread widely in the wake of depopulation, but on many islands newly arrived grazing animals checked this process of recolonization. Their introduction was part of a Noah's ark of alien species introductions to the Pacific in the age of Cook, some intentional, but many accidental. Here I will deal with only a very few of the animals, weeds, and crops that constituted the invading swarm. Their full effect was first to destabilize island ecosystems, then to further their homogenization, just as human settlement had done.

Grazing animals found good forage on the abandoned lands, whereas tall forest would not have suited them so well. The ecological vacuum created by drastic human depopulation helped goats, cattle, and pigs to colonize widely. Their numbers grew exponentially in the absence of predators and perhaps initially of diseases as well. In one documented instance, in the Galápagos, 3 goats released in 1959 became 20,000 goats by 1971 (Nunn 1990, p. 133). Whalers often stranded goats on Pacific islands so as to ensure a ready food supply in event of need, hoping for and often achieving caprine population explosions of similar proportions. Cattle were introduced to Hawaii in 1793, and by 1845 they had become a pest, eating and trampling crops. Teeth and hooves were enemies new to Pacific plants, many of which could not survive the attentions of cattle and goats and became extinct or much reduced in extent.[17] This spelled opportunity for alien weeds able to coexist with grazing animals. Hawaii acquired at least 111 new plant species between Cook's arrival and 1838, and it has almost 5,000 alien species today. Some, like Brazil's guava and Central American clidemia, are pernicious weeds that thrive on the new conditions humankind and grazing animals have created. Hawaii now has a pantropical biota, with plants from India, China, Australia, and the Americas, as well as some temperate invaders, such as gorse and broom (Nagata 1985; Cuddihy and Stone 1990, pp. 73–91).

Other alien species triggered far-reaching effects. Hawaii acquired mosquitoes for the first time in 1826 and the *Aedes aegypti* in the 1890s, providing suitable vectors for the transmission of new tropical diseases.[18] New rodents, particularly the brown rat and the Norway rat, upset every island's ecology. Imported in their millions and breeding prodigiously, they flourished to the detriment of birds, the Polynesian rat, crops, and some wild plants.[19] Rats' devotion to certain seeds even affected the species composition of Hawaiian forests (Cuddihy and Stone 1990, pp. 68–70). In many cases, rats may have been the single most consequential alien intruder, and they ought to be considered the shock

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[17] Kirch and Sahlins 1992, 2:169–70; Cuddihy and Stone 1990, pp. 40, 53–57; Spriggs 1991. The impact on native plants of introducting grazing and browsing mammals is still strong. Wild horses are destroying vegetation in the Marquesas, especially Nuk Hiva; deer and possums are chewing away at New Zealand forests.

[18] Laird 1984. Bushnell (1993, pp. 50–51) believes *A. aegypti* (or else *A. S. albopictus*) must have been present by 1852 on account of an epidemic diagnosed as dengue fever. Yellow fever, borne by the same mosquito, has never established itself in the Pacific, for reasons that continue to confound the medical profession. Hawaii still lacks anopheles mosquitoes, and hence malaria, which has long been deadly in Melanesia.

[19] Here is Herman Melville on rats aboard whaling ships: "They stood in their holes peering at you like old grandfathers in a doorway. Often they darted in upon us at meal times and nibbled our food . . . every chink and cranny swarmed with them; they did not live among you, but you among them" (quoted in King 1984, p. 68). Two healthy rats in three years can generate 20 million descendants; in ten years, if all went well—it never does—they could produce about 5×10^{17} (50 quadrillion) progeny (Druett 1983, p. 213).

troops of ecological imperialism in the Pacific. The bird life of New Zealand and Hawaii, already reduced in its variety since the arrival of Polynesians, suffered further depredations from the new rat species. The powerful effect of rats on unprepared bird life is especially clear in the case of Lord Howe Island, because it had no human population until the eighteenth century. Once, the island had fifteen or sixteen species of land birds, of which three became extinct between 1788 and 1870 under the impact of European sailors and settlers. There were no further extinctions until 1918, when *Rattus rattus* first arrived there and began to feast on birds' eggs. Five further extinctions followed in short order, and then a second era of stability ensued. Seabirds remained unaffected by the depredations of rats and men (Hindwood 1940).

In New Zealand, where the process of exotic invasion is very well documented, intrusive species revolutionized the biotic landscapes after European settlement began in 1840. Many of the exotics were intentionally introduced, some by "acclimatization societies" formed for that explicit purpose. Their impact in many respects has proven beneficial from the human point of view, for the food-producing capacity of New Zealand multiplied with the arrival of potatoes, grains, and livestock. But native species have suffered from the competition. Deer, rabbits, and opossums have had a notorious effect on native trees and grasses, many of which have been widely replaced by alien species more compatible with these creatures. New Zealanders especially liked game animals, notably deer, which their nonpatrician forebears had not been permitted to hunt in Britain (Druett 1983; Thomson 1922; Wodzicki 1950; Clark 1949; Crosby 1986).

Several species were intentionally introduced to control runaway populations of earlier introductions. Frequently the hired assassins ignored their missions and attacked more vulnerable native species. In New Zealand the introduction of cats, stoats, weasels, and ferrets, intended to control the rat population, led to further decreases in the number of native birds (King 1984). The mongoose was introduced to Fiji in 1873 to control rats in the canefields, but instead it extinguished seven native species of birds. (This same story of cane, rats, and mongoose was repeated in Jamaica in the late nineteenth century.) Biological pest control in fragile ecosystems is an unpredictable business (Mitchell 1989, pp. 208–209).

Elsewhere new crops also became established, generally to the benefit of human populations. Between 1821 and 1846, one valley on Oahu (Anahulu) acquired watermelon, corn, tobacco (perhaps not beneficial), cabbage, beans, oranges, limes, lemons, guava, cucumber, squash, red peppers, coffee, and rice. Many of these aliens ran wild and colonized on their own, replacing native species in the gashes left behind by human depopulation (Kirch and Sahlins 1992, pp. 2:169).

All told, the arrival of Europeans and their portmanteau biota was a disaster for lowland organisms and soils in the Pacific islands. Many native species suffered extinction, and many more found their domains reduced under the onslaught of the invaders. The highlands and their plants and animals felt far less impact (Fosberg 1992).

All this disturbance, extinction, and replacement involved unconscious ecological teamwork, as one invader cleared the path for the next. By killing islanders, microbes paved the way for livestock to graze widowed lands, which in turn helped new weeds gain a foothold. The process resembles the ecological imperialism outlined by Crosby, except that outside of New Zealand it did not involve or require considerable European settlement. Occasional visits and the extreme vulnerability of island biotas sufficed.

