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The Environmental History of the Hawaiian Islands

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The plants and animals that inhabit a region are influenced by a variety of factors. The amount and yearly fluctuations in sunlight, precipitation, and temperature are among nature's controls. Chance is also part of the equation. What are the odds that a drought could eliminate the food source of an endemic species? How often does an area experience volcanic eruptions? These natural catastrophes weaken species viability, increase competition for scarce resources, and can lead to extinction. Unfortunately, our own anthropogenic activities have led to reduced biodiversity. In a world of rapidly diminishing species richness, it is important to study and learn from our worst mistakes. The history of the Hawaiian Islands is not just the sad story of irreversible ecosystem change, but also, in today's context of global climate change and mass extinction, it is a valuable lesson in positive feedback – a small disturbance has far-reaching consequences.

Trade has been a catalyst for environment alteration. The stimulus for such change in Hawaii began in St. Petersburg. European diplomats were informed in 1760 by Czarina Catherine the Great that the Russians were in northwestern North America (T.L. Snell, 1974, p. 170). Officially the English sent Cook to find the famed Northwest Passage, but he also had special instructions from the British Admiralty to determine what the Russians where doing (p. 182). In 1778, Cook sailed up from the

Pacific into the Gulf of Alaska, where he found a few Russian fur traders. Months later, Cook's ships docked in China, where his men traded the furs they had acquired cheaply from the Aleut Indians. The Englishmen sailed home with dollar signs in their eyes, because they had discovered that the Russians were making a fortune selling Alaskan sea otter pelts to the Chinese. Another discovery made on Cook's final voyage was the Hawaiian Islands.

Almost 2,400 miles from both California and Japan lay the Hawaiian Island Chain. It is composed of eight large islands and more than a hundred mainly uninhabitable islets and atolls. The easternmost island, Hawaii, is the largest and the youngest. Almost 2,600 miles to the northwest, the Kure Atoll is the end of the Hawaiian Chain. Their position between North America and Asia has made them an ideal port of call, a place where ships could resupply and transfer their cargoes. Up until 1789, British fur trading ships, following the Russian example, sailed from Alaska to China, but they went via the Hawaiian Islands (Bradley, 1942, p. 12). American, Russian, and French ships later came to Hawaii. With their cargo holds full of furs, traders stopped to buy pigs, bananas, firewood, and sweet potatoes in exchange for nails, beads, and ribbons. These sailors initiated the third major transformation of the Hawaiian landscape.

The first major alteration was an invasion of sorts which began with algae and lichens brought in on the wind as spores. They converted bare, volcanic rock into soil in the initial transformation of the Hawaiian environment. Lichens are a symbiotic combination of fungi and algae in which the fungi break down rock for nutrients so the algae can perform photosynthesis. Certain types of algae tolerate high temperatures, the high sulfur content of volcanic rock, and levels of nitrogen too low for other plants (Smathers & Meuller-Dombois, 1974, p. 87). As microorganisms and lichens increased the quality of the soil, ferns and mosses began to grow. Meanwhile, millions of years of volcanic eruptions were under way.

The island of Hawaii was formed by five different volcanoes. The tallest, Mauna Kea, is 13,681 feet high and has the steep slopes characteristic of an explosive cinder-cone volcano (H.V.O., 2006). Mauna Loa, less than forty miles to the southwest, is an enormous shield volcano, distinguishable by its gradual slopes formed from fluid lava flows. On Mauna Kea there are moraines, mounds of rock transported by glaciers, serving as evidence that Hawaii was cooler during the Ice Ages; today, snow accumulates to a depth of several feet on both summits (MacDonald et al, 1983, p. 256). Kilauea, the most active volcano, lies to the southeast of Mauna Kea and Mauna Loa. The geologically young volcano of Hualalai, in western Hawaii, is 8,300 feet high. A range of hills and low mountains

called the Kohala Mountains composes the backbone of northwestern Hawaii.

