Seabirds of Hawaii

Natural History and Conservation

CRAIG S. HARRISON

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To Mom and Dad

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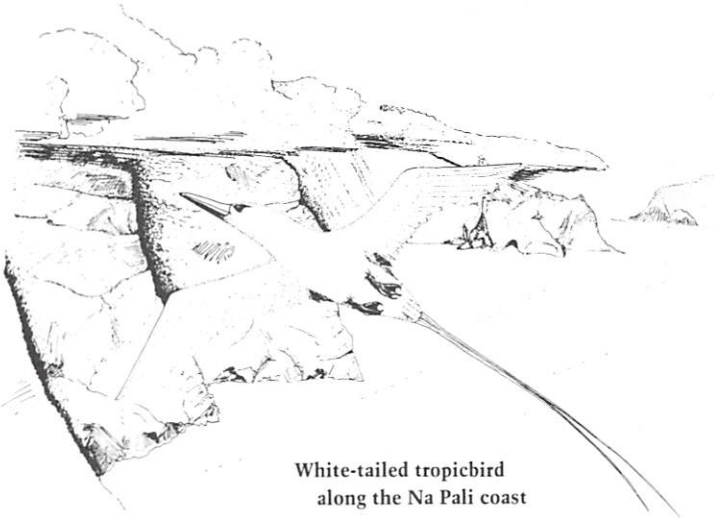

White-tailed tropicbird
along the Na Pali coast

PART I

The Environment and Humans

On landing, we were much annoyed by the birds, many of which made their attack flying, while others ran after us, pecking at our legs: it was with great difficulty we could keep them off, even with our canes. . . . The heat of the day was excessive, and, almost at every step, we sunk up to our knees in holes, that were concealed by overgrown creeping plants, and contained nests, as we supposed, of various birds; for we often heard their cries under our feet from being trampled upon. . . . [Lisianksi] promises nothing to the adventurous voyager but certain danger in the first instance, and almost unavoidable destruction. . . .

—Captain Urey Lisianski, October 10, 1805

1 THE ISLANDS

The National Oceanographic and Atmospheric Administration's ship *Townsend Cromwell* rolled and pitched in the choppy late-February seas as squalls alternated with clear patches in the turquoise-charcoal expanse of sea and sky. On the lee side of the bridge I was protected from the sloppy weather while awaiting my first glimpse of the famous Laysan Island. It was unimpressive. Except for one grove of palms, the low, flat band that appeared on the horizon increased little in relief as we carefully approached through the coral shallows. Dozens of Laysan and black-footed albatrosses circled the research vessel while we waited for the seas to moderate so that the crew could safely put a zodiac over the side. With the wind and swells bearing from the northwest, the eastern shore provided sufficient protection to allow our team of biologists to land. The rough days at sea were worth the trouble. This flat, sandy island greeted me with one of the finest remaining wildlife spectacles on earth—hundreds of thousands of clacking albatrosses, subterranean colonies of wedge-tailed shearwaters that moaned eerily at night, bevies of inquisitive white terns, scores of endangered monk seals dozing on the beach. Soon enough I also met clouds of pesky house- and blowflies that seemed to be the size of bats when they swarmed around my face.

Although the Hawaiian archipelago stretches almost 2,500 kilometers across the North Pacific Ocean, most people think of it as consisting of the eight main or high islands in the southeast portion of the archipelago, which includes over 99.9 percent of its 16,600 square kilometers of land mass and virtually all of the human population. But Laysan exemplifies another Hawaii—Hawaii's seabird colonies. That Hawaii consists of tiny islets and stacks offshore the main islands, such as Molokini and Moku Manu. And it includes emergent rocks,

low-lying coral reefs, and sand spits northwest of Kauai with romantic-sounding names such as French Frigate Shoals, Gardner Pinnacles, and Pearl and Hermes Reef.

No other volcanic islands are so far from a continent as the Hawaiian Islands. They are not even close to other islands of appreciable size. Virtually alone in the North Pacific, the Hawaiian Islands are almost 4,000 kilometers from North America and the Marquesas and over 6,000 kilometers from Japan. The nearest neighbors are small islands—Johnston, Wake, Marcus (Minami Torishima), Palmyra. Geological evidence indicates that the Hawaiian chain was never a continuous strip of land, nor has it ever been connected to any continent. No "vanished" islands can reasonably be imagined between Hawaii and North America. The Hawaiian archipelago comprises about 132 islands, reefs, and shoals that straddle the Tropic of Cancer. Of these, twenty-seven or so, those from Nihoa to Kure Atoll, are designated the Northwestern Hawaiian Islands (Figure 1) by the geographer of the State of Hawaii. The precise number changes when sand spits form, disappear, or merge after severe winter storms. Disappearing Island in French Frigate Shoals is appropriately named, and Seal-Kittery in Pearl and Hermes Reef was once two distinct islands.

The Volcanic Origin of the Hawaiian Islands

The Hawaiian Islands are almost entirely volcanic in origin—sedimentary rocks form only a narrow ridge around the edges of some large islands. The vast majority of the volcanic rocks are lava flows, formed by outpourings of liquid magma. A few were formed of fragments thrown out by volcanic explosions. The volcanic nature of the islands is inescapable to any resident or visitor. Kilauea Volcano, on the island of Hawaii, is the most continuously active volcano on earth, and such volcanic features as cinder and tuff cones, domes, and giant shields are prominent on most main islands. Tremors are common and can be felt daily on the island of Hawaii.

Oceanic islands are almost always volcanic in origin. What forces control the formation of islands that must rise 5,000 meters from the ocean floor merely to break the sea surface? The theory of plate tectonics, formulated by earth scientists in the late 1960s, provides simple answers to such questions. Plate tectonics unifies observations concerning continental drift and sea-floor spreading and provides an explanation of the evolution of ocean basins and continents over the past 200 million years. The theory of plate tectonics is as important a unifying theory within the earth sciences as the theory of evolution is to the biological sciences.