Pacific islands—and Pacific waters—were also vulnerable to ecological change that came directly through the economic activity of human intruders, European, Euro-American, and Japanese. In 1784 Britain reduced its tea duty from 119% to 12%, bringing tea from the palace to the cottage and bringing the world to Canton. Except for whaling, all the nineteenth-century pillaging of the Pacific—for sandalwood, sealskins, bêche-de-mer, in some cases even timber—was done for the Chinese market. European, American, and Australian merchantmen organized the exchange, in which Pacific island products were acquired for Western manufactured goods, then exchanged for Chinese silk and tea. From the 1790s to 1850 a world-girdling "triangular trade" linked the Pacific island economies and ecosystems to Europe, North America, and China, with the most powerful consequences for the smallest and least integrated. New Englanders played a prominent role in this trade (Spate 1979–88, 3:264–96; Dodge 1965).

While rats feasted on the native bird life of the Pacific, men energetically fell upon the marine life. They began with fur seals, which maintained breeding colonies on the cooler shores around the Pacific. Before the 1770s these seals had been hunted, but haphazardly and almost only in New Zealand; after 1770 they aroused the keen attention of sealers eager to sell the skins to China. Australians and Americans descended on southern New Zealand, especially between 1790 and 1810, and worked with "reckless efficiency" butchering seals as easily as "men kill hogs in a pen with mallets." Bleaker island outcrops of land in the sub-Antarctic—the Chathams, Macquarie, Auckland, Campbell—all attracted sealing parties, mostly Americans, between 1800 and 1830. Probably the best sealing grounds were the Juan Fernández Islands off Chile, pioneered by Americans in 1782. These islands sent 3 million sealskins to China in only seven years. By 1824 seals had become hard to find there and until recently were believed extinct. Around the Pacific between 1780 and 1830 several million fur sealskins were sold in Canton. Other varieties of seal suffered somewhat less depletion, but the sealers put themselves out of business by 1830. In two human generations the fur seals of the Pacific had almost disappeared (Bonner 1982, pp. 59–61; Dudden 1992, pp. 11–13; Wester 1991, p. 29; King 1984, pp. 55–56 [quotations]; Spate 1979–88,3:284–87).

Whalers showed no more restraint. If they learned anything from the short history of Pacific sealing, it was not conservation but rather urgency: they sought to get their share while the supply lasted. The destruction of Pacific whale populations is one chapter in a long human assault on whales. Evidence extends back only a millennium, but the pattern is clear: wherever new technology permitted or new whaling grounds were found, men quickly overexploited whale stocks (Hilborn 1991). All whales provided oil from blubber, which was used as lubricant or as fuel in lamps; baleen whales also provided whalebone, the plastic of the nineteenth century, used in corsets and umbrellas, among other things. Sperm whales provided the most valuable oil of all, and those that had ulcers also provided ambergris, worth several hundred dollars per ounce in China as a spice and aphrodisiac.

Pacific whaling opened up in the late 1780s. East India Company monopoly rights kept Britons and Australians from exploiting whales until 1801, giving French and American whalers a headstart. By 1820 the Americans, generally New Englanders, dominated the business, initially concentrating on the nutrient-rich Humboldt Current off Chile and Peru. In the Pacific as elsewhere, whalers first devoted themselves to right whales, found chiefly in temperate latitudes. These were easiest to catch because they swim slowly, prefer inshore waters, and float when killed. New Zealand right whales, first hunted heavily around 1830, had been depleted by 1850; they remain very rare in New

Zealand waters today. Sperm whales, found in the deep sea and usually within 30 degrees of the equator, held greater commercial value, and the Americans specialized in catching them. By the 1840s sperm whales attracted 500–700 ships and 15,000–20,000 men to the Pacific in any given year, of which 80–90% were American (Howe 1984, p. 93; Campbell 1989, pp. 64–65; Dodge 1965, p. 54; Wilkes 1970 [1845], 3:67). The other target of tropical whaling was the humpback, which crossed the tropics on annual migrations. Tropical whaling flourished between 1835 and 1860. Whalers typically spent three or four years in the Pacific, migrating with the seasons in search of the best hunting grounds. The northern Pacific was worked from Honolulu, which first developed as a whaling port (Kirch and Sahlins 1992, 1:101–37). The south Pacific whaling ports were Hobart in Tasmania and Russell in New Zealand. Japanese and Russians hunted whales in the northwest Pacific, but generally only in coastal waters until 1920 (Tonnessen and Johnsen 1982, pp. 129–30). The whalers' effect on whale populations is impossible to gauge accurately, but they reduced numbers sufficiently that whaling virtually ceased until technological innovations around the turn of the century made it possible to hunt rorquals (larger whales).[20] Whaling also had some effect on island vegetation, since reducing blubber to oil required fuelwood. Hawaii at one point produced half a million barrels of whale oil a year (Cuddihy and Stone 1990, p. 38).

The marine creatures of island lagoons also attracted commercial attention in the nineteenth century, as did island forests. Sea slugs or sea cucumbers (known to seafood connoisseurs as bêche-de-mer and as *Holothurioidea* to marine zoologists) enjoyed a strong market in China, where through the efforts of Yankee traders they found their way into countless soups. They too are alleged to have aphrodisiac qualities; at any rate they are almost 50% protein. Fiji and other islands produced sea slugs in quantity, especially between 1828 and 1850. It is hard to assess the impact of this trade on lagoon ecology, but the sole authority on historical sea slugs believes it depleted Fijian lagoons (Ward 1972). Truk, in the Carolines, produced half a million tons of sea slugs annually

[20] The innovations in question were the steam-powered catcher boat (which could chase the fastest whales), the mounted harpoon gun with explosive harpoons, and pumps that inflated dead rorquals (which otherwise sink), allowing whalers to process them at sea. The rise of petroleum as a fuel and lubricant also reduced the commercial viability of whaling after 1860. Baleen prices remained high, however.

around 1900. Whatever the impact on lagoons, it did not last. The trade withered away, and sea slugs are abundant today. But the trade also affected vegetation. Drying the sea slugs involved keeping fires burning day and night, and this consumed "enormous amounts of timber" in Fiji; Ward calculates that the Fijian trade required 1 million cubic feet of fuel and had profound implications for coastal vegetation (Campbell 1989, pp. 65–66: Ward 1972, pp. 117–18). Even palm groves were cut to supply the drying houses.

