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STORY OF AN OCEANIC ARCHIPELAGO

BY

F. RAYMOND FOSBERG

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[**Editor's note:** This was given as the Third Carl O. Sauer Memorial Lecture by Dr. Fosberg on Thursday 23 October 1980 in the Alumni House Lounge of the University of California at Berkeley. Carl Sauer (1890-1975) was Professor of Geography from 1923-1957 and Chairman of the Department for 31 years. A group of colleagues, students and friends established the fund to support the annual lectures.

The text was never published and is included here to show Dr. Fosberg's ideas about the past, present and future of oceanic islands. The text is from a typed copy corrected in Dr. Fosberg's hand. Among the corrections was a change of the announced title, "The story of an oceanic mountain range".]

From the time, at least several billions of years ago, when the outer layers of a molten, or at least somewhat fluid, earth became solid enough to be called a crust, the interior, or mantle on which this crust rested or floated, has apparently been in a state of extremely slow but constant convective motion. If the crust ever formed a continuous solid layer, it could not have persisted long with this slow-motion turbulence going on in the mantle beneath. Inevitably fragmentation took place. Segments of different sizes, but very large, formed, some with layers of lighter rock forming their upper surfaces. to be called continents, others without. Convection in the mantle very slowly moved these segments, or *plates*, of more rigid rock this way and that, jostling and grinding their edges together. Their margins slid over and under each other, causing local melting, volcanic and tectonic activity. Of the early eons of this stage in the planet's history we can know little or nothing, though recently a brash and scarcely convincing, but possibly not too far off, attempt has been made to reconstruct the pre-Mesozoic movements of the lighter or continental layers of those plates known to have such layers.

There seems to be some agreement that during the Permian period (280-225 million years ago) these continental plates were united into a single principal mass, now called Pangaea, leaving the remaining area of heavier, submerged crust as Panthalassa, the World-Ocean or Pre-Pacific Ocean. Continued motion in the mantle pulled Pangaea apart into major fragments corresponding in some slight measure to the present continents or their precursors. Enclosed by them was a

Department of Botany, National Museum of National History, Smithsonian Institution, Washington, D.C., U.S.A.

major portion of the World Ocean which became our vast Pacific.

Bathymetric maps and diagrams of the sea-bottom suggest that this great body of water anything but deserved the name given it by Magellan. Great rifts, ridges, and fracture zones, evidence of movements of plates continuing even to the present time, can be seen. Some of these patterns on the sea-bottom show as ridges and chains of undersea volcanoes. Whether these mountain ranges represent cracks in the sea floor, through which vast amounts of molten rock have been extruded, or whether, as seems to be the latest idea, permanent stationary weak points or ''hot spots" in the mantle cause local melting of the plates as they slowly pass over them, resulting in successions of volcanoes, oriented in the direction of movement of the plates, is not for the non-geophysicist to say. Suffice it to know that outpourings of basaltic lava have slowly built enormous mountains on the sea-floor. Some of these became high enough to extend for thousands of meters above sea-level as, at first, bare, black, slaggy oceanic islands.

The present distribution of islands in the Pacific gives some idea of the widespread occurrence of volcanic activity on the sea-bottom through the later geologic ages. However, detailed study of the sea floor by means of echo-sounding apparatus reveals hundreds, if not thousands of other submarine mountains that do not, at present, show on the surface, even as reefs or banks. These are called *sea-mounts*. Many of them, given the special name of *guyots*, have curiously flat tops, off of some of which have been dredged the skeletons of shallow-water corals. These guyots are interpreted as volcanic islands, which have once extended above the sea surface, that have been eroded down and have gradually subsided, allowing coral reef platforms to grow on their tops. Continued subsidence has in some cases been faster than reef-growth and now some have their flat tops at 1000 to 2000 meters below present sea level, others still reach the surface as coral atolls. Few people are aware of how many sea-mounts and guyots are known, as the various navies of the world regard this as highly important strategic information and give it a high security classification.