The island of Maui Nui lay less than fifty miles to the northwest of Hawaii's Kohala Mountains. Volcanoes formed the island less than two million years ago, and it existed for 500,000 years before erosion carved it into the separate islands of Maui, Molokai, Lanai, and Kahoolawe (Olson, 2004, p. 7). Maui is the second largest island of the Hawaiian chain (Hawaii itself has almost half of the state's land mass). Maui's western volcano is largely eroded, but the 10,000-foot volcano of Haleakala was active as recently as 500 years ago (H.V.O., 2006). The small islands of Kahoolawe and Lanai lie off the west coast of Maui. Kahoolawe is relatively flat, while Lanai has one extinct volcano above 3,000 feet. Twenty miles to the northwest of Maui is Molokai, where tall sea cliffs and mountains comprise the eastern portion of the island, and eroded plateaus and plains constitute its western half.

Oahu, forty miles from the west coast of Molokai, is the third largest island. It formed between two and three million years ago (MacDonald et al, 1983). There are two low-lying mountain ranges, the Ko'olau Mountains bordering the eastern shore and the Wai'anae Mountains along the west coast. Lava from the volcanoes that formed the mountains flowed together and created the flat Schofield Plateau. Northwest of Oahu is the island of Kauai, which is home to just one ancient volcano. The island formed five million years ago (Olson, 2004). The eastern and southern shores are paralleled by extensive coastal plains, while the interior is mountainous. The northeast drains into the Alakai Swamp, and nearly the entire western quarter is cut from the rest of the island by the "Grand Canyon of Hawaii" or Waimea Canyon. Another small island, Niihau, lies twenty miles to the southwest of Kauai; eroded, low-lying hills and plains make up its topography.

In 1963, the geologist J. Tuzo Wilson first proposed that the Hawaiian Archipelago was formed as the crust of the Pacific Ocean floor moved over a fixed plume of molten material from Earth's mantle (Macdonald et al, 1983, p.338). Each new volcanic island was then carried away from this geologic hotspot as the Pacific tectonic plate crept to the northwest at a rate of several inches a year. As one island's source of lava was cut off, another island was born. An entire chain of islands was formed in this way. As time went on, they were eroded by rain, wind, and waves. This is why the tallest and largest islands are also the youngest. The effect of years of erosion can be observed in the Northwestern Hawaiian Islands. They are atolls, which are old volcanic islands that have eroded or subsided and are now surrounded by rings of coral reefs. Each coral polyp builds a limestone skeleton that it can hide or rest in. As the colony grows, new coral build upon the skeletons of dead coral. The

result is a rock-like reef that surrounds a lagoon and island. The Northwestern Hawaiian Islands are made up of many ephemeral sand bars and nine islands surrounded by millions of acres of coral reefs (About the Area, 2006). The largest of these are Midway, Nihoa, Layasan Island, and Lisianski Island. According to Olson (2004), the tiny islands and extensive reefs begin 200 miles from Niihau and stretch for 1,800 miles. Their ages vary from seven million years old (Nihoa) to thirty million years old (Kure Atoll).

In this area of the ocean, twenty-nine degrees of latitude is as far north as coral can grow fast enough to keep up with the natural subsidence of old atolls. The Kure Atoll is at twenty-eight degrees north latitude, and as the Pacific Plate drags it to the northwest, the island will sink and meet the fate of former islands even farther north. Ranging from thirty to seventy million years old, the Emperor Chain of seamounts dots the Pacific floor all the way to the Russian coast (Camp, 2006). Any last vestiges of the islands created by the Hawaiian hotspot are at last erased as the Pacific plate is subducted under the Aleutian Islands.