Sandalwood (Santalum), a genus of aromatic tree that can reach 20 meters in height, was common throughout the high islands of the tropical Pacific (as well as in South and Southeast Asia). Pacific islanders had used it for various purposes and had burned it to clear land. But the Chinese market, long fed from India, focused on Pacific sources of supply in the nineteenth century. Sandalwood went into ornamental chests, boxes, and furniture, and its fragrant oil was used in Chinese incense, perfumes, and medicines. Traders aware of its worth in Canton went first to Fiji (1804–16), then to the Marquesas (1815–20). Next they turned to Hawaii (1811–31), where an efficient royal monopoly expedited depletion, and lastly to Melanesia, especially the New Hebrides (1841–65). In Hawaii kings and chiefs put several thousand commoners to work cutting sandalwood. They burned dry forests to make the precious timber easy to find by its scent (only its heartwood was valuable, so charred trunks were fine). In the heyday of the Hawaiian trade, between 1 million and 2 million kilograms of heartwood went to China every year, eventually reducing the supply by about 90%. Only the poorest and remotest specimens remained. Hawaiian royalty, attached to the goods that sandalwood could buy, even tried to exploit stands in the New Hebrides by outfitting two ships for Vanuatu in 1829 (they were never heard from again). Everywhere sandalwood disappeared widely and quickly, and in most places it scarcely returned. The commercial opportunities of 150 years ago have made an enduring impact on the species composition of Pacific vegetation.[21]

Other trees became the target of timber merchants, especially in Hawaii. In the late nineteenth century road construction, the

[21] Shineberg 1967; Merlin and VanRavensway 1990; Kirch and Sahlins 1992, 1:57–97; Juvik and Juvik 1988, p. 381; Cuddihy and Stone 1990, pp. 39, 58. The trade was revived in Hawaii in 1988: the last stands of mature sandalwood were converted into a profit of either $40,000 or $1 million, depending on whom one believes.

presence of draft animals, and the availability of metal tools gave rise to a Hawaiian logging industry. It focused on koa, a native acacia that makes a fine cabinet or furniture wood. Some Hawaiian koa went for railroad ties in the United States (Cuddihy and Stone 1990, pp. 45–47).

New Zealand forests also felt the impact of nineteenth-century commerce. Northern New Zealand once had magnificent stands of kauri, a hardwood much admired by shipbuilders. These stands disappeared between 1790 and 1860, primarily to satisfy the timber requirements of Britain's Royal Navy. As the only Polynesian islands where Europeans settled on a large scale in the nineteenth century, New Zealand had its vegetation and soils dramatically affected by nineteenth-century economic forces. By 1900 stockmen and farmers had burned off perhaps half the forests in existence at the time of initial European settlement in 1840. In the 1890s alone, 36,000 square kilometers of forest disappeared, equal to 14% of New Zealand's land area. This transformation continued uninterrupted into the twentieth century (Reed 1951; Roche 1990).

Smaller trades in the nineteenth century had smaller ecological impacts. The pig and pork trade from Tahiti to Sydney (1793–1825) provoked a boom in Tahitian hogs, with consequences for Tahitian vegetation. The tortoiseshell trade (actually Hawkesbill turtle) led to a sharp depletion of the turtle population. Pearls, pearl shell, coral moss, and birds' nests were traded to China from the Society Islands and elsewhere. Mother-of-pearl oyster *(Pinctada margaritifera)*, especially sought for buttons, found a strong market after 1802. About 150,000 metric tons was extracted from the oyster beds of the Society Islands. Here and in the Cook Islands, the only sizable oyster banks in the Pacific, supplies shrank after 1820, and the trade shriveled accordingly. Today only aquaculture can revive the business, because natural stocks remain close to zero (Young 1967; Ward 1972; Salvat 1981, on pearl).

Throughout the nineteenth century, commerce that meant little to China, America, or Europe had powerful effects on the Pacific islands. This was true politically because disruption followed the development of new forms and sources of wealth and new technologies of destruction (guns). It was true economically, as many islanders for the first time found themselves linked to long-distance trade networks they generally knew little about and therefore could not often use to their advantage. It was also true ecologically for two major reasons, perhaps two sides of the same coin.

First is the ecological condition of the islands at the beginning of the age of Cook. Their long isolation from other ecosystems had made them vulnerable to rapid disruption. Pacific island birds were not equipped to compete for niche space with rats, cats, and mongooses. Pacific islanders' immune systems could not recognize tuberculosis and smallpox. Pacific plants had not adapted to an environment of fire. This accounts for the spectacular impact of exotic introductions, especially mammals and microorganisms.

Second is the cultural effect of isolation. The cultural configurations of island societies (some more than others) contributed to their vulnerability to ecological and other disruptions. Where firm hierarchy prevailed, as in Fiji and Hawaii, the extractive trades of the nineteenth century recommended themselves to chiefs and kings who saw profit in them. They organized the necessary labor, sold the desired products to Yankee traders, and participated in the ecological depletion of their islands. Some no doubt felt they needed to do so to acquire the guns needed for their survival and available only from the Europeans (including Americans). Others did so simply for the satisfaction of possessing exotic goods, useful or not. European and American traders, whalers, and sealers operated in the Pacific at great financial and personal risk; they wanted to make money fast, had no stake in preserving any resource, and behaved accordingly. Island politics often encouraged islanders to do the same. Pacific island politics and ecology interacted in unfortunate ways when confronted with new commercial opportunities, a story with many parallels around the world.

Beyond this, the constraints island societies had devised against resource depletion often disintegrated with the cultural transformations of the nineteenth century. Christianity lacks taboos on resource use, though it has strong taboos on abortion and infanticide. It is a continental ideology, not an island one. Mission education and its public successors neglected local ecological knowledge, so that in the course of the nineteenth and twentieth centuries, each successive generation understood less and less of the cycles of nature. The price mechanism and the doctrine of individual advancement contributed to the corrosion of traditional restraints on overexploitation. The forests, pasture, lagoons, and reefs of the Pacific suffered the fate of the seal rookeries and whaling grounds. Chaotic culture change turned these often well regulated common resources into poorly regulated or unregulated commons, producing the unhappy effects noted by observers from Aristotle to Garrett Hardin (Klee 1980, pp. 268–71; Fosberg 1973; Aristotle, *Politics* 2.3; Hardin 1968).

The rapid and widespread environmental change in the early age of Cook had two main driving forces, one essentially ecological, the other economic. The ecological force was the sudden uniting of Pacific ecosystems with those of the wider world, combined with inherent lability. The economic force was concentrated demand, as dispersed markets became connected suddenly to small zones of supply in the Pacific. The demand for whale oil, for sandalwood, even for sea slugs focused the consumer demand of millions in America, Europe, and China upon Fiji, Hawaii, Tahiti, and the good whaling grounds. Next to this sudden impact, the environmental change attributable to natural causes, such as climate change, seems paltry (but see Nunn 1990,1991).

Taking the very long view of evolutionary biology, the entire age of Cook, from 1769 forward, is a point of punctuation in the punctuated equilibrium of Pacific evolution. But from the less Olympian height of history, one can see an era of accelerated change from about 1790 to 1850, followed by a slackening in the rate of change from about 1850 to 1880.

The important exotic species (mammals and microorganisms) had arrived early in the century, and although their disruptive effects continued, their greatest impact came at an early stage when their populations mushroomed. The rate of human depopulation slowed and in most islands stopped before the end of the nineteenth century. The slackening in rates of change was mild, indistinct, and impossible to demonstrate satisfactorily, given the overlapping complexities of population biology among dozens of introduced and native species. Much clearer is the slackening derived from the decline of the China market.