It is essential to the further development of our story to understand that these enormous masses of volcanic material extruded on the sea-floor seem mostly to show a tendency toward very slow subsidence. While there is general agreement on the fact of this subsidence, its mechanism has been the subject of much controversy. Some authorities favor the idea, first proposed by Charles Darwin, in support of his theory of the formation of coral atolls, of widespread subsidence of large parts of the earth's crust. Others, such as Molengraaf and Davis, with perhaps more convincing arguments, favor the idea of local isostatic adjustment, to compensate for the great weight of volcanic material pressing on the immediate portion of the slightly fluid earth's mantle beneath a volcano. The result is very slow subsidence of each individual mountain or mountain range until an isostatic equilibrium is reached, as with an iceberg floating in the sea. Tectonic movement may, of course, elevate individual islands or portions of the crust so that occasional islands or areas of sea bottom show features indicating elevation rather than subsidence. Such exceptions to a general pattern do not necessarily invalidate the pattern. Most islands and oceanic mountain ranges, as well as continental mountains, show evidence of subsidence after early orogenic phases are over or slowed down.

For our story we could choose one of several existing Pacific island groups or mountain chains - the Hawaiian, Samoan, Society, Austral, Tuamotu, or Marianas, all of which show some of the features to be discussed. However, to make our story more complete maybe it is better to create an imaginary mountain range, extending northwest to southeast, somewhere on the Pacific sea-floor, that will exhibit all of the features and kinds of islands that we want to discuss. Suffice it to be reasonably sure that all of the phenomena to be described actually have existed or taken place somewhere. The thing to remember is that the high peaks of our mountain range tower above the sea-floor as the high Himalayas do over the Gangetic Plain, and that they emerge above the sea-surface as islands, some of them for thousands of meters. The geomorphological, biological, and cultural history of these islands is the subject of our lecture this evening.

We know all too little of the actual birth of submarine volcanoes, of the first extrusion of molten basalt from vents in the sea floor, to form "pillow" lavas, which pile up into masses of enormous volume and grow into eminences that herald their approaches to the surface by "sulfur boils" discolored steaming patches on the sea surface. Such occurrences have been witnessed a considerable number of times and even photographed. Breaking of the surface by lava, itself, has less often been seen, especially by geologists and volcanologists. The cream of Japanese volcanologists sailed forth to study one such occurrence, Myojin Volcano, south of Japan. They apparently got too close, as they did not return.

Myojin, and also Falcon island in the Tonga Group, have appeared above the surface and then disappeared several times. The sudden cooling of the molten rock on contact with sea-water causes a shattering of the glassy masses of material and the infant islands are loose, unstable piles of cinders, clinkers, and pumice, which are soon reduced to sea-level or below by wave-action, only to be pushed up again by more magma rising from below. Finally there may be a big enough mass of this material to resist the attacks of the waves long enough to build a permanently emergent subaerial volcano.

These basaltic oceanic volcanoes are usually of a gentler character than the explosive Vesuvius, Lamington, and St. Helens type, found on continental masses and along plate boundaries. Once a sufficiently broad base is built up a bit above sea-level, basalt flows can be poured out on its surface, weighing it down and compacting it. Flow after flow alternating with bed after bed of ash and cinders, added to the platform, gradually form a wide dome-shaped slaggy black surface.

We have no way of knowing what the oceanic climatic patterns were many millions of years ago, but given the vast expanse of the Pacific, then as now, uninterrupted by continents or very large islands, there seems no reason to think that the climate then was very different from now, except perhaps warmer during the Miocene. In all probability there were prevailing northeast and southeast trade-winds, dry doldrums and horse-latitudes, violent hurricanes, and powerful high elevation antitrades, and "jet-stream" winds blowing eastward. We can observe the effects of these now on islands and infer that they were similar a long time back. Trade-wind rains, latitudinal rainfall gradients, orographic rainfall, rain-shadows, convection rains, widespread "kona" rainfall, heavy rain that often accompanies hurricanes, occasional droughts, all doubtless occurred then as now, making the climatic patterns probably similar to those we can now observe.

It can be safely assumed, I think, that from the very beginning, some of the same dispersal agents as are active now brought occasional potential plant and animal colonists to our young volcanic islands. Strong winds would have carried small seeds with adaptations for wind dispersal, small flying insects, drifting spiders in their webs, from other islands and continents. Typhoons, hurricanes, and their included tornadoes would have picked up and carried heavier seeds and other propagules up to where the jet-streams could have scattered them to great distances.