Earth scientists now recognize that the outer layer of the earth's surface is divided into many blocks or plates. Most plates consist of continental land masses and adjacent ocean floor, but some consist entirely of oceanic areas. Most of the Pacific basin, including the Hawaiian archipelago, is located on the

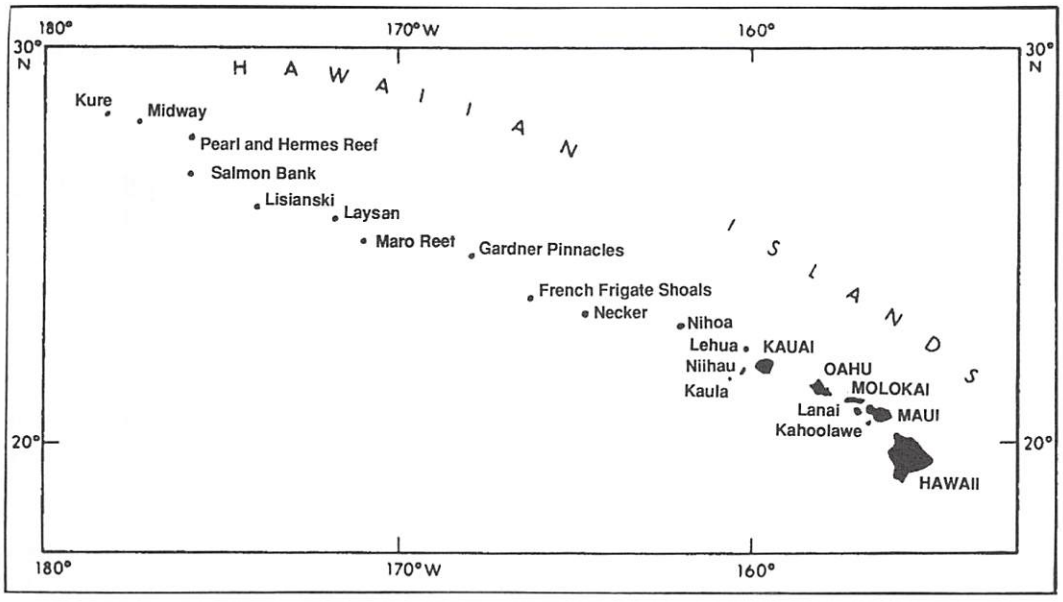

Figure 1. The Hawaiian archipelago

Pacific plate, the largest on earth. Like all plates, the Pacific plate is rigid and moves over a layer of molten earth some 60 kilometers below the surface. Where two plates converge, as they do near the Marianas Islands, a trench is created where one plate overrides another. Where two plates diverge, partially molten material rises to the surface through the weakened crust and forms ridges.

The unique and crucial phenomenon that has created the Hawaiian archipelago is the existence of a hot spot in the Pacific plate, which is currently located in the vicinity of the island of Hawaii. A hot spot results from a plume of magma that rises to the earth's surface from deep in the mantle. Geologists recognize sixteen such hot spots on the face of the earth. The molten rock at a hot spot is forced up through a rupture or fault in the basalt rock of the ocean floor. Over hundreds of thousands or millions of years, small amounts of lava ooze out, each new layer piling up on previous layers. Such processes created the Hawaiian islands, some of which rise ten thousand meters from the ocean floor and only half of which are above sea level.

The volcanos of the Hawaiian archipelago were built in a northwest–southeast direction across the North Pacific Ocean floor. The islands are so closely grouped in the chain and have extruded so much lava that they are connected by huge submarine ridges. The ages of basaltic lava on different islands can be estimated by radioisotope methods. The oldest, Kure Atoll, was formed about 30 million years ago. While the hot spot's location has remained fixed, the Pacific plate has gradually moved northwest, shifting the locations of eruptions

on the plate until now the only active volcanos are those in the southeastern portion of the chain. Salmon Bank, a submerged volcano near Pearl and Hermes Reef, is estimated to have formed about 20 million years ago. French Frigate Shoals is about 10 million years old.

A similar pattern holds even among the main or high islands. Kauai, at the northwest end, is about 4 million years old; Hawaii is less than a million. Loihi Seamount, some twenty kilometers southeast of Hawaii, is potentially the next Hawaiian island. It is actively building now, and if it increases only about a thousand or so additional meters, it will emerge as an island. This process may occur quite quickly by geological standards, but rather slowly in human terms—estimates vary between 2,000 and 20,000 years. Several of the main islands were formed by a wedding of two separate volcanos, such as the Waianae Mountains and Koolau Mountains on Oahu. Even there the west–east pattern is remarkably constant: the western Waianae range is older than the eastern Koolaus.

Abundant geophysical evidence has established that the Hawaiian chain is related geologically to the Emperor Seamounts, a series of submarine peaks that extend north beyond Kure Atoll as far as the western Aleutians (Figure 2). The Emperors are similar in profile to other oceanic islands, but smaller. They rise several kilometers above the ocean floor with circular or elliptical bases and steep slopes and are grouped in a line running from north to south. The oldest reef corals in the Emperors have been recovered from Koko Guyot, which is estimated to have formed 48 million years ago. Meiji Guyot, the northernmost volcano edifice at 53 degrees north latitude, is 70 million years old. The Emperors emerged over the same hot spot as the Hawaiian chain.