Whale oil aside, the major products hunted and gathered for export from the Pacific after 1780 went to China. By 1850 Chinese tea could be had without hunting down the last seals or sandalwood. Opium provided the key that unlocked Chinese trade. As the British East India Company converted tracts of Bengal to opium production, China's commercial horizons shifted, and the Pacific trade lapsed into insignificance. At the same time, the great Taiping Rebellion (1850–64) convulsed China, reducing its appetite for Pacific specialty goods. And after decades of hunting or gathering, seals, sandalwood, and sea slugs grew scarce; the China trade had skimmed off the cream of readily exploitable resources. Until commercial production replaced commercial hunting and gathering, the ecological impact of the age of Cook would abate.[22]

The Age of Cook, Part II: Steamships and Plantations, 1880 to the Present

As plantation agriculture developed, so did regular networks of transportation and communication, organized within the context of colonial economies. In consequence, environmental change accelerated once again. The formal end of colonialism in the mid- and late twentieth century did not make much difference, in environmental matters at least. Environmental change in the Pacific since 1880 has been comparatively well documented. I will offer only the barest outlines of the story and a brief assessment of why things took the direction they did.

Toward the end of the nineteenth century European and American interest in the Pacific heightened, as it had in the 1760s, primarily for geopolitical reasons. Ambitious great powers needed a presence in the Pacific, preferably colonies and coaling stations. Keeping these supplied required regular shipping, which Europeans established for the first time. Steamships shortened traveling time, allowing certain organisms a better chance of surviving the trip from one place to another in the wide Pacific. The Panama Canal, completed in 1914, sharply lowered the costs of sailing between the Atlantic and Pacific and made for easier transport between the Pacific islands and the economic powers of the day. Extensive and regular transport by steamship linked the Pacific more firmly to the wider world, and this closer connection had ecological repercussions. The links grew tighter still during World War II, when the movement of men and goods around the Pacific briefly accelerated still further. Air travel during the war and civilian air travel after 1950 reduced formidable distances to mere trifles and permitted the introduction of a few new alien

[22] This chronology does not hold well for New Zealand, where environmental change peaked in the century after British settlement (1840–1940) and the China trade mattered little. But even here the crescendo came after 1880; see below.

organisms that did not ordinarily travel well. As in the period 1769–1850, advances in human transport caused considerable ecological change, almost all of it unintended and unforeseen.[23]

Most of the consequential exotic intrusions into the Pacific had taken place before the 1880s. Naturally, it took time for the invasive species to make their way everywhere they could, so their colonizations and consequences continued to ripple throughout the Pacific. In the Cook Islands cats, which had been introduced in the nineteenth century, exterminated indigenous birds throughout the twentieth century. New Zealand also continued to lose native birds during the twentieth century, mostly to predation by species introduced in the nineteenth century. Nibblers and browsers, such as rabbit and deer, also introduced in the nineteenth century, had degraded New Zealand forests and pastures by 1930–50, prompting concern about the pastoral economy and eventually provoking vigorous control measures. The most remote islands did not feel the impact of invasive species until the twentieth century.[24] At the same time countless new species joined the Pacific ark. Hawaii, which acquired a new species every 100,000 years in prehuman times, now acquires 20 invertebrates alone every year, mostly by airplane.[25] Here I will confine myself to the stories of the treesnake of Guam *(Boiga irregularis)* and the giant African snail *(Achatina fulica)*.

In the 1970s people began to notice that the native birds of Guam were fast disappearing. No one knew why. Eventually the culprit was identified as an introduced snake, *B. irregularis*. It climbs trees and devours chicks and fledglings in one gulp. Guam's avifauna had no experience of such a predator and lacked any defenses. Bats and lizards too have almost disappeared, while

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[23] An indication of the role of human transport in the dissemination of organisms is the speed at which influenza outbreaks traveled in the twentieth century. From early in the century until the late 1950s they spread at the rate of ship and rail traffic; after the 1960s, at a rate determined by air transport (Goldsmid 1984, p. 196).

[24] Clipperton Island, for example. It has always had a minimal biota, and one subject to sharp changes. Before the mid-nineteenth century it was uninhabited and covered with low forest. Then some calamity befell it, probably a tropical storm, after which its open landscape was dominated by seabirds and land crabs. But between 1897 and 1917 phosphateers visited Clipperton Island, and their pigs revolutionized the biota, feasting on the birds and crabs. Pigs and low vegetation spread, at the expense of all other species (Sachet 1963).

[25] According to Alan Holt, The Nature Conservancy, Honolulu. *The Economist*, 10 April 1993:91–92.

the snake's population densities in some places have reached 100 per hectare.[26] The snake also likes to climb on electrical wires and has caused hundreds of power outages on the island. Its history is a classic case of population explosion of an introduced predator. *B. irregularis* is native to Melanesia. It did not exist on Guam when U.S. forces arrived in 1944. But when salvaged war equipment from Melanesia was routed through the Admiralty Islands (Papua New Guinea) and Guam, it probably carried snakes, which disembarked at Guam. Up to 1960 their numbers remained modest. But by 1970 the snake had colonized most of the island, and was soon obliterating its food supply. *B. irregularis* is likely to spread to other islands, with much the same consequences.[27]

The giant African snail is native to the East African coast. It was deliberately introduced to Mauritius and Réunion early in the nineteenth century so French planters could enjoy escargots in their soup. But the snail is a superb stowaway, capable of attaching itself to materials of almost any sort. It is also hermaphroditic and reproduces prolifically. It soon spread throughout the Indian Ocean and was established in India by 1847. It entered the South Pacific via Indonesia and the Philippines by 1930 at the latest. Before World War II it was well established in Papua New Guinea, Micronesia, and Hawaii. It reached Guam during the war. It is now very widely distributed throughout the tropical Pacific, where it is a major crop pest, afflicting cocoa, rubber, banana, sweet potato, cassava, yams, breadfruit, and papaya, among others. It has acquired a beachhead in the continental United States, in Florida, where an eight-year-old boy brought some home from a trip to Hawaii in 1966.

The African snail has also brought indigenous snails to the brink of extinction. It has eliminated a genus of native snail *(Pastula)* from Moorea in the Society Islands; that genus now survives only in a reptile tank on the Channel island of Jersey. In driving out *Pastula* the African snail was helped by an American variety, *Euglandina rosea,* a predator deliberately introduced to check the African snail. But the American ignored the formidable African and feasted instead on the native snails, hastening their demise.

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[26] *The Economist* (10 April 1993:91–92) reports 30,000 per square kilometer, or 300 per hectare.

[27] Rodda et al. 1992; Savidge 1987. Several snakes have made it as far as the Honolulu airport, but none farther (*The Economist,* 10 April 1993:91–92). Military aircraft may also have brought stowaway snakes.