The Aleutian Islands support life similar to that of mainland Alaska. The contrast between the biota of the Hawaiian Islands and the Aleutian Islands is the difference between oceanic and continental islands. At some point, a continental island was connected to a larger landmass. Either plate tectonics ripped the island from its continental moorings or a change in sea level drowned its land bridge (Quammen, 1956, p. 53). An oceanic island is very different. Life there must start from scratch as there are no preexisting ecosystems of plants and animals. In order for anything to reach an oceanic island, it must be seafaring, seaworthy, or lucky. Had Hawaii been a continental island like the Aleutian Islands, pioneering mosses would have been replaced by native grasses and sedges from Alaska. Instead, Hawaii developed flora brought by the wind, the sea, and the birds of distant continents.

The algae, lichens, ferns, and mosses that initially came to Hawaii made the moon-like volcanic landscape very attractive real-estate for a large group of plant species, the angiosperms. These are the flowering plants that produce nuts, grains, seeds, and fruits. Sea birds brought stowaway seeds and grains stuck on their feathers and feet. Nuts, beans, and coconuts drifted in the Pacific for months before being washed ashore. In the tropics, during the wet season, rivers undercut their banks sending intact pieces of forest, held together by their root systems, downstream (Sparks, 1976, p. 76). These rafts of floating vegetation are presumably the vectors for not only plants but also for the land snails, spiders, and insects that reached Hawaii.

The invading angiosperms soon inhabited environments influenced by the great variability in the local climate. During the wet season

from October to April, winds from the west develop into cyclones that bring the heaviest rainfall to the islands (Price, 2006). For most of the year, there is a nearly constant wind from the northeast, and the windward sides of the islands experience orographic rainfall: the northeasterlies make landfall, rise up the volcanic slopes, and cool, generating precipitation. The mountainous windward slopes of all the larger islands are known for tropical rainforest, while the leeward slopes, lying in what is called a rain shadow, are home to dry savannas and woodlands. Within a relatively short time, 300 species of plants, 400 species of insects, and a small number of birds colonized the islands (Olson, 2004, p. 16). There were few if any predators for many of the species. Birds took to nesting on the ground and lost the ability to fly, while insects without wings evolved. There was little competition, and food was relatively abundant. Best of all, there were many unoccupied environmental niches on the islands.

The ancestral Hawaiian plants, insects, and birds underwent adaptive radiation, a process in which a single species quickly exploits different environments and evolves into several separate species. On a continental island, the niches are already occupied by other organisms well adapted to their environment. On Hawaii, a type of finch developed into at least fifty-seven different species of birds (Olson, 2004, p. 16). These birds, called honeycreepers, became adapted to eat seeds, insects, and nectar. A species of Drosophila fruit fly evolved into 800 distinct species (p. 20).

Not only finches and flies diversified. The original colonists became at least 10,000 species of insects and 1,700 species of plants (Olson, 2004, p. 20). The islands came to be home to 1,300 different species of land snails (Loope, 2006). 140 species of birds were found on Hawaii and nowhere else (Youth, 2006). The islands' herbivores were large flightless geese, ducks, and rails, while predatory birds such as hawks and owls were at the top of the food chain. Several birds developed long curved beaks for a diet of flower nectar; others evolved large beaks to eat land snails.

The first Polynesians that came to the islands cared nothing about bird diversity. All they saw was food, and this is why they had come. The human colonization of Hawaii 1,500 years ago was an answer to overpopulation and starvation (Rose, 1980, p. 57). Native Hawaiians are descendants of refugees from the Marquesas Islands, which are part of French Polynesia today. The Marquesas are only twice the size of Rhode Island, and periodic wars turned villages into groups of seafaring refugees (Fowler, 2006). Human migrations from the Marquesas and later from Tahiti began the second major transformation of the Hawaiian Islands.

During the four-month long Hawaiian holiday of Makahiki, the entire population stopped working (Storr, 1966, p. 33). There was much cause for celebration, for Hawaiian fields and fisheries yielded great surpluses. However, introduced species and agriculture had severe environmental impacts.