The rocks and atolls of the Northwestern Hawaiian Islands, covering less than fourteen square kilometers, are worn to mere vestiges of their ancient estate. What did the chain look like millions of years ago? As now, it was certainly an archipelago of isolated islands far from any continent, with a tropical or subtropical climate similar to the one we know today. The Northwestern Hawaiian Islands were once high volcanos, but just how high and how large is a matter of conjecture. The size would have fluctuated over time with the dynamic processes of island building and the eventual decay and erosion wrought by wind, rain, and sea. Some of the atolls and shallow banks surrounding the islands rival today's high islands in size, and the former masses of the Northwestern Hawaiian Islands were probably once at least the size of Kauai or Oahu. During glacial periods, huge accumulations of ice dramatically changed the levels of the ocean. Although such changes would have occurred over thousands of years, it is certain that at times the sea level was at least 100 meters lower than it is today. If the sea were at such a level now, the atolls at French Frigate Shoals, Pearl and Hermes Reef, Pioneer Bank, and Salmon Bank would be large islands. It is probable that some 17,000 years ago, during the Wisconsinian glacial period, the shallow channels that today separate Maui, Molokai, and Lanai were dry land, so that the three islands formed a single large one; geologists have named it Maui Nui. Penguin Banks, a submerged shelf west

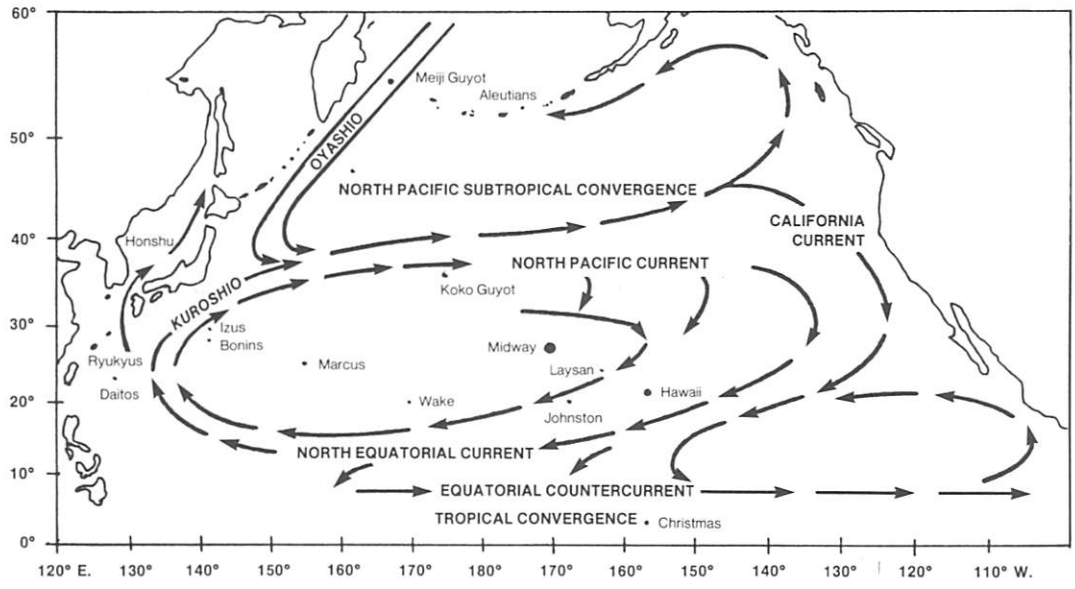

Figure 2. The North Pacific

of Molokai, was then an emerged island. What the sea level can give it can also take away. During warm periods with minimal polar ice caps, sea levels have been at least 30 meters higher than they are today. Such levels, if not accompanied by concomitant growth of coral reefs, would drown all of the present Northwestern Hawaiian islands except outcroppings at Nihoa, Necker, La Perouse Pinnacle, and Gardner Pinnacles. Such levels would also submerge the coastal areas of the main islands, shrinking their land masses substantially. Conceivably, during periods of increased sea levels in the past, Maui and Molokai have each been split into two separate islands.

The transition stage between a high and a low volcanic island passes rapidly in geological terms. Even as periodic ejaculations of molten lava are building a volcanic high island, natural forces begin to chip it away. Wind, rain, and lichens break down the sheets of flat rock to form soil. Waves cut down high sea cliffs, streams carve deep valleys, and after a few million years a once-mighty volcano has begun to disappear beneath the sea. In tropical and subtropical regions such as Hawaii, reef-building corals flourish in the nutritious nearshore waters. As long as the seawater remains above 18 degrees centigrade, corals (relatives of jellyfish) and coralline algae can grow in coastal waters down to depths of 30 meters, depending on the depth that sunlight can penetrate. A reef is a colony of millions of tiny individual animals or polyps, each of which secretes a chalky, cuplike skeleton. As each polyp dies, it leaves behind a calcium carbonate skeleton on which successive generations of corals live. The countless skeletons that are deposited over eons form a calcium carbonate wreath around the drowning island; only the surface layer is alive.

Coral reefs function to ensure the continued existence of most of the North-

western Hawaiian islands. As long as the rate of coral growth and other sources of limestone production keep pace with the changes in sea level which cause an island to drown, the Northwestern Hawaiian Islands will remain emerged. The depth of coral deposits that cap the basalt bedrock of the Northwestern Hawaiian Islands has not been determined but is probably considerable. Borings at Eniwetok and Bikini atolls in the Central Pacific went through 1,400 meters of coral deposits before hitting bedrock. A threshold for atoll formation, called a Darwin point, exists today near Kure Atoll. North of Kure, growth and development of coral in the cooler waters are too slow to keep pace with the forces that erode and drown islands. Research by Richard Grigg of the Hawaiian Institute of Marine Biology suggests that the Darwin point has remained near its present location at 29 degrees north latitude for 20 million years or so. The principal submerged peaks of the Emperor Seamounts are capped by drowned coral reefs that were unable to grow fast enough once the Pacific plate pushed the reefs into the cold North Pacific waters beyond the Darwin point.