Wide ranging sea-birds would have visited our islands from the very first, depositing guano and improving the habitats for plants, perhaps also bringing an occasional seed. Storm-carried or off-course migrating land-birds might be expected occasionally, judging by modern observations. They also may have occasionally brought seeds, either carried internally or clinging to feet or feathers. If conditions were right the birds may even have succeeded in establishing themselves, if they arrived in pairs or flocks. These events, of course, happened extremely infrequently. Certain lowland or strand species, especially plants, salt-tolerant and adapted to floating arrived, probably much more often carried by currents. Marine organisms with free-floating or free-swimming stages doubtless colonized as soon as suitable marine habitats were available, very shortly after stable consolidated lava shores had formed.

Since the complete history of an oceanic island can never be observed, we are forced to reconstruct its probable course from observation of many existing islands in various stages, a method that provides ample opportunity for error. However, extensive observation and experience, along with an element of judgment and estimation of probabilities, may yield a fairly plausible scenario.

The ages of existing islands are matters of great uncertainty. Many years ago, when I was concerned with the origin of the Hawaiian flora, I asked a Pacific geologist about the probable age of the Hawaiian Islands. He said the geologists had no reliable means of estimating this, except that, hopefully, the biologists might give some clues. He suggested a tentative 10,000,000 years, taking into account the probable age of the ancient, subsided northwest chain. For my own purposes, I "conservatively" adopted a figure of 5,000,000 years. Since then drill cores have given a suggested late Cretaceous age for the lowest levels of sediments in the Marshall Islands and at least earliest Miocene for Midway, in the Hawaiian Leeward Group.

In considering the time that has been available for the development of the biota of a closely associated group of islands it is essential to take into account the earliest land surfaces, as it was most likely there that the first successful colonizations took place and that the biota had its beginnings. Even islands now disappeared or reduced to sea-level coral cays or atolls may well have been, in their earlier histories, the sites of significant evolutionary events, of the origins of important lines of insular plants and animals. A pertinent observation is that many complexes of plants and animals in particular archipelagoes have related species on different islands in the groups that they inhabit. In other words, inter-island colonization has been a rather more frequent occurrence. The history of an island group must be looked at as an intricately connected and related series of events. Many things were happening simultaneously.

As mentioned above, as soon as a stable cool surface and shore line were available, colonization could begin. Planktonic larvae of benthic marine organisms could settle and develop on the hardened rock of the shore-line. Birds could use the islands as resting and nesting places, and initiate soil development with the nitrogen, calcium and phosphorus compounds in their guano. Weathering of the ash and rock surfaces would begin at once.

Very soon (in a geologic sense) water-borne strand-plants, bird- and wind-carried seeds and spores of pioneer rock-inhabiting plants could find a habitat. Ordinary rain showers would occur, and on the windward slopes, orographic rainfall would be more abundant the higher the island became. Plant-cover or *vegetation* would begin to appear. As soon as this took place it was possible for small-animal colonization to start. In addition to the sea-birds and their parasites, spiders and small insects probably came first, borne by the wind. Spiders could arrive but not survive until sufficient populations of insects had built up to provide them with food.

A feature of almost any early colonization would have been the extremely impoverished genetic stocks represented by the single or very few individual colonists. One might think that further evolution, requiring genetic variability as a base, would be most unlikely. Yet much evolution did take place. The key to this paradox is that these early habitats were completely open. In most or all species of organisms over repeated generations, mutations of various sorts occur. Because so few of the total offspring normally produced by an organism survive, the chances of even a beneficial mutation surviving are almost infinitesimal under ordinary conditions. In an open habitat, however, where almost any seed that falls in a favorable place is likely to produce a mature plant, non-lethal mutations can rapidly accumulate in a population, providing the variability requisite for evolution. The rigid control by competition that normally maintains the identity of species is temporarily relaxed until the population numbers reach the saturation point in a particular habitat and relative stability is achieved. By this time a normally variable or heterozygous (potentially genetically diverse) condition may have come about.

In the earliest stages of Pacific basaltic islands there was, judging by modern examples such as Mauna Loa, relatively little habitat diversity. Windward sides were wet, leeward sides dry. Temperatures were lower at higher elevations. There were rough and smooth lava surfaces and areas of ash and pumice. Strong winds occurred on high summits. Isolating factors within an island were presumably almost entirely ecological. Populations of organisms were free to spread over as much of the island surface as their ecological amplitude permitted, and large, relatively uniform, though often genetically heterozygous, populations may have been almost the rule.