The first people to set foot on the Hawaiian Islands brought plants from their Polynesian homeland; these included breadfruit, taro (a potato-like crop), ginger, and coconuts. They also brought trees for food and shelter, the kukui tree for its nuts, and the mountain apple for its fruit (Cuddihy & Stone, 1990, p. 32). All three trees, along with several weedy Asian plants, became naturalized and displaced native species. Pigs, chickens, dogs, and rats accompanied the first human colonists. Pigs are notorious for eliminating forest floor plant species, but two botanists that visited Hawaii in the early nineteenth century reported dense undergrowth and no feral pigs (p. 33). The chickens probably had little effect on native wildlife. Dogs were kept for human food consumption but hunted native ground-dwelling birds. The most devastating introduction was stowaway rats. The Polynesian rat eats mainly grasses, seeds, and fruit, but in Hawaii, it attacked lowland bird species by preying on their eggs and on nestlings (Tobin, 2006). Gnawing rats also girdled certain species of small trees and shrubs, which led to localized changes in forest species composition (Cuddihy & Stone, 1990, p. 33).

The coastal shrublands and forests were the first areas to be altered for settlements. Slash and burn techniques and, later, permanent agriculture cleared much of the lowland rainforests. Fire was used to encourage introduced plants grown for pig food or thatch. Native grasses and shrubs were not adapted to a regular burning regimen and perished. The savannas and shrublands of the leeward regions were much easier to clear than rainforest. The western, drier slopes of the larger islands were turned into intensive agricultural zones that supplied sweet potatoes, yams, and vegetables. Wetter windward valleys were converted into taro fields. By 1778, most of the trees below 3,000 feet had been cut down, and at least fifty-five species of birds had become extinct (Youth, 2006). Perhaps the most dramatic impact of native Hawaiians was the slaughter of millions of seabirds. Fossil evidence shows that migratory birds nested throughout the Hawaiian Islands in high densities before man and rat arrived, and their nutrient-rich guano fertilized the soil (Loope, 2006). Today, the remaining bastions for seabirds are the Northwestern Hawaiian Islands where fourteen million birds of eighteen species either visit or reside (NHI, 2006). When the seabirds were killed on the main islands, the loss of nutrients in the soil made some areas less hospitable to certain plant species. An example is the tree called the ohia which dominates many of Hawaii's forests. Many stands of ohia periodically experience

dieback that has been linked to this break in the local nutrient cycling (Loope, 2006).

When Cook arrived in the Hawaiian Islands in 1778, the natives were 400,000 in number (Porteus, 1945, p. 14). The Hawaiian culture didn't reach its zenith until King Kamehameha in the late 1790s, who was the first ruler to unite all of the islands under one ruler. Kamehameha desired expensive European goods and needed something other than pigs and potatoes to trade with.

In 1801, American traders found sandalwood growing on the islands, and now the third major transformation that had been begun by the fur traders intensified. Shiploads of the wood of four native sandalwood species were sent to China. In order to find the valuable wood, fires were started, and natives waited downwind to catch the scent of burning sandalwood. Several years of thorough and destructive harvesting changed the species composition of large areas of the islands.

Only the Hawaiian royalty profited from the sandalwood trade. Commoners were required to help with the gathering, but they received no compensation for their hard labor. Foreign visitors after 1810 noted that fields and animals were practically abandoned, because many people had to spend long periods of time in mountainous regions as sandalwood became rare in the lowlands (Storr, 1966, p. 50).

Visits from foreign ships increased during this time. Russians from Alaska built a fort on Kauai and controlled trade on that island from 1815 to 1817 (Bradley, 1942, p. 50). However, it was American whalers who dominated the Hawaiian economy for decades and contributed significantly to the islands' environmental degradation. Just as sandalwood was becoming rare, whaling ships began visiting Hawaiian ports. American whalers discovered the "Offshore Grounds," 1,400 miles west of Peru, in the 1790s and other important whaling grounds in the northern Pacific in the 1820s (Storr, 1966, p. 86). During the whaling era's peak in the 1840s, hundreds of ships visited the islands each year. Firewood was urgently needed. Every ship needed great quantities of wood to fuel the boilers that separated the whale oil from the blubber. Thousands of acres of forest across the Hawaiian Islands were chopped down to sell to whalers.