Twenty native Hawaiian snails have gone extinct this way. This is an example of attempted biological control of pests gone awry—a common story in twentieth-century Pacific history. About 100 inadvertent extinctions are attributable to intentionally introduced species that behaved in unexpected ways (Dharmaraju 1984, pp. 264–66; Mitchell 1989, pp. 204–206; Howarth 1992).

Numerous other crop pests infiltrated the Pacific after 1880, including rabbits, insects, and diseases. Most of them spread during the golden age of Pacific shipping from 1914 to 1965, when two to three vessels sailed weekly along the main shipping routes. Plant pests colonized islands via these routes, bringing harvest failures in their wake. Around 1900 feral rabbits overran Lisianski Island (North Hawaii), nibbling vegetation nearly to oblivion.[28]

One factor that helped crop pests spread throughout the Pacific was the creation of plantation agriculture, with its monocultural production patterns and emphasis on exports. This improved the prospects of both travel and sustenance for the rhinoceros beetle, the coconut beetle, and others that delight in coconut groves, sugarcane fields, and the like.

Plantation agriculture appeared in the middle of the nineteenth century and grew rapidly toward the end of it. Steamships, colonialism, and—in cases such as Fiji—imported indentured labor helped. Pacific plantations reflected, and continue to reflect, the demand for copra, sugar, pineapple, margarine, coffee, and other tropical products.

Plantations invariably bring large-scale environmental change. Broad expanses must be cleared for crops, and generally forest land is preferred, certainly for sugar. On Pacific islands, most suitable lowland forest had often already been cleared, so plantations made do with swidden fields where virgin forest no longer existed. The fuel requirements of sugar boiling contributed greatly to forest clearance in Fiji and Hawaii, as they had in Brazil and the Caribbean. In Hawaii sugar became a major crop in the 1890s, and by the 1970s occupied 100,000 hectares. Pineapple,

[28] The rabbits, incidentally, starved themselves into extinction this way, and vegetation recovered (Nunn 1990, p. 133). The sailing routes were France–Tahiti–New Caledonia; Australia–Solomons–Papua New Guinea; New Zealand–Tonga–Samoa–Fiji (Dale and Maddison 1984, pp. 244–50). Some human pests spread too, such as the malaria-bearing anopheles mosquito, which since 1945 has colonized broad areas of the malaria-free Pacific from bases in Southeast Asia and Melanesia (Laird 1984, pp. 303–309). As yet, malaria plasmodium has not become established in Polynesia or Micronesia (Marshall 1993, p. 485).

introduced early in the nineteenth century, covered up to 30,000 hectares at its peak in the 1950s. Bananas and coffee accounted for smaller areas. Land clearing for commercial crops has been the main cause of plant extinctions in twentieth-century Hawaii, where about 10% of the native flora is gone and another 50% is endangered (Cuddihy and Stone 1990, pp. 41–44, 104).

Smaller-scale plantation agriculture developed in the Society Islands after 1860, at first emphasizing cotton in response to shortages arising from the American Civil War. In the 1920s the Japanese converted Saipan, Tinian, and Rota (which they had acquired from Germany as a League of Nations mandate) into "one vast cane plantation." Most small islands, insofar as they developed plantation agriculture, produced only copra, which in the days of regular interisland shipping found ready markets (Purcell 1976, p. 202; Peattie 1984, pp. 192–94 [quotation]; Newbury 1972a).

Ranching, which can be considered plantation pastoralism, also contributed to vegetation change in the twentieth-century Pacific. Cattle suppress forest regrowth and favor the success of introduced grasses. Repeated burning has the same effect. Both ranching and plantation agriculture intensified the fire regime of much of Hawaii, promoting fire-resistant (mostly African) grasses.[29] In Hawaii commercial ranching dates from the middle of the nineteenth century but expanded quickly only in the twentieth century. By 1960 half the area of the archipelago was turned over to beef cattle; the proportion declined to a quarter by 1990. As in the famous "hamburger connection" of Central America since 1960, a large chunk of forest conversion in Hawaii is a result of the beef export trade. Sheep accounted for a small fraction of the conversion to pasture. Their numbers varied between 20,000 and 40,000 from 1870 to 1940 (Cuddihy and Stone 1990, pp. 59–63). Even remote Easter Island felt the ungentle touch of commercial ranching. Sheep first arrived in 1864, at a time when the human population verged on extinction. Commercial sheep ranching began in 1870, and cattle ranching followed. Sheep raising was the mainstay of (lie Easter Island economy for over a century, until

[29] The intense fire regime associated with plantation agriculture and ranching (or indeed any intense fire regime) has an effect upon ecosystems analogous to that of highly infectious disease. Upon its initial appearance it is highly destructive, but gradually, as it becomes endemic, it creates an ecosystem composed chiefly of species adapted to (or "immune" to) the effects of fire. Fiji, Hawaii, and much of the Pacific had to adjust both to new disease regimes and to new fire regimes between 1840 and 1950.

the 1980s, and cattle are still raised there. Ruminants, owned and controlled by Chileans, have in effect selected the modern vegetation of Easter Island.

Nowhere has ranching assumed a greater role in environmental change than in New Zealand, which developed into an economically successful pastoral plantation. In 1830 forests still covered 18 million hectares in New Zealand; in 1980, that figure had dropped to only 6 million. In 1840 New Zealand had 8 million hectares of grasslands; in 1980 it had 14 million, of which two-thirds consisted of imported grasses (Williams 1980, p. 194; Cumberland 1961, pp. 149–50). This amounts to a transformation of the New Zealand landscape, most of it done in the name of livestock. Stockmen eagerly burned off the forests and seeded grasses to run sheep or cattle.[30] From 1840 to 1880 wool led the way. Britain's industrial revolution in textiles promoted the ecological transformation of the South Island's high country, as it did in the cotton lands in Egypt, India, and the United States. After 1882, when refrigerated ships began to sail from New Zealand to Europe, the focus of forest clearance, settlement, and ecological change shifted to the North Island, which developed an intensive dairy industry. The resulting economy, although entirely dependent on the British market for butter, cheese, wool, and meat, provided a fine living for New Zealand. In 1940 it was the richest country in the world in per-capita terms, with the most labor-efficient agriculture, the longest life expectancy, and the lowest infant mortality anywhere. This bounty was achieved with great effort and at the cost of exposing New Zealand soils to the forces of erosion, which has ravaged many parts of the country since 1860. Since 1950 pastoral and agricultural productivity and the high standard of living have been maintained only through heavy applications of chemical fertilizer—much of which derives from phosphate deposits on other Pacific islands.[31] New Zealand did not make the

[30] Here is Guthrie-Smith, a reflective man, a considerable naturalist, who catalogued the changes in the land on his Hawke's Bay sheep station (North Island) over his lifetime: "Few sights are more engrossing, more enthralling, than the play of wind and flame. . . . As a lover wraps his mistress in his arms, so the flames wrap the stately cabbage trees, stripping them naked of their matted mantles of brown, devouring their tall stems with kisses of fire. . . . Alas! that the run cannot once more be broken in . . . a fire on a dry day in a dry season i s worth a ride of a thousand miles" (Guthrie-Smith 1969 [1921], p. 230). Even a man who lamented land degradation and loss of species enjoyed burning the forest.