However, the processes of weathering and soil-formation undoubtedly commenced as soon as the volcanic material cooled and was exposed to sun, air, water, and, at high elevations, frost. Loose material, whether ash and cinders or weathering products, immediately started to be moved downward by water and wind, and to serve as abrasive agents. This abrasion started to carve the volcanic land-forms and to produce erosion features.

Those in the audience who have seen the windward coasts of the Hawaiian Islands know that the heads and sides of valleys and gulches eroded in layered basalt are vertical cliffs. Ridges, peaks, plateaus, and valleys bounded by such escarpments serve as very effective isolation for most populations of plants and animals. Isolation of populations is, as is well-known, the first step toward, and one of the essential conditions for, speciation.

By this erosion the widely distributed populations that formed on the gentle slopes of the young volcanic domes were segregated into many isolated subpopulations. Inevitably differentiation took place. Since this isolation was geographic, and effective, the resulting varieties and species need not have developed genetic isolation or sterility barriers.

As this diversity of taxa developed, habitat diversification also proceeded. Where, in a continental situation, with its wide spectrum of families, genera, and species, pre-adapted forms would have been available for almost any habitat that developed, this was not true on an oceanic island. Many taxa were developing but as variations in relatively few families and genera. Dispersal was occurring and a new habitat sooner or later was colonized, not necessarily by a form especially well suited to it, but by one able to survive. Natural selection, even in a genetically relatively impoverished stock, would gradually result in better adaptation to the habitat, even eventually leading to the often strikingly well-adapted forms described in discussions of "adaptive radiation," a term applied to the evolution of differing populations to occupy different available habitats.

As the normal geomorphic cycle proceeded, the sharp topography that maintained the isolation of the small, mainly still interfertile, populations or taxa mentioned above, became gradually worn down. Slopes became gentler, isolation became less effective, and ranges of related taxa began to come together. Some of the previously discrete taxa hybridized in these zones of contact. Their distinctions began to become fuzzy. A new type of evolutionary process became prevalent. Occupation of existing habitats and newly formed ones became more complete, and the patterns of adaptive radiation became more intricate. By now the vegetation, except on new lava flows and landslide scars, had become closed forest except at very high elevations and on exposed crests.

The birth, growth, erosion, and gradual subsidence of an island, its slow colonization by organisms and the evolution and eventual decline of its biota are continuous, if incredibly slow, processes, not really episodic as my description may have suggested. We must remember that during the enormous span of time during which the first islands to appear in our mountain range reached the maximum development of their biotas, one after another, a whole series of younger islands emerged from the sea. Thus, at any one time all or most of the principal stages or conditions described earlier were in existence simultaneously. In addition to occasional successful new colonizations from outside the young archipelago, more frequently plants and animals from islands within the group succeeded in crossing the smaller water barriers between the islands. Thus the distinctive biota of the archipelago was evolved and maintained.

As the millions of years passed, new volcanoes arose, extending the mountain range to the southeast, and enlarging the archipelago as the Pacific plate slowly moved northwestward.

The oldest islands on the northwest end of the chain gradually eroded away and subsided, giving an opportunity for the myriads of calcium-carbonate-secreting, reef-building organisms to grow and build the wondrous structures and communities of organisms that we call coral-reefs. These reefs, at least ones of any large extent, are formed on slowly subsiding coast-lines. Darwin, in his well-known theory of atoll formation, showed the gradual change from fringing reefs, closely lining the island shores to more distant barrier reefs ringing the partly subsided, eroded remnants of volcanoes with coral just breaking the surface and carrying sand-cays and islets of coral sand and debris. Eventually, when the central volcanic peak or peaks had subsided out of sight, a ring of coral reef and coral islets, called an atoll, remained. The term atoll is modified from the language of the Maldive Islands, a notable archipelago of these coral rings or "necklaces" in the central Indian Ocean.

As this geological process took place, the relatively rich biota of the high island became attenuated and impoverished in species as the terrain became more flattened and simplified. The loss of diversity of habitats, as well as the increasing prevalence of salt-spray, resulted in a drastic reduction of the biota. This was more conspicuous on dry than on wet atolls. For example, the two driest of the Marshall Islands have only nine flowering plant species each, while the wet southern atolls of the same group have up to five to eight times as many.

