Seabirds of Hawaii

Natural History and Conservation

CRAIG S. HARRISON

Comstock Publishing Associates A DIVISION OF

Cornell University Press ITHACA AND LONDON

To Mom and Dad

THIS BOOK IS PUBLISHED WITH THE AID OF GRANTS FROM THE HAROLD K. L. CASTLE FOUNDATION AND THE COOKE FOUNDATION, LTD.

First published 1990 by Cornell University Press.

Printed in the United States of America.

Color plates printed in Hong Kong.

Library of Congress Cataloging-in-Publication Data

Harrison, Craig S.
Seabirds of Hawaii : natural history and conservation / Craig S. Harrison
p. cm.
Includes bibliographical references.
ISBN 0-8014-2449-6 (alk. paper)
1. Sea birds—Hawaii. 2. Birds, Protection of—Hawaii.
I. Title.
QL684.H3H37 1990
598.29'24'09969—dc20 89-71222

∞ The paper used in this publication meets the minimum requirements of the American National Standard for Permanence of Paper for Printed Library Materials Z39.48–1984.

2 THE SEA

During my first five-hour flight from the West Coast to Honolulu I periodically glanced out the window of the 747 as the featureless North Pacific Ocean passed by. I became convinced that oceans are the dominant feature of our blue planet. In an era of jet aircraft with iced drinks, magazines, and feature motion pictures to pass the time, it is easy to forget just how much water separates Hawaii from the continents and how insignificant the islands appear from a distance. Yet it is difficult to be far removed from the sea in Hawaii—the evolution of the land, the creatures, and the humans has been intimately tied to the sea. An understanding of the nature of the tropical and subtropical ocean that surrounds the Hawaiian Islands is fundamental to the natural history and ecology of its seabirds. While the waters that bathe the Hawaiian archipelago extend to depths of four kilometers offshore in the north-central Pacific basin, it is the surface waters that are most important to seabirds.

The distribution and abundance of seabirds in all bodies of water depends on the interaction of physical and biological phenomena, and birds usually appear wherever they can find sufficient food and suitable surface water conditions. Seabird species throughout the world are closely associated with particular water masses, so that it is often possible to predict surface water conditions on the basis of the presence of certain birds and vice versa. Like all marine biological communities, the Hawaiian marine ecosystem is characterized largely by the availability of food, which is affected by sunlight, the temperature and salinity of the water, and the nutrients in it. Hawaiian waters have unique characteristics that ultimately prescribe the food chain that supports seabirds.

Global Oceanography

Marine biologists divide the global marine environment into five broad oceanic zones on the basis of latitude: (1) antarctic, (2) subantarctic, (3) subtropic and tropic, (4) boreal (subarctic), and (5) arctic. Ideally, the surface temperature of each zone would be equivalent to a corresponding vegetation or climactic belt on land. But ocean currents drastically distort the idealized boundaries of many zones: the Humboldt current off the west coast of South America extends the cold waters of the subantarctic zone as far north as the equator.

The temperature and chemistry of marine water masses do not vary continuously from one zone to another. Instead, the major zones consist of discrete water masses that are relatively uniform in their temperatures and chemistries. Fairly abrupt changes occur at the borders of adjacent water masses. In these convergence zones, denser water sinks below the surface, and the associated mixing generates choppy seas. Changes may be dramatic, as in the antarctic convergence, where oceanographers have measured temperature changes of five degrees centigrade over a few hundred meters. The North Pacific subtropical convergence is a more typical boundary, with gradual changes in surface waters which extend many kilometers. The precise boundary of each latitudinal zone varies with seasonal and annual weather conditions. The tropical convergence, about 1,300 kilometers south of Honolulu, and the subtropical convergence, about 2,200 kilometers north, are so far from the Hawaiian Islands that the Hawaiian marine ecosystem remains subtropical throughout the year.

Surface water movements cause well-marked zones of convergence and divergence. The intertropical convergence zone is located near the equator in all oceans where both southeast trade winds and northeast trade winds transport surface water toward the equator. In the Pacific, the zone is located north of the equator near Panama and meanders southeast to about 1,500 kilometers south of the equator near Australia. At the intertropical convergence zone, warm water accumulates and is forced downward. Conversely, water upwells wherever divergence occurs. Such vertical movements of water are important to the biological economy of the sea. Ascending, cold water is rich in the nutrients essential to marine life. Descending, warm water tends to be barren. The mixing associated with large-scale convergences and divergences is an important element of oceanic circulation systems, often extending to depths of over a thousand meters.

What are the sources of ocean currents? The energy for the movement of vast masses of seawater ultimately comes from the atmosphere and the earth's spin. The planet's spin and the heating and cooling of air masses generate planetary winds. Oceanic circulations derive partly from the action of wind on the surface of the sea, partly from the earth's spin, and partly from temperature differences in water masses. Surface currents are predominantly wind-driven. Trade winds, which are largely a consequence of the earth's east-to-west spin, help produce the great equatorial currents. The north equatorial current of the Pacific flows over 14,000 kilometers west from Central America before being deflected northward to become the Kuroshio off the east coast of Japan (Figure 2). From Japan, the Kuroshio mixes with the cold Arctic waters of the Oyashio as the North Pacific current, which flows east across the Pacific near 40 degrees north latitude. Off the coast of North America, the flow is deflected south as the California current, which eventually rejoins the north equatorial current, thus completing the clockwise circulation in the North Pacific basin. A similar circulation occurs in the Atlantic Ocean and includes the Gulf Stream and the Atlantic equatorial current.