[31] Williams 1980, pp. 102–13. New Zealand is geologically young, and the climate features plenty of rain and wind, so vegetation cover is crucial in limiting erosion. Major works on New Zealand erosion are Cumberland 1944; Eyles 1983; McCaskill 1973; O'Laughlin and Owens 1987.

most of its environmental transformations (millions of cubic meters of good timber have gone up in smoke), but it has not done badly. Other Pacific societies have been less fortunate—partly because they have had less control over the process.

Forest clearance in the twentieth century has affected all the high islands in the Pacific. In some cases plantation agriculture played the dominant role, while in other cases subsistence agriculture, driven by population expansion (see below), has done so, In the Solomons, and elsewhere in Melanesia, the richest forests in the tropical Pacific have attracted the timber trade, lately for the Japanese market. Since 1970 timber harvesting has combined with agricultural expansion to reduce forest cover in the Solomons, Fiji, Samoa, and elsewhere in the Pacific, bringing on erosion problems, habitat loss, and some extinctions (Mitchell 1989; Brookfield and Overton 1988; Routley and Routley 1977; Nunn 1990, p. 132).

Extractive activities have changed more than the vegetation in the Pacific. Mining has altered the face of land directly. In New Zealand alluvial gold mining has chewed up the bed of the Clutha River; in New Caledonia and the Solomons, mining has fundamentally changed many localities in recent decades. The biggest copper mine in the world, the Panguna mine, is found on Bougainville in Papua New Guinea's Solomons province. Its slurry has killed all life in the Jaba River and altered the riverbed and delta. In the 1970s, 155,000 metric tons of earth were displaced daily, 99% of which was dumped as waste rock or tailings (Nunn 1990, p. 133; Gilles 1977). Phosphate from Makatea in French Polynesia enriched Japanese, New Zealand, and American soils, but mining it destroyed much of the island's surface between 1910 and 1960. Japanese phosphate mining did much the same in Palau after 1914 (Newbury 19720; Pureell 1976, p. 190).

Nowhere has mining affected the environment as dramatically as on Nauru and Banaba (formerly Ocean Island). On these two atolls, visiting seabirds over the millennia have left deep fossil guano deposits, the richest in the world and almost pure phosphate. In 1900 and for a long time before, the phosphate was covered by topsoil and forest. Mining began in 1905 and will end within a decade. About 100 million tons have been extracted, of which two-thirds went to Australia, more than one-quarter to New Zealand, and the balance to Britain, Malaysia, and Japan. The people of Banaba have not done well out of this industry, having had their island mined out by 1979. Many Banabans now work for wages on Nauru. Nauruans, of whom there are about 5,000, are more fortunate: none of them need work. They renegotiated the lease after independence in 1968 and have since become both the least populated state in the world and the richest, with a per-capita income greater than that of Saudi Arabia or Switzerland. Nauruans have invested their proceeds, so that they will be rentiers when the phosphate runs out, as they expect it will before the turn of the century. But there is little surface left of their island: on four-fifths of Nauru, miners have extracted the guano to a depth of 6–7 meters, leaving empty pits amid limestone pillars showing where the land surface once was. Little land suitable for agriculture remains. Full recovery of native vegetation will take millennia, unless Nauruans decide to intervene.[32] This economically logical ecological barbarity is one of the indirect results of the livestock economy in Australia and New Zealand.[33]

Pacific whaling in the twentieth century, as in the nineteenth, qualifies as an extractive industry because no effort to sustain stocks has been effective. The moribund industry revived around the turn of the century, thanks primarily to the inventions of a Norwegian whaler, Sven Foyn, whose explosive harpoon gun revolutionized whaling. The nineteenth-century Yankee whalers had hunted much like mammoth hunters of the late Pleistocene, by throwing a spear into their prey. Thanks to the harpoon gun and other developments, whaling entered the industrial age. Big, fast, and deep-diving rorquals became accessible targets; indeed, no whale species, or whale stocks, were left unhunted. Norwegians dominated international whaling from 1900 to 1930 and pioneered the exploitation of the previously undisturbed Antarctic stocks in 1904. By 1914 they had developed the factory ship, which allowed them to do all processing at sea and avoid regulations imposed by the countries (usually Britain) that controlled the islands that had previously served as shore bases.

Others soon copied the Norwegian artillery and factory ship,

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32 Manner et al. 1985. Abandoned mining zones do recover vegetation in Nauru. Initially 90% of the species are exotic weeds, but within decades some native species colonize where there is soil. Even in this extremely degraded environment, exotic species require the continued disturbance of human action, and absent that, native species can survive and flourish.

33 Hein 1990; MacDonald and Williams 1985, pp. 61, 564–69; Mitchell 1989, pp. 26–31. Phosphate imports to Australia and New Zealand since 1920 have paralleled sheep numbers and meat production in those countries. High pasture productivity depends completely on aerial topdressing with phosphates and superphosphates.

especially Russians and Japanese, who dominated Pacific whaling after 1945. By the late 1930s blue whales, the largest and most valuable of the rorquals, had grown scarce. Fin whales became depleted by about 1960, sei whales by about 1975. Further technological refinements, such as the use of sonar and satellite imagery, have made whaling a highly scientific hunt, bringing all but Minke whales, the smallest and least valuable of the rorquals, to the edge of extinction. This has happened all over the world, including the Pacific. The oft-ignored restrictions imposed by the International Whaling Commission (founded in 1946–47) are the only barrier between modern whalers and the final extinction of their prey (Tonnessen and Johnsen 1982; Cherfas 1989, pp. 91–106).

The driving forces behind the environmental changes in the Pacific after 1880 are the same as in the first half of the age of Cook—with one alteration and one addition. In both periods, concentrated demand from numerous and distant consumers was focused on small Pacific islands. This gave rise to the plantation agriculture of Fiji and Hawaii, the livestock runs and ranches of New Zealand and Hawaii, the phosphate mining of Nauru. The ebb and flow of demand for various products in the United States, Japan, Australia, and elsewhere around the rim, has had strong consequences for Pacific island environments. China has disappeared from the position of dominance it held in the nineteenth century, although it may yet return to that position in the twenty-first.

In both periods, progressive advances in transport technology and reductions in transport times and costs brought Pacific ecosystems into ever closer contact with those of the rest of the world. Most of the important consequences of this trend emerged in the nineteenth century, but many continued into the twentieth. New exotic species, from microbes to mammals, arrived, and those previously introduced were more widely dispersed. Native species continued to suffer the effects of new competitors.