Occasional tectonic activity results in elevation of islands already ringed with reefs, and even of atolls. On elevated volcanoes fossil reefs may be seen as limestone terraces or benches on the slopes, or as dissected walls of rough coral limestone at the bases of the slopes. A few examples exist of elevated atolls and of extensive raised reef-tracts. The elevated atolls appear as flat- or concave-topped limestone plateaus, and more extensive tracts became eroded into weird karsts, often protruding ruggedly above the sea surface. Such may now be seen in the southern islands of Palau, Micronesia, and in the Lau Islands of Fiji. Elevated atolls may have vast deposits of calcium phosphate in their summit depressions, as seen on Makatea and Nauru, presumably derived from the guano of innumerable prehistoric seabirds.

In their pristine condition all of the variations of tropical oceanic islands described above, except a few of the very driest, were clothed with forests, largely made up of endemic species of trees and their accompanying endemic smaller plants, insects, and other invertebrate animals, as well as birds, bats, and a few reptiles. Many of these organisms had evolved weird and remarkable forms comparable to the tree lobelias and the silver-sword of Hawaii and the dodo of Mauritius.

Of particular importance from our viewpoint, looking back from the future, were several related features of the biota of these, and other oceanic islands. The plants and animals had mostly evolved in the absence of large herbivores. Except for features which the original colonists may have brought with them, the island plants had evolved no means to protect themselves from the normal continental hazards of grazing, browsing, or trampling by large animals. Even the thorns, spines, stinging hairs, bitter or poisonous substances that may have characterized the species which originally colonized the islands were mostly lost as the new biota evolved. Only some of the most recent arrivals were still prickly, acrid, or otherwise disagreeable.

Root systems were frequently very shallow and had no adaptations to deal with trampling, as there were no large animals to damage them by trampling.

The entire biota had evolved to take full advantage of a comparatively benign environment, harsh in some respects, but without many of the hazards and kinds of competition normal in continental situations. In many ways the equilibria achieved on the islands were very delicately adjusted to make maximum use of existing resources by the available range of organisms. Through adaptive radiation the limited original biota had diversified to fill most ecological niches. All of this took many millions of years and was prior to the arrival of man.

Humans clearly first came to oceanic islands in small parties, in sailing canoes, possibly blown far out to sea by storms, or merely wandering, to see what was there. The first-comers undoubtedly found very poor picking, except in the matter of sea-food and birds and their eggs. The vegetation of oceanic islands contains few edible plants, indeed.

The popular idea of south-sea islands fringed with coconut palms is, as to pre-human days, certainly a myth. Possibly the coconut is indigenous in the Seychelles, in the Indian Ocean, as Jonathan Sauer has suggested, but it certainly came with man to the oceanic Pacific islands.

Ancient Pacific peoples, probably even on casual canoe voyages, carried stocks of a few edible plants, at least as provisions. Any serious colonizing party undoubtedly brought an assortment of useful plants, and the knowledge of their culture. At least pigs, dogs, and chickens came, as domestic animals, not necessarily at the same time. Thus the early arrivals in our island group came well prepared to initiate the series of profound changes in the island geography and biology that followed their advent.

Dependent, at first, on the resources of reef and ocean, the early settlers established themselves near the sea, especially around the mouths of large valleys on the high islands, and probably along lagoon margins on barrier islets and on atolls. Coconuts, bananas, taro, breadfruit, and possibly sweet potatoes, were doubtless planted at once, as well as some other plants. This involved a certain amount of clearing of native vegetation, but for many years the effects were relatively minor. There were doubtless slight disturbances in the reef fauna. Small flat areas back of the beaches and in valley bottoms were cleared for villages, coconut and breadfruit groves, taro pits and other forms of garden culture. A few cultivated plants and some "camp-followers" or weeds were added to the floras of the islands. A few insects and other invertebrates (parasites on man and his domestic animals and plants), some commensals and incidental accompanying animals (possibly including rats) established themselves and become naturalized and part of the fauna.

While the human population remained small, changes in the island ecosystems were slow and the results mostly not catastrophic. Most plants and animals that came with the human colonists did not succeed in invading closed vegetation except where it was opened up by man. An exception, perhaps, was the candlenut or kukui tree, probably brought by man, which on some high, deeply dissected islands, occupied the 60-90 inch rainfall belt on steep slopes almost to the exclusion of other plants.