More rats arrived with the whaling ships. Brown and black rats are larger and more aggressive than Polynesian rats, and they preyed heavily on native bird and insect populations. In 1827, a whaling ship emptied its old water barrels into a Maui stream (Youth 2006). Days later, natives were bitten by the islands' first mosquitoes. At least a dozen species of birds became extinct, because the new pests carried avian malaria and bird pox, to which the native species had no immunity. Several epidemics reduced the native Hawaiian population. The first was

brought by Captain Cook. Later epidemics of bubonic plague, cholera, small pox, influenza, whooping cough, and measles took their toll on the islands' population. By 1823, a missionary census counted only 142,000 native Hawaiians, and in 1850 there were only 70,000 (Storr, 1966, p. 172). By the 1860s, many villages had been abandoned.

The decline in the native Hawaiian population actually coincided with the growth in export agriculture. Many different crops had been brought to the islands by a Spaniard named Francisco de Paula Marin, who arrived in Honolulu from Mexican California in the early 1790s (Marin, 2007). Marin kept up a correspondence with ranchers and botanist-monks in California, while ship captains brought him plants from all over the world (Storr, 1966, p. 106). He experimented with pineapple, wheat, tobacco, and sugarcane, among other crops.

Many other agricultural projects by American planters, Hawaiian royalty, missionaries, and New England businessmen were undertaken including potatoes, oranges, and wheat, which were either sold to whalers or shipped to San Francisco to feed Sierra Nevada gold miners (Storr, 1966, p. 225). Coffee was introduced in the early nineteenth century. It grew well in a few places on the drier, leeward slopes of the large islands, but cultivation remained quite limited. During the Civil War, Hawaiian cotton was exported to New England textile mills. The soft hairs of Hawaii's tree ferns were used in pillows and mattresses. Between 1860 and 1864, 600,000 pounds were exported each year (Cuddihy & Stone, 1990, p. 39). Often the entire tree fern was destroyed in the harvesting. Native Hawaiian taro patches were replaced with rice. The pineapple wasn't grown for export until the end of the nineteenth century, but by the 1950s, thousands of acres, including the entire island of Lanai, were in pineapples (p. 42).

A variety of sugar cane, possibly introduced from the Marquesas, grew wild in Hawaii, but no sugar could be produced without a mill. The first successful mill exported four tons of sugar from Kauai in 1836 (Storr, 1966, p. 233). Sugar cultivation increased exponentially after that. By 1970, sugar cane covered 250,000 acres, and over one million tons were produced (Cuddihy & Stone, 1990, p. 42).

The value of sugar and pineapples to the Hawaiian economy was immense but had serious consequences. Pineapple and sugar plantations pushed agriculture into marginal areas that required irrigation and fertilizers. Huge amounts of firewood were needed to fuel the boilers that processed the sugar. Railroads were laid down to move cane and firewood from the fields to the mills. Planters realized they were harvesting the wood faster than it could grow and planted thousands of acres of fast-growing, nonnative trees.

Sugar refineries were not the sole reason behind the disappear-

ance of much of Hawaii's forest cover. The forests of southern Hawaii were cut down to make railroad ties for the continental United States, and 30,000 acres were logged for this purpose up until 1913. For years, state planners envisioned commercial timber plantations that would rival the success of the islands' sugar cane. Since 1950, state initiatives and private interests have cleared and planted thousands of acres, but high milling costs have kept these enterprises from being successful. However, small-scale logging on former ranchlands is increasingly profitable. Today, ranchers export small quantities of wood from native and introduced species to Southeast Asia and California (Cuddihy & Stone, 1990, p. 47). The dormant sandalwood trade was renewed by ranchers in the 1980s; a single shipment in 1988 was worth one million dollars (p. 58).