The Main Hawaiian Islands

Little is known about the numbers or even species of seabirds that nested on the main Hawaiian islands when Westerners arrived. Our knowledge about the situation before the archipelago was colonized by the Polynesians is restricted to what we can learn from fossils and middens. Studies by Storrs L. Olson of the Smithsonian Institution have greatly expanded our knowledge of the fossil avifauna in the main islands. Today most of the main islands' nesting seabirds are found in relatively high mountain areas. Cliff-facing ledges and crater walls such as those on Haleakala Crater on Maui, at Mauna Loa and Mauna Kea on Hawaii, and in the canyons of Hanapepe Valley on Kauai sometimes harbor nesting birds, as do predator-free coastal headlands such as Kaholo Pali, Lanai, and Crater Hill, Kauai. Such areas are usually sparsely vegetated, with only a few grasses and ferns interspersed among the rocks. Some coastal areas support colonies of red-footed boobies, which nest on shrubs well above ground level. Burrowing birds require nest sites free from predators, and such habitat is now particularly rare in the coastal portions of the main islands. The vegetation of the main islands is generally varied, and much of the Hawaiian landscape has been usurped by alien species, especially in coastal areas.

The primary factor that determines the locations of seabird colonies on the main islands is the absence of introduced predators. In their pristine prehuman condition, the Hawaiian Islands were home to a single terrestrial mammal, the hoary bat. No land-based predator posed a threat to nesting seabirds. Ancient Polynesians brought dogs, pigs, and probably Polynesian rats to the islands. Much later, Westerners brought European pigs, black rats, Norway rats, cats, mongooses, and mosquitos, which harbor avian malaria in their salivary glands. Many alien mammals eat eggs, chicks, and adult birds. High mountain rocky

outcrops and canyon walls provide nesting sites free from such predators. Similarly, dense stands of uluhe ferns on Kauai provide protection for Newell's shearwaters at elevations as low as 150 meters. Elsewhere, small colonies may form where local topography affords protection. White terns in recent years have nested in various exotic trees in the parks of urban Honolulu, especially Kapiolani Park in Waikiki. Red-footed boobies nest in shrubs at Ulupa'u Head in the Kaneohe Marine Corps Air Station, Oahu, and along the steep cliff face at Kilauea Point, Kauai. Wedge-tailed shearwaters nest at many coastal sites on mongoose-free Kauai. They fare best on a flat-topped peninsula at Kilauea Point, where refuge managers use fences and traps to exclude dogs and cats. Cliff faces in isolated headlands such as Waihe'e Point, Maui, also provide sufficient natural protection for wedge-tails to nest, and undoubtedly biologists will discover other small colonies when the coasts of the main islands, especially Niihau, have been carefully surveyed. Several caves and cliffs along Kauai's Na Pali coast provide sufficient protection for small colonies of black noddies.

Suitable protection tends to be found on the small islets that lie just offshore the main islands. The tuff cones and sea stacks are rarely large enough to support populations of medium-sized predators such as dogs and cats, but rats are frequently a problem. Several small colonies of seabirds are found offshore Hawaii (Figure 3), Maui (Figure 4), Molokai (Figure 5), and Lanai (Figure 6). The difficulty of landing on such islets makes information scarce but also provides the protection that is needed for successful nesting. Thirteen colonies, two of them large and important, are located within a kilometer of windward Oahu (Figure 7). Manana (Rabbit) Island just offshore Waimanalo consists of two tuff cones, one of which encompasses about 63 acres. Manana is vegetated primarily with grasses, but wild tobacco and several palm trees also grow there. European rabbits were introduced by 1900 and probably have restricted plants to such an extent that they no longer attract shrub-nesting seabirds. Rabbits and mice apparently have not posed serious problems to the large colony of five ground- and burrow-nesting seabird species there, and rabbits may have died out naturally during the 1980s. As Manana can easily be reached by small boat from Waimanalo pier, it is a convenient location for scientific studies and naturalist field trips. Moku Manu (Bird Island), an eroded volcanic cone just offshore Ulupa'u Head, Kaneohe, consists of an eighteen-acre main island adjacent to a three-acre rock. It has sufficient shrubbery to allow red-footed boobies to nest, in addition to at least eleven other species. Landing is problematic at best, and I bear scars from clambering ashore there during a biological survey in heavy surf. Mokoli'i (Chinaman's Hat), Moku'auia (Goat Island), and Popoi'a (Flat Island) harbor rats, possibly because of their proximity to shore.

There are several seabird colonies on Kauai (Figure 8) and Niihau. Lehua and Niihau (Figure 1) were once a single island, but when the land that connected them was worn down to an underwater shelf, Lehua was created as a 291-acre separate island. Despite the presence of European rabbits and rats, Lehua has a colony of at least ten seabird species. Kaula Island, a 136-acre rock about 40