Characteristic of oceanic islands is that their resources useful to man are limited both in quantity and in kinds. Furthermore, islands of different geographical nature offer different assortments and proportions of resources. Volcanic islands with considerable ash in their composition weather more rapidly and yield richer soils than do those of hard flow-basalt. On dry islands water may be limiting. On very wet ones severe leaching and erosion may deplete soils more rapidly than soil-building processes develop them. Coral atolls, especially drier ones, present a poor terrestrial environment, but are likely to be rich in marine resources, especially if there is a good lagoon with active water circulation. Elevated atolls are so well drained that water may be scarce, although the phosphatic soils may be rich.

Cultural development and population growth depend both on the culture the colonists brought with them and on the nature and abundance of resources occurring on the island.

In all likelihood, limited resources if not too extreme, served as a stimulus to cultural development. To flourish it was necessary to learn to utilize fully and in diverse ways, the range of resources provided by the island. Many island cultures show remarkable ingenuity in their adaptations to their environments and utilization of everything available. The diversity shown by the cultures found on our chain of islands in varying stages of island "life histories" reflected the diversity of the islands. Settled by people of similar Polynesian stock as diverse, of course, as the islands from which they came, the nature of the island imposed each its own stamp on the further cultural evolution of its people. Peoples on fertile, moderately wet islands tended to emphasize agriculture, or, rather, horticulture, making a comfortable living. Populations grew rapidly. Atoll peoples developed great skill and ingenuity in catching and using reef animals and often pelagic fish. They also soon discovered the possibilities of pits excavated to the fresh-water lens lying a few feet below the island surface. Culture of the several taros, and even of bananas could be carried on in such pits, protected from salt-spray by windbreaks of natural vegetation left when clearing for coconut and breadfruit groves, and as gardens were established. The diversity of uses for coconuts and *Pandanus*, learned long before in their ancestral homes, was increased in various directions.

A phenomenon surprising to us, now, was the population size achieved on the more favorable islands. Since the colonists undoubtedly were a healthy lot, to be able to endure the vicissitudes of long voyages and the hardships of settling new islands, and since their numbers were small, the number of diseases they brought with them was small. The inherent biotic potential of man being high, dense populations were reached in relatively short periods. Undoubtedly the limits of carrying capacity of the different islands were soon reached. Then the obvious controlling factor in many islands was warfare. Some cultures, while able to defend themselves, found other means of population control. Contraception was apparently fairly widely known. Infanticide was certainly not unknown. Emigration and search for new island homes was a means of relieving population pressure and a factor in the almost complete settlement of the habitable islands in pre-European time. There were a few uninhabited Pacific islands at the time of arrival of Europeans, but in almost every such case, the island was for one reason or another unsuitable for habitation by Polynesians and Micronesians. Most of them showed signs of having been visited and temporarily occupied. Lack of dependable water-supply was the most frequent reason for lack of human habitation. Most populations on inhabited islands, by the time Europeans arrived, seem to have achieved, but by one means or another exceeded. reasonably sustainable levels. The few records made by the early Europeans visitors show little or no evidence of over-population, depletion of resources, or environmental degradation. For a few island cultures, such as that of the Marshall Islands, we have information on actual conservation practices, usually woven into the religious fabrics and apparently quite effective. What seems to have been a satisfactory, functioning blend of material and social culture had usually been achieved. The occasional very war-like societies may have been exceptions to this generality. Or, perhaps these warring tendencies may have been merely the means evolved for population control. We really know rather little of this period in island history.

One condition, very generally prevailing, was a lack of immunity to many of the important human diseases. Apparently the early colonists in the Pacific came from peoples who had enjoyed long isolation from the dense centers of human population where the common diseases developed. Lack of exposure to these maladies resulted in lack of selection pressure to evolve resistance to them. In a way this was comparable to the lack of defenses, in the indigenous island vegetation, against the effects of large grazing and trampling animals.

The centuries and millenia of presumably orderly and non-catastrophic evolution of island cultures and their adjustment to their insular environments came to an abrupt end in the second half of the Eighteenth Century. Up to that time, though European ships had crossed the Pacific in several directions, the only actual beach-head of European culture was the savagely destructive Spanish settlement in the Marianas Islands. The rest of Micronesia and all of Polynesia were almost completely uninfluenced. Iron was known to many island peoples but only as tiny bits presumably gleaned from rare floating ship-timbers and other wreckage. A few other suggested traces of continental civilization are known, such as the possible presence of pineapples, American in origin, and the existence of these is still very conjectural and controversial. The presence of the American sweet potato in Polynesia was certainly pre-European.