In the past 200 years, 1,813 plant species have become naturalized in the Hawaiian Islands (Wester, 1992, p. 105). The exotic species come from every continent except Antarctica. Many are escapees from agricultural fields and gardens. Several introduced plant species are stimulated by the fires set by plantation workers and ranchers. After a few anthropogenic fires, highly flammable nonnative grasses predominate and increase the threat of wildfires (Tunison, 1993, p. 376).

Many of the exotic plant species that threaten native ecosystems are spread by introduced animals and birds. At least 160 species of birds have been introduced, and they help to spread invasive plants by favoring their fruit and seeds over those of native plants (Youth, 2006). Whalers and traders intentionally let pigs loose all over the islands, and the soil of thousands of acres of windward rainforest has been altered by rooting wild pigs. Hawaiian plants had evolved in an environment without large grazers and lost their thorns and toxicity. In fact, a field guide to the poisonous plants of Hawaii reveals only one native species; the rest are introduced (Arnold, 1968, p. 27). When cattle were brought to the islands in 1792, they ate their way through native forests and trampled large areas (Morris & Love, 1992, p. xxi). Invasive plant species grew well in the disturbed soil and quickly outgrew native species. The firetree is probably the worst menace, and its dense stands infest 54,000 acres today (Whitaker & Gardner, 1993, p. 226).

Today, pineapple and sugar cane cultivation is declining. Tourism is now the largest contributor to the local economy and to habitat fragmentation. Agricultural land and pasture next to urban areas are more valuable as housing developments and resorts. An old joke is that the construction crane is the new state bird, but urbanization was under way by the 1940s. While the island of Hawaii has seen the fastest growth in recent years, Oahu experienced the worst growing pains. Honolulu has seventy-two percent of the state's population, and as the city grew, its local wetlands were filled in (Economic and Research Information, 2007).

Up until the 1970s, the metropolis's raw sewage was dumped only four miles from Waikiki Beach (Gray, 1972, p. 115). A recent survey showed that several insects endemic to southern Oahu have become extinct due to the intense development of the past thirty years (Loope, 2006). The exact number of insects endemic to Hawaii will never be known because predation by introduced species, anthropogenic fires, and agriculture probably drove some into extinction before Captain Cook ever reached the islands. Scientists do know that seventy birds are extinct and thirty-one more are endangered (Loope, 2006). Almost 900 species or seventy-one percent of Hawaii's native land snails are extinct. At least one bird, the Lanai Hookbill, disappeared after its main food source, an endemic land snail, became extinct (Lanai Hookbill, 2006).

However, the greatest changes to the islands will come from global warming. As greenhouse gases trap solar radiation and increase global temperatures, the ice of Greenland and Antarctica will melt, which in turn will raise global sea levels. If sea level rise occurs over a short time period, the coral reefs of Hawaii, whose biodiversity is comparable to that of tropical rainforests, will die in water too deep for enough sunlight to penetrate for photosynthesis. In addition, huge quantities of carbon are being absorbed into the oceans and the pH of sea water is decreasing. A more acidic ocean will weaken or possibly dissolve the calcium carbonate structures not only of coral, but of shellfish and plankton. Finally, the rising temperatures will enable disease-bearing mosquitoes to spread into the remaining upland forests on Maui and Hawaii, which are the last stand for several native Hawaiian birds.

The list of environmental alterations is long and the net result has been a trend towards extinction. Although the native Hawaiian population has rebounded from years of nineteenth-century epidemics, native communities face new catastrophes looming on the horizon. A thorough understanding of Hawaii's environmental history is only half of what is needed to preserve what is left. We need to act to prevent global warming, habitat fragmentation, and extinction.

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