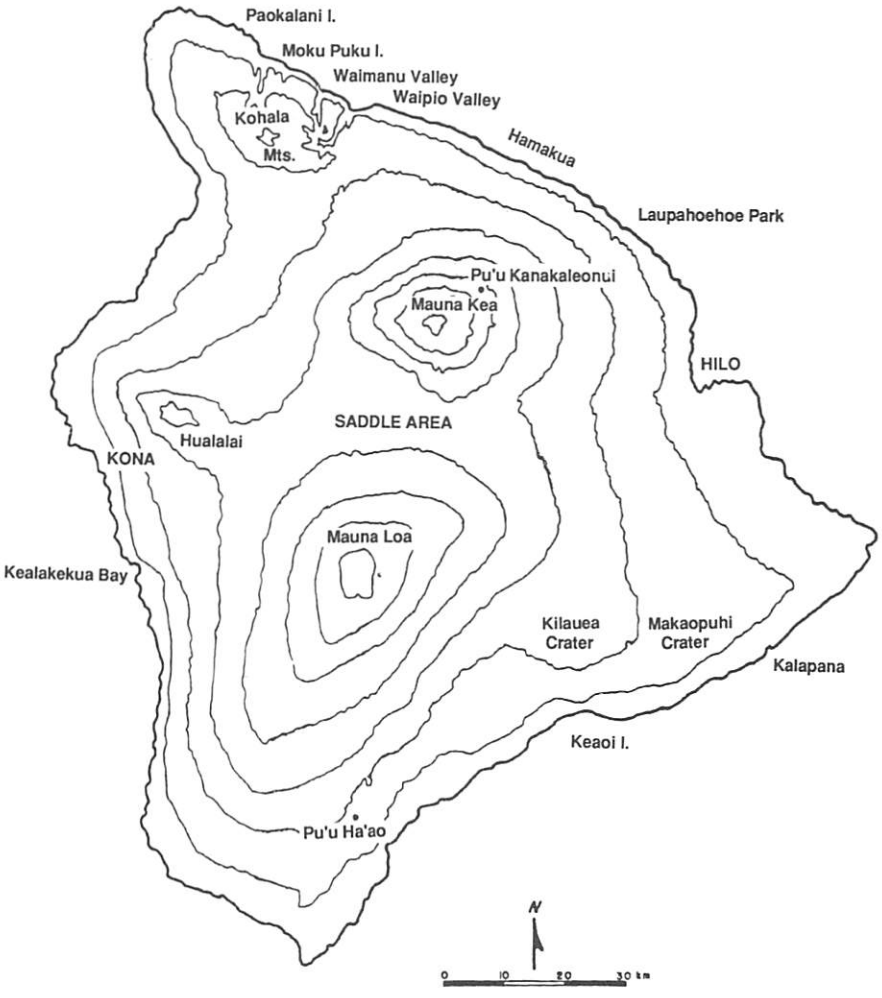

Figure 3. The island of Hawaii

kilometers southwest of Niihau, is also an important seabird colony. Although it has been used by U.S. Navy and Marine Corps aircraft for bombing and strafing practice since 1952, at least sixteen species of seabirds breed there. An unknown species of rat was present there in 1938.

The Northwestern Hawaiian Islands

The Northwestern Hawaiian Islands are quite small. The plant community consists of the typical beach species that are distributed throughout the tropics by coastal currents. These islands, however, are home to several endemic plants

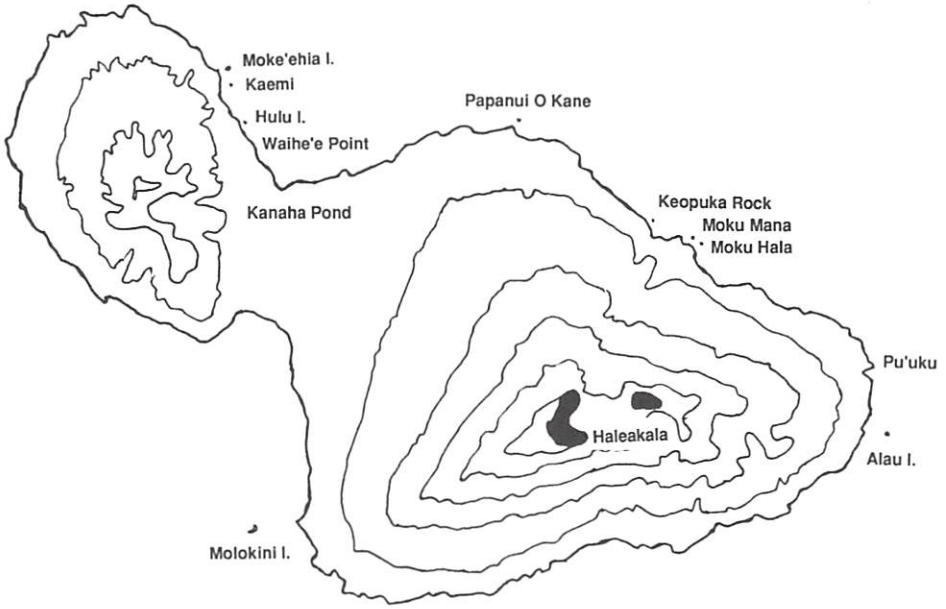

Figure 4. Maui. Shading represents nesting areas of dark-rumped petrels.

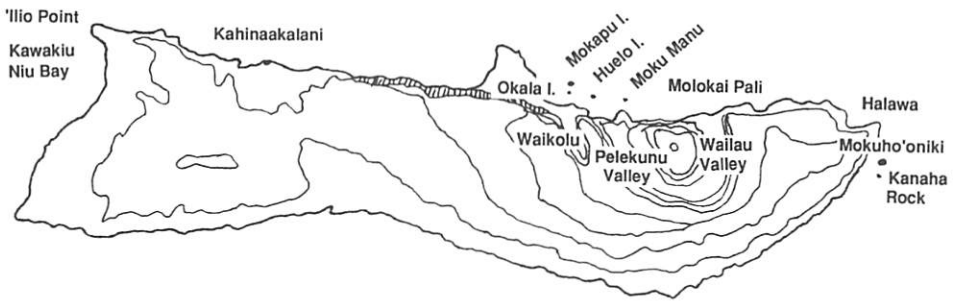

Figure 5. Molokai

and birds and a Hawaiian monk seal that is found nowhere else, as well as to 14 million of Hawaii's 15 million seabirds, including eighteen of Hawaii's twenty-two species.