This slow evolution of highly developed cultures ended abruptly with the penetration by English, French, and other explorers, especially Wallis, Cook, Bougainville, and Vancouver, followed by traders, whalers, missionaries, and settlers. These brought domestic herbivorous animals, steel tools, guns, alcohol and diseases. The results were catastrophic.

A steady flow of exotic plants, both cultivated and weeds, followed. The domestic herbivores escaped and became feral on most islands, opening up, eating and degrading the highly vulnerable vegetation, providing new habitats for the exotic species. The steel tools and the trading rewards for provisions for ships encouraged the clearing of more land than had been needed to support the native populations; great changes in the landscape became apparent. Tuberculosis, measles, colds, influenza, as well as over-indulgence in alcohol decimated many populations. Mosquitoes, fleas, and lice came in, and the diseases they spread became established.

Missionary activity destroyed the religious fabric that supported the indigenous cultures. Fanatical new beliefs were introduced that altered vital features of these cultures.

Sailors and other visitors mixed with the natives and greatly altered the genetic composition of the island populations. At the same time they brought venereal diseases to further contribute to the population decline that was an outstanding feature of this period. Some islands were virtually depopulated.

Meanwhile, land, the basis of the island civilizations, came more and more into the hands of settlers from outside. Plantation agriculture, especially coconuts and sugar cane, became widespread, usually on the best of the land. The children of the missionaries and other settlers saw opportunities for Western-style enterprise and eagerly grasped them. The second Missionary generation became sugar planters.

These events and activities had profound effects on the landscape, the biota, and the social structure of the human populations of our islands. The low-island landscape, even in its undisturbed state not very diverse or varied, changed from an appearance of pleasant informality, dominated by groves of coconut palms and stately breadfruit trees, with thatched huts, to a monotony of coconut plantations. The trees were planted in strictly orderly rows, the houses had sheet-iron roofs, the ground kept free of undergrowth, with all trash and humus neatly burned. Soil fertility tended to decline, as the nuts were turned to copra and exported, taking nutrients along. Little attention was given to replacing them. The humus content of the already poor soils became lower, both from natural causes and from burning.

The level lowlands and gentle lower slopes of the high islands were likewise covered by plantations, both sugar cane and coconut, later also pineapple. Towns and, later, cities appeared, attracting the natives away from the villages, to populate the poor parts of the cities, while the well-to-do outsiders built exclusive, beautiful homes in the better parts, away from the crowded and ugly down-town sections.

The mountainous or hilly areas were devastated by the charcoal burners, feral goats, sheep, cattle, horses and pigs. The forests were cut and degraded to poor scrub increasingly dominated by lantana, guava, kiawe (*Prosopis*), and other weedy shrubs and small trees. Fires became frequent in the drier leeward areas. Erosion was accelerated, exposing bedrock on steeper slopes, and depositing fine red silt in the shallow water, smothering the corals and degrading the reefs. Soil covering, with its important soil-biota and accumulated nutrients that took millenia to develop, were lost in a few decades. The capacity to support, not just humans, but populations of many kinds of organisms was seriously reduced.

On each high island, a wondrous biota, largely composed of unique species, even genera endemic to one or a few islands, suffered depletion and impoverishment. Many of these species disappeared before they were known to science, or even known to man. Such a loss is both an ecological tragedy of reduced diversity, and an impoverishment of the interest and the aesthetic quality of the habitat of man. Some might say that if man did not know what he lost it made no difference to him. I do not subscribe to this notion.