In the twentieth century as in the nineteenth, population has crucially affected environmental change. The mechanism, however, has fundamentally altered: in the nineteenth century environmental effects resulted from population decline, while in the twentieth century derived from population growth. In the nineteenth century depopulation created empty niches in the islands, which other species (and, in New Zealand, other branches of humankind) rushed to fill. In the twentieth century population growth, from natural increase and immigration, filled most islands to historic maxima. By mid-century Oceania's populations were rising by 3% each year; at the end of the century growth stands at 2.5% in Melanesia, a bit less in Micronesia and Polynesia. In most cases population growth has required an extension of cultivation, with unhappy consequences for native vegetation and soils. It has often led to intensified use of reefs and lagoons as well (Wiens 1962, pp. 454–66).

In addition, temporary population surges, resulting from tourism or military presence, have begun to affect environments on a few islands. Tahiti, Saipan, and Oahu have experienced both. Tourism has flourished since the 1970s, bringing millions to Pacific island coasts. By and large Japanese tourists predominate north of the equator and Australians south of it. Entrepreneurs and developers have radically redesigned coastal districts to suit the preferences of the tourists. Their projects have led to chain reactions of effects on coastal vegetation and soils, reefs and lagoons. Waste disposal on scales never before necessary now vexes several islands. Some tourists are drawn to the Pacific by the ecological distinctions of the islands, and serve as a force for nature conservation. The tourist boom is still very much in progress, and its full effects remain to be seen (Daws 1977; Baines 1977; Peattie 1984, p. 210).

Less seasonal and less predictable temporary surges in population have come with warfare. World War II brought sudden influxes that doubled or tripled island populations, straining local resources. Troops came and went swiftly, as whalers had done a century before. Sometimes they took local men with them, as the Japanese did in Micronesia when they recruited labor battalions for their Southeast Asian campaigns. The isolation of Japanese-held islands late in the war, when the Americans controlled air and sea, led to acute overpopulation and undersupply: all edibles were gathered or hunted by hungry locals and Japanese. At the war's end, islands of Japanese settlement, primarily in the Marianas, were suddenly deflated as their Japanese populations —as much as 90% of the total in some cases—departed for Japan. In the war years numerous islands, even remote ones that had felt little impact from trade or plantations, experienced the scouring ecological effects of population instability in a concentrated, if brief form (Peattie 1984).

Indigenous island populations fluctuated in the twentieth century in response to inducements and discouragements to migration. This has brought more durable changes than wartime's human ebbs and flows. The most dramatic case is the Marianas, where Japanese settlement increased population tenfold between 1920 and 1935, but postwar repatriation almost emptied the islands. More recently, islanders everywhere have been migrating to the Pacific rim and to cities. Samoans have moved in large numbers to New Zealand and the United States. Cook Islanders have left for New Zealand, where they now outnumber those still at home by two to one. Auckland has the world's largest concentration of Polynesians. The decline of shipping and rise of long-haul air traffic has economically isolated most of the islands, a bitter irony for those that in the nineteenth and twentieth centuries had abandoned self-sufficiency for participation in the international economy. They can no longer export copra; thev must export people (Ward 1989, pp. 243–44 and passim; Peattie 1984, p. 210).

Such population movements amount to another widespread fallowing, a reduction of pressures on lands and lagoons, less sudden and as yet less profound than that of the first age of Cook. Once again, this does not necessarily translate into a resurgence of native vegetation and marine life, at least not in the short run, because exotic species are now present, entrenched, and in cases nimble colonizers. On steep land, emigration has meant labor shortage, abandonment, and accelerated erosion as terraces and irrigation channels suffer neglect. Migration to the cities has promoted a new kind of environment, with new problems, the most serious of which is waste disposal. The population mobility and instability of the twentieth century have caused environmental pressures distinct from those of secular growth or decline.

The additional driving force in Pacific environmental change, almost absent in the first age of Cook but conspicuous in the second, is the colonial and military presence. European colonialism after 1880 favored the development of plantations, mines, and timber concessions. British power over Nauru allowed Australia and New Zealand to obtain phosphate cheaply (royalties to Nauruans were originally ,£50 per year and remained trivial until 1968). U.S. dominion in Hawaii eased the way for sugar, pineapple, and cattle barons. Japanese control of the Marianas permitted state-supported sugar plantations. But a great deal of the economic and environmental change that took place in the twentieth century did not require the colonialism of the great powers, only the linkage to the great economies.

The military impact of the great powers is another matter. Military occupations led to the forcedl depopulation of some islands (something the Spanish had done in the Marianas in the seventeenth century). Japanese occupation, though brief, brought some islands of Micronesia and Melanesia into more regular contact with the wider world. World War II helped materially in the dispersal of weeds, insects, and pests throughout the Pacific. New Zealand acquired four major crop pests during the war.[34] Lengthy combat, as on Guadalcanal or Okinawa, blistered some islands, with consequences still visible half a century later. Naval bombardment nearly obliterated vegetation on many atolls (Fosberg 1973, p. 213). The effects of combat, however intense, are not likely to last. On Saipan, the scene of bitter lighting in 1944, vegetation has erased almost all the scars of war, as well as the prewar canefields. Probably most consequential, and certainly most durable, is the environmental impact of the nuclear programs of the Americans, British, and French—all of which did require colonialism in one form or another.

Nuclear testing began in the Pacific in 1946 when the United States detonated a bomb at Bikini Atoll in the Marshall Islands (Micronesia). The first hydrogen bomb test, also American and oddly entitled Operation Greenhouse, was conducted in 1952 on neighboring Eniwetak. It apparently killed off the rat population of the atoll (Jackson 1969). Britain's nuclear testing began in Australia in 1952, but British hydrogen bomb testing took place in the Gilbert Islands starting in 1957. The French moved their nuclear weapons testing to the Pacific after 1962, when Algerian independence deprived them of their Saharan testing grounds. They took the precaution of incorporating the new sites, the atolls of Moruroa and Fangataufa, into France in 1964, so that any decolonization in French Polynesia would not jeopardize French nuclear testing in the Pacific. All in all, about 250 nuclear tests have taken place in the Pacific since 1945 (Firth 1987, pp. 5–12, 24–27, 70–82, 94–108; Mitchell 1989, p. 212; Danielsson 1984; Danielsson and Danielsson 1986).