Nihoa Island

Nihoa Island, the easternmost of the Northwestern Hawaiian islands, is 400 kilometers from Honolulu. Landings on Nihoa can be difficult, especially during winter, and consequently much of its natural history is poorly known. It sits at the southwest edge of a submarine bank where water depths range from 50 to

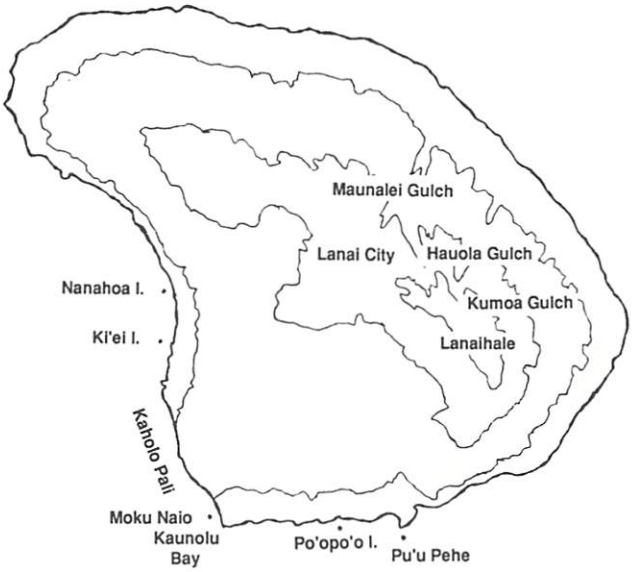

Figure 6. Lanai

Figure 7. Oahu

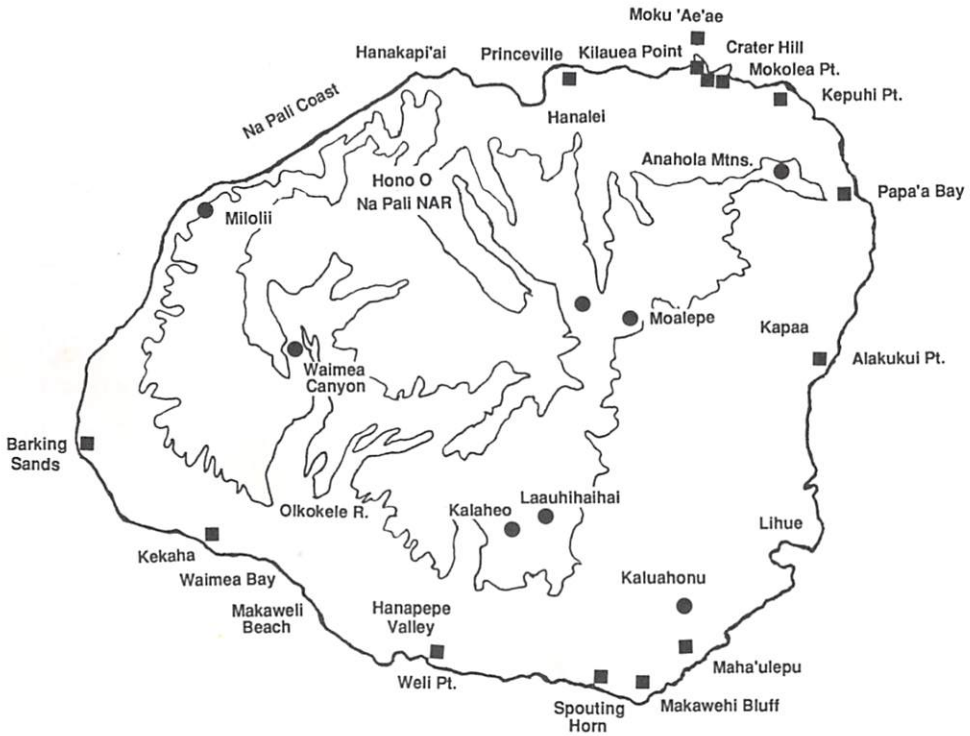

Figure 8. Kauai. Newell's shearwater colonies are represented by circles, wedge-tailed shearwater colonies by squares.

70 meters. With an area of 156 acres, Nihoa is the largest of the lava islands northwest of Niihau. This precipitous remnant of a volcanic cone has steep slopes and rocky outcroppings. Nihoa is too sheer to have a fringing reef. The northern and eastern edges are vertical cliffs, the result of waves driven into the island by the prevailing trade winds. Fanning out from Adam's Bay are six well-developed valleys that are densely vegetated with low shrubs such as goosefoot, nightshade, and ilima and an endemic loulou fan palm. Bunchgrasses are common on the ridge areas but Miller's Peak (300 meters in elevation) and Tanager Peak are mostly bare. As the island has no streams and only a few seeps, it is subject to drought between storms. Nihoa supports a remarkable flora and fauna that occur nowhere else, including four plants, 35 arthropods, about 3,000 Nihoa finches (a honeycreeper), and 350 Nihoa millerbirds. Populations of the endemic birds seem to fluctuate widely. Small numbers of Hawaiian monk seals and green sea turtles bask on Nihoa's small beaches but rarely reproduce there.

Necker Island

Necker Island is a sharply rising ridge of volcanic rock which, like all of the other Northwestern Hawaiian islands, is a remnant of a volcanic cone. This rocky island lacks a fringing reef and is located on the northwestern end of a

large, shallow bank some 120 kilometers southeast of French Frigate Shoals. With an area of only 41 acres, it is one-quarter the size of Nihoa. Necker has steep slopes, shallow valleys, and a craggy, wave-sculpted appearance. The island consists of two parts. The principal one is a 1,300-meter-long ridge that varies in width from 60 to 200 meters. The lesser part, Northwest Cape, is separated from the main island by a gap that is barely above sea level. Landings at the gap can be dangerous during high surf. Necker has no trees and its thin soil has permitted the establishment of only five plant species, two of which (goosefoot and ohai) are shrubs. No land birds are found there, probably because the island is too small to support them. Green sea turtles bask on the gap area of Necker, but they cannot nest on the island because it has no sandy beaches. Increasing numbers of Hawaiian monk seals have hauled themselves out on Necker during recent years, and some pups are born there.