Loss of native species was not the only change in the biota brought about by the stepped-up human activity and by the new human immigrants. People have a tendency to introduce plants wherever they go. Economic or possible economic plants, food, forage, fiber, timber plants, ornamentals, and "camp-followers" or weeds, came in, in great numbers. Most were planted or established in fields, gardens, orchards, and around dwellings. However, many plants have effective means of dispersal, mechanisms to take advantage of wind, birds, people, and feral animals. The native vegetation tends to resist invasion by exotic plants while in good condition. The degradation and opening up of this closed forest vegetation by feral herbivores, fire, clearing, road-building and other kinds of disturbance so effectively provided opportunities and habitats for exotics that, before many years, the vegetation at low and moderate elevations on many of our islands was dominated by these immigrants. Scrubby forests of kiawe (*Prosopis*), opiuma (*Pithecellobium*), guava (*Psidium*), ironwood (*Casuarina*), mango (*Mangifera*), and *Eucalyptus*, scrub of *Lantana*, *Acacia*, *Melastoma*, *Leucaena*, and *Schinus*, and rank grasses (*Pennisetum*, *Panicum*, *Andropogon*, *Saccharum*, *Melinis*, and *Sorghum*) covered vast areas in the lowlands and lower slopes, wherever the land was left uncultivated or fallow. It soon became a fact that a visitor could travel in the islands for months without seeing a native plant. The habitats of native species of both plants and animals were usurped by these aliens, and the native biota, just as the native peoples, declined rapidly. Hundreds of native plants, as well as snails, insects, and other invertebrates, along with numbers of bird species, disappeared, mostly never to be seen again. Gentler upper slopes were converted to pasture, making large livestock ranches. Even on steeper slopes, native forests were invaded by exotic vines (*Passiflora*, *Paederia*) and aggressive shrubs (*Eupatorium*, *Lantana*, *Clidemia*), or logged off and replaced by *Eucalyptus* or *Pinus*. The landscape was altered beyond recognition and the natural diversity seriously reduced.

Due to erosion, water became scarcer. Irrigation of plantations became more and more expensive. During dry cycles and on some of the drier islands, droughts occurred. Even domestic water consumption at times had to be regulated. As the native vegetation, a superb mechanism for absorbing and holding rain-water, became reduced, the water supplies for the constantly augmented populations became more uncertain and precarious.

What of the native peoples? With introduced public-health measures, sanitation and available medical services, the population decline was, in most islands, arrested, and native peoples, mostly now of mixed blood, began to increase. However, because of their period of decline, and often because of their disinterest in working for the plantation owner, workers were scarce and the planters had to look elsewhere for their field and factory labor. Large numbers of foreign workers were brought in. They stayed and multiplied, in time becoming majorities of island human populations. They rapidly adopted the dominant western cultures; the native peoples tended to do likewise. Thus the remarkable local cultures that had evolved in the islands, disappeared. The peoples tended to be more or less effectively amalgamated, but much of what had made them unique was lost. A monotonous tropical version of western "civilization," with a few artificial, imitated "native" forms of entertainment were what remained of the fabulous "South Seas" for the tourists to flock to see.

We will pass over the period of war, with its profound and traumatic effects and accelerated change.

Much of the scenery remains beautiful. Much of the planted exotic vegetation is showy. The swimming is good. Away from the cities the pace and the atmosphere are relaxing. The climate is pleasant. Visitors who come tend to want to stay.

In the cities the pace is frantic. Traffic is worse than in many continental cities. The people are money-mad. Taxes are high. Everything is expensive. There seems to be no limit to the engineering projects and construction of all sorts. Sky-scrapers sprout up everywhere. Nothing is too beautiful to be sacrificed if it happens to be in the way of "progress." Entertainment and comfort are provided for the tourists and retirees. If they stopped coming, the metabolism of this frenetic society, fueled by tourist money, would fall to a subsistence level that would barely be sustained by such plantation agriculture as survived the immigration and tourist floods. So far, this has not happened, and fuel energy has not yet become so expensive as to bring the mechanized civilization to a stop.

The South Sea idyll, which attracts the tourists and retired people, is now an artificial and false counterfeit, but still convincing. Hordes of visitors come, many stay, and the population grows. There are not small islands enough to supply the demands of the wealthy who want private islands of their own. Solitude is becoming a memory only, but it is not what the crowds want, though it is what the advertising promises. Air-travel makes practically every island accessible.

What of the future? If energy supplies remain adequate, even though expensive, I can see no future except that the islands will become more and more uniform, a tropical version of standard western civilization. The diversity that still makes them fascinating will more and more rapidly become lost. People will become even more ubiquitous than now, as they will everywhere else.

If energy supplies fail, as they very well may, travel and communication will become difficult and isolation will result. The amenities that have become necessities will become more and more scarce, and more and more concentrated in the hands of fewer and fewer people. The social structure will become more and more unstable. Local strong-men will probably emerge. Violence and repression will prevail. Island versions of Ibanez' *Four Horsemen* may appear. Sooner or later the isolated, now impoverished and degraded island ecosystems will have their human, animal, and plant populations reduced to the levels of the real carrying capacities of their habitats. Perhaps limited but stable subsistence societies may again become the rule. Or perhaps man may eliminate himself and nature may start a new experiment.

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