The full environmental effects of these tests are impossible to assess because the details are kept secret. The British and French

[34] Dale and Maddison 1984, p. 253. The pests in question included the German wasp and Australian soldierfly. New Zealanders have also named an unwelcome week Wild Irishman. It is curious how weeds, especially wartime introductions, easily acquire the names of unloved nationalities. Greeks call a noxious weed allegedly introduced in World War II Germanikos, or German. Would more class-conscious peasants name their weeds differently? Wild Banker or Prickly Landlord?

have been more careful in this matter than the Americans. The Bikini Islanders, for example, have attracted considerable study. Evacuated before the first atomic tests, many of them returned to their island early in the 1970s after it was officially declared safe. They were removed once more after this assessment was called into question in the late 1970s. Their health has become a controversial issue. The only clear truths are: (1) they have unusually high rates of thyroid malignant tumors, miscarriages, and stillbirths; (2) they tend to ascribe any and all ailments to radiation poisoning; and (3) they have become adept at the politics of nuclear compensation (Firth 1987, pp. 39–48). The health of their atolls is good enough to support resurgent vegetation. Since testing ended there in 1958, recolonizing plants have covered most of Bikini, although the species composition is quite different from 1946. Whether this is merely an early stage in ecological succession or betokens the triumph of species tolerant of higher levels of radiation is unclear. Some plants have attained spectacularly large size (Fosberg 1988).

The broader consequences of nuclear tests may be great or small. Secrecy makes it difficult to know, one way or another. Atmospheric testing, abandoned last by France in 1974, dispersed fallout throughout the global atmosphere and minimized the local effects. Undersea testing, abandoned in the 1960s, dispersed radiation with the ocean currents. Underground testing, performed only by the French in the Pacific, persisted until a moratorium in 1992. The reefs of Muroroa are impregnated with highly lethal plutonium, some of which is slowly leaking into the sea. The consequences, great or small, will be durable, for plutonium has a half-life of 24,000 years.

Environmentalism and Conservation

The profound ecological changes of recent times in the Pacific have attracted notice and often criticism, but by and large they have not generated any powerful environmental movements. The great exceptions to this are the international outcries over the fate of whales and seals, and over nuclear testing.

Local conservation practices, whatever their motives, have a long tradition in the island Pacific. Larger-scale efforts date from 1870, when the United States took action to maintain the population of seals on the Pribilof Islands in the North Pacific. This was an isolated event and ran counter to the practice of the times.

Only a few, ineffective voices were raised in the nineteenth century against the rapid and widespread environmental changes in the Pacific. By and large such changes were understood as inevitable, as a reflection of Darwinian struggles (as to some extent they were), or as acceptable costs for economic benefits (as for some people they were).

In New Zealand and Hawaii, where money has been less of a problem than elsewhere, some early conservation efforts got under way before World War II. New Zealand launched major reforestation schemes beginning around 1930. The intent was to grow cheap timber and to reduce unemployment, but among the welcomed effects has been relieved pressure on native forests. Huge landslides and generalized erosion aroused widespread concern and some efforts at soil conservation were made in the 1930s and 1940s. New Zealand, like the rest of the Western world, acquired an active environmental movement in the 1960s, created in large part in a struggle to prevent a hydroelectric installation at Lake Manapouri. As elsewhere, environmental concern has filtered into mainstream politics and civic consciousness. In 1991 New Zealand officially committed itself to creating a sustainable society (whatever that might mean). Lately New Zealand has sought to market its farm products and tourist attractions under the slogan "clean and green." Prime Minister Jim Bolger appeared on *Good Morning America* (4 May 1993) and could speak of nothing else. The inertia of human behavior being what it is, such commitments and rhetoric are not matched in action, but they represent an extraordinary evolution in thought and public discourse.

In Hawaii extensive reforestation schemes date from the 1870s. Sugar planters, keen to maintain their supply of irrigation water, promoted forest conservation and watershed control. After the turn of the century, a Division of Forestry with American professional foresters managed Hawaii's montane forests, with an eye toward preservation of watersheds. Eventually, with urbanization, and with tourism replacing sugar as the economic mainstay of the Hawaiian Islands, Hawaii's forests acquired new protectors, people interested in outdoor recreation or entranced by the romantic appeal of native bush (Juvik and Juvik, 1988, pp. 381–86).

Elsewhere in the Pacific only the nuclear issue has mobilized opinion effectively for any length of time. Few people care about exotic introductions or extinctions; few indeed recognize the origins of the plants and animals they encounter. Soil erosion excites no one who is not directly menaced by it. Driftnet fishing by Japanese, Koreans, and Taiwanese has lately aroused objections among some island populations, and the prospect of global warming and sea-level rise has interested some people on low-lying atolls (Brookfield 1989). But only French nuclear testing has met with universal concern and nearly universal condemnation. The recent testing moratorium is a reaction to the condemnation, as well as to the end of the Cold War. Ironically, the moratorium has excited protest in French Polynesia, where jobs and subsidies, some 15–20% of the local economy, depend on the French military presence.

Most islanders are too poor to regard environmental change as a pressing issue requiring political action. Exceptions of course exist. The population of Palau in Micronesia has rallied to resist use of its deepwater harbor by nuclear vessels. Biological conservation is taken seriously in the Galapagos. Scientific organizations and regional associations, such as the South Pacific Regional Environmental Program, are active, but they are often supported by outside funding and are not indicative of interest on the part of the general population or the governing classes. In the absence of strong grass-roots environmental movements, crusaders such as Greenpeace have wielded unusual influence in matters ranging from nuclear issues to whaling to coral reel protection (Elliott 1973; Costin and Groves 1973; Mitchell 1989).

Conclusions

The environmental history of the Pacific exemplifies the costs of splendid isolation—or more accurately, of the end of isolation. Island ecosystems were highly labile, increasingly so from west to east along the gradient of increasing isolation. Indeed, one might claim the same for their cultural systems. This in effect conferred extraordinary power upon external agents of all biological ranks. Similar patterns of isolation and its breakdown have produced cataclysmic change around the world, in polar latitudes, in rainforest refugia, and on many islands outside the Pacific. In every case, advances in transport, the process of economic integration, and to some extent the political links of colonial empires and war efforts broke down the barriers of isolation, provoking sudden changes, most of them unfortunate for indigenous organisms and societies. Once the human presence was firmly established, ecosystems, individual immune systems, and sociopolitical systems all proved vulnerable to outside disturbance. It could hardly have been otherwise.

From the biological viewpoint, Pacific environmental history seems to carry a strong overtone of determinism, derived straightforwardly from the penalties of isolation. But from the historical viewpoint it also bears the mark of accident. Little of the actual environmental change was desired or intended. No one wanted any but a few of the extinctions. No one wanted the depletions and range contractions of various plants and animals, terrestrial and marine. No one wanted the depopulation of the early age of Cook. All these things happened by accident in human terms. Most were unforeseen and unintended consequences of human action. The law of unforeseen consequences is a potent one, in history as in ecology. Only a few environmental changes, such as sandalwood depletion or atomic radiation, could have been expected. They happened because some people—often not Pacific islanders—regarded them as an acceptable or a negligible price to pay for some economic or political gain. The laws, or at least the probabilities, of unequal power are potent as well.

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