French Frigate Shoals

French Frigate Shoals is located at the midpoint of the Hawaiian archipelago. The atoll is unusual in that La Perouse Pinnacle, a one-acre rock standing 40 meters above sea level, still stands as the last vestige of the high island from which the atoll was derived. French Frigate Shoals is an imperfect, crescent-shaped atoll on an oval platform 40 meters deep. The crescentic reef is double. The outer arc, 56 kilometers long, is almost continuous, whereas the smaller inner arc is broken. In addition to La Perouse, twelve small, sandy islets exist in the atoll today. Topographical changes have taken place periodically during the past century. Gin, Little Gin, and Disappearing islands are inundated from time to time, and Bare, Mullet, Near, Round, and Shark islands are essentially continuously shifting sandbars. Whale-Skate Island consisted of two separate islands as recently as 1923 but they are now "permanently" joined into a single islet, at least until a major storm rearranges the atoll.

The transitory nature of many of the islets in French Frigate Shoals is reflected in the vegetation. Only about a third of the 111 acres of emergent land within the atoll is vegetated, and well-established vegetation is restricted to Tern, Trig, East, and Whale-Skate. Ironwood trees have been planted along the runway at Tern and a few beach magnolia and beach heliotrope shrubs grow on some of the islets. Otherwise, all of the vegetation consists of typical low herbaceous atoll plants, such as morning-glory, puncture vine, purslane, and *Boerhavia*. Tern Island originally covered about 11 acres but was converted into a 57-acre spoil island to serve as an airfield during World War II. Much of its surface today is covered by the airstrip, fuel tanks, and buildings. There are no native land birds within the atoll, but the islands are crucial to the continued existence of Hawaiian monk seals and green sea turtles. William Gilmartin estimated a population of about 800 monk seals there during the late 1980s, by far the largest population anywhere. Each year 300 or so green sea turtles nest within French Frigate Shoals and account for about 90 percent of the sea turtles nesting in the Hawaiian Islands.

Gardner Pinnacles

Gardner Pinnacles is the smallest island group in the Northwestern Hawaiian Islands, comprising two volcanic rocks totaling three acres. It is the westernmost volcanic island in the Hawaiian archipelago and almost certainly the oldest piece of emerged lava in the chain. Gardner Pinnacles lack a fringing reef and are located on the northeast portion of a large submerged bank with depths ranging between 18 and 80 meters. The bank is roughly 32 by 80 kilometers in extent and would be larger than Maui if it were entirely emerged. The larger basalt pinnacle is 58 meters high and from a distance appears to be capped with snow, which on closer inspection is revealed to be liberal coats of guano. The rocks are largely barren, and only a few plants such as purslane and ohai have successfully gained a roothold. Access to the islands is extremely difficult, and scientists aboard research vessels rarely even attempt to land. A few monk seals and green sea turtles can be seen nearby, but they do not pup or nest there.

Maro Reef

Maro Reef, between Gardner Pinnacles and Laysan (Figure 1), is an oval-shaped coral bank 45 by 29 kilometers. The entire area consists of submerged reefs and coral heads except for a single rock that barely protrudes above sea level. Among the submerged banks of the Northwestern Hawaiian Islands, Maro Reef is unique in the extensiveness of its shallow portions.

Laysan Island

Laysan Island is located about 1,100 kilometers northwest of Honolulu. Like other islands in the chain, it sits on the flattened top of what was once a massive volcanic peak formed perhaps in the Miocene. Shallow water less than ten meters deep extends in all directions for eight kilometers, and the bank defined by the 200-meter contour line around the island encloses an area of over 500 square kilometers. Laysan is somewhat unusual in being slightly elevated, so that it has a larger land mass than most other atolls. What would normally be a lagoon inside a barrier reef is primarily land, some of which is ten meters above sea level. A fringing reef surrounds the island, varying from 100 to 500 meters in width at the northwest end. With an area of 913 acres, it is the largest of the Northwestern Hawaiian islands. About one-fifth of the area is a lagoon in a central depression which harbors brine shrimp and is much saltier than the ocean.

Laysan is roughly rectangular and is ringed by large, stabilized sand dunes. Except for the coastal dunes, it is generally well vegetated. The beaches have patches of beach magnolia and beach morning-glory. Clumps of tall bunchgrass characterize the area that slopes gently toward the lagoon. Low-lying succulents such as carpetweed grow in the mudflats and along the edge of the lagoon. The only trees on Laysan are a grove of introduced coconut trees in the

northwest corner of the island and a single stunted ironwood. The relatively large area combined with its isolation have permitted Laysan to develop unique flora and fauna. Five endemic plants and an equal number of endemic birds occurred before the turn of the century, but various depredations brought the extinction of Laysan sandalwood, loulou fan palms, rails, millerbirds, and honeyeaters. Today about 500 endemic Laysan ducks and 10,000 endemic Laysan finches live there. The island is an important rookery for Hawaiian monk seals and a minor nesting area for green sea turtles. Unfortunately, humans have introduced house- and blowflies, which are noxious and constant irritants to visitors.

Lisianski Island

Lisianski Island sits on the northern edge of Neva Shoal, a 170-square-kilometer reef bank. Another major submerged reef, Pioneer Bank, lies 35 kilometers to the east. Like Laysan, Lisianski is an upraised atoll with a central depression, but unlike Laysan, it has lacked a central lagoon, at least during historic times. Lisianski is a flat sand-and-coral island. With an area of 450 acres, it is larger than any of the Northwestern Hawaiian islands except Laysan and either Midway island. Few of this oval island's physical features are noteworthy. The eastern beach has an exposed ledge of reef rock, but otherwise the island is fringed by a narrow sandy beach. The only trees are a few scattered ironwoods, several of which are dead. A rim of beach magnolia grows along its entire perimeter, the most dense growth being found in the sand dunes in the northeast portion. The interior is covered with a lush growth of bunchgrass and several associated plants. Beach morning-glory and spawling mats of puncture vines are also common. Lisianski has no endemic plants or birds, possibly because of widespread destruction of vegetation during the early years of the twentieth century. As on Laysan, humans are plagued by swarms of alien flies. Lisianski is an important rookery for Hawaiian monk seals and harbors a few green sea turtle nests.

Pearl and Hermes Reef

Pearl and Hermes Reef is a large classical atoll in the center of a submerged bank located almost 2,000 kilometers northwest of Honolulu and 160 kilometers southeast of Midway Islands. The fringing reef encompasses a shallow lagoon 70 kilometers in circumference which opens to the west. Like French Frigate Shoals, Pearl and Hermes Reef has undergone considerable changes in topography over time. Although an 1858 map of the atoll shows twelve islands, only eight are present today. As recently as the 1960s a ninth island existed, but Seal and Kittery islands have since merged. The ephemeral nature of the 85 acres of emerged land is exemplified by Bird, Planetree, and Sand islands, each of which is a barren, continuously shifting sandbar. The other islands are

sufficiently permanent to permit the growth of low foliage such as bunchgrass, purslane, nightshade, puncture vine, and carpetweed. There are no trees today on the atoll and visiting biologists are blinded by the noonday glare off the flat expanse of coral rubble. A few scrawny beach magnolia and nightshade plants grow to sufficient proportions to be deemed shrubs if one adopts a charitable definition. Refuge managers introduced Laysan finches to Pearl and Hermes Reef in 1967 and they still survive on Southeast and North, the two largest islets. The Hawaiian monk seal population has declined precipitously since the 1960s in the northwestern portion of the Hawaiian archipelago but a few seals continue to live at Pearl and Hermes. Green sea turtles are common and several nest there each year.

Midway Islands

The Midway Islands are the most recognized location in the Northwestern Hawaiian Islands. Situated over 2,000 kilometers from Honolulu and almost precisely halfway between North America and Asia, they have provided strategic and commercial benefits to the United States for almost a century. The atoll is a nearly circular rim of coral reef, about eight kilometers in diameter. Most of the lagoon is an expanse of shallow water, but the central portion deepens to 21 meters. Much of the northeast portion of the reef is fairly wide and stands sufficiently above sea level to be visible from the islands. Sand and Eastern (Brooke's) islands lie close to the southern rim of the atoll, separated by two semipermanent spit islands. The islands cover 5.5 square kilometers; the largest is Sand. Before human contact, Eastern had vegetation typical of low coral atolls, such as bunchgrasses and beach magnolia. George C. Munro and Henry Palmer surveyed Eastern in 1891 and found it to be the greenest of the Northwestern Hawaiian islands. In its natural condition, Sand consisted primarily of huge dunes of white, shifting sand and was well named. Henry Palmer, a member of the Rothschild expedition, described Sand on July 11, 1891:

> Although this island is comparatively large, it is the most desolate place I was ever on. There is hardly any vegetation except for a few tufts of grass on the south end, and in rough weather most of the island is under water.

During the early twentieth century, employees of the Commercial Pacific Cable Company transformed the island. They imported 9,000 tons of soil and planted exotics such as ironwood trees and San Francisco grass. Today Sand's towering ironwood trees along Commander Row and near the dilapidated Pan American Hotel rival in size any such trees in their Australian homeland. Except for beach areas, little of Sand or Eastern has natural cover—airfields, harbors, roads, houses, buildings, and bare asphalt cover much of the naval air station and the horizon is broken by antennas, guy wires, and tall trees. Sand is heavily planted with introduced vegetation, including the grass of a nine-hole

golf course. Many alien wildlife species have been introduced. Laysan rails and finches flourished on Midway in the 1930s, but were wiped out by black rats and avian malaria at the end of World War II. Today black rat populations can be enormous, and introduced canaries, mice, and mosquitos thrive. Few Hawaiian monk seals and green sea turtles use Midway Atoll.

Kure Atoll

Kure Atoll, the northern- and westernmost of the emerged Hawaiian islands, is the northernmost coral atoll on earth. Coral grows more slowly here than at any other atoll in the Hawaiian archipelago, yet obviously it grows quickly enough to keep pace with erosion and ensure that the island does not drown. The atoll is nearly circular with an outer reef almost completely enclosing a 46-square-kilometer lagoon. The lagoon is fairly shallow and nowhere more than 14 meters deep. Two islands rise on the southern portion of the atoll. Sand is a bare, sandy islet that often splits into several sandbars. Green is a stable, heavily vegetated island encircled by sandy beaches. A dense forest of beach magnolia, up to two meters high, covers much of Green. A United States Coast Guard LORAN station there has necessitated the building of a 1,200-meter runway and the erection of a 200-meter LORAN tower in the central plain of Green. Most of the vegetation at Kure today has been introduced, including ironwood trees and beach heliotropes. Hawaiian monk seals live and reproduce at Kure Atoll, but their population has been declining for many years. Green sea turtles are also seen but they rarely breed here. An unexplained puzzle is the occurrence of Polynesian rats, which may not have been brought by Western ships. Alexander Wetmore believed that they were distributed from island to island in the Pacific as stowaways in the great sailing canoes of the Polynesians, who located atolls such as Kure by searching the skies for green-tinted clouds. Possibly the rats on Kure are the legacy of an errant canoe that otherwise has been lost to history.