Eddies are also characteristic elements of oceanic circulations. They occur in both surface and deep waters and can be so extensive that they cover thousands or even tens of thousands of square kilometers. Some eddies are remarkably persistent and last several years. They are too transient to be shown on maps of average oceanic conditions, yet can have profound effects on the tiny marine plants and animals that may be transported far beyond their typical ranges.

Tropical and subtropical zones tend to have high air pressures, weak winds, clear skies, and much sun. Such factors make surface waters warmer and saltier than those in cooler climates. Cool waters off the coasts of Asia and North America, where the minute plant life called phytoplankton is abundant, are usually gray-green. In contrast, tropical and subtropical seas contain few algae and have a blue cast caused by the scattering of light by molecules of clear water. Biologists have difficulties in defining precisely the difference between tropical and subtropical oceanic zones because they are fairly similar. Tropical zones are usually defined to include all waters where sea surface temperatures remain 23 degrees centigrade or above all year. Tropical zones have only minor seasonal temperature changes in surface waters. Warmer surface waters are separated from cooler subsurface waters by sharp discontinuities called thermoclines, which are present year round and limit the flow of nutrients into surface waters from the deep. The lack of nutrients results in low productivity, especially in areas far from land. Seas adjacent to continents often receive land-based nutrients from rivers, which increase the growth and development of marine organisms.

Some Distinguishing Features of Hawaiian Waters

The waters that stretch to the horizon from the eight main islands (Hawaii, Maui, Kahoolawe, Lanai, Molokai, Oahu, Kauai, and Niihau) are somewhat different from those of the Northwestern Hawaiian Islands, which extend from Nihoa to Kure Atoll. Like oceans everywhere, Hawaiian waters are a quilt of microenvironments, and adjacent water masses possess slightly different physical characteristics. Water temperature, salinity, and primary productivity can vary within short distances as a result of vicissitudes in currents or eddies, rainfall, cloud cover, winds, and marine organisms. Because weather changes constantly, the ocean never becomes a truly homogeneous water mass.

Surface water temperatures near the main Hawaiian islands average about 25 to 26 degrees centigrade during summer and two or three degrees lower in winter. The temperatures of the waters of the Northwestern Hawaiian Islands change correspondingly with the seasons, but are always a degree or two cooler than those of the main islands. All Hawaiian waters have a permanent thermocline, which acts as a physical barrier to mixing between the warm surface water lens and the great masses of deep, cold North Pacific water. The thickness of the warm surface layer varies with the location and the season but is usually about 100 meters near the main islands and 70 in the vicinity of the Northwestern Hawaiian Islands.

Surface salinity in Hawaii is typical of that of subtropical waters, ranging from 35.0 to 35.4 parts per thousand. Salinity is slightly higher between Gardner Pinnacles and Pearl and Hermes Reef. On a global scale, the salinity of virtually all oceanic waters falls between 33 and 37 parts per thousand. As one might expect, warm tropical areas with limited rainfall have the highest concentrations of salts, while cold areas with lots of precipitation have the lowest.

Sunlight is an important factor in every marine ecosystem because photosynthesis is the ultimate source of most life. Light penetrates to a depth that is proportional to the turbidity of the water. Because the blue subtropical waters of Hawaii contain fewer algae than California waters, light penetrates fairly deeply. The photic zone, or layer of water that receives sufficient sunlight to enable photosynthesis, averages more than 100 meters. It is slightly shallower in the Northwestern Hawaiian Islands and decreases during summer, when more phytoplankton are in the water column. In productive areas of the world the photic zone rarely extends more than thirty meters and in extreme situations can be as shallow as a few centimeters. The length of the day varies less throughout the year in Hawaii than in high latitudes. The longest day in Honolulu lasts between thirteen and fourteen hours and the shortest about eleven, while comparable day lengths in Maine are almost sixteen and less than nine. One consequence of fairly uniform day length is that photosynthesis can occur all year, whereas it cannot in such northern waters as the Bering Sea. The growth of algae in Hawaii is never limited by an absence of sunlight.

Permanent thermoclines typically occur in subtropical open-ocean areas where surface layers are strongly heated during most of the year. Surface waters in higher latitudes receive less solar heat and develop shallow thermoclines only during summer, if at all. Winter winds and waves in northern waters mix surface and deep waters sufficiently to break down any temporary stratification that may have developed between them. The permanent thermocline in Hawaii is a barrier to the upward movement of cold, deep subsurface waters that have high concentrations of essential nutrients. Such an impediment to the free flow of nutrients has important consequences for marine organisms.

As in all tropical and subtropical marine habitats, the productivity of Hawaiian waters is limited by the availability of nitrates. Surface waters have similar concentrations throughout the archipelago, but slight increases are apparent during winter and in the Northwestern Hawaiian Islands. Nitrates and to a lesser extent phosphates are scarce in surface waters because they are constantly removed when marine creatures die. Dead plants and animals sink below the thermocline to deep waters, where the nutrients they assimilated in life are released as they decompose. Most surface waters in Hawaii are deficient in nutrients because the lens of warm surface water rarely mixes with the cooler, nutrient-rich deep water. Inshore waters such as the shallow lagoons at French Frigate Shoals and Pearl and Hermes Reef have higher concentrations because nitrates tend to be retained and recycled in the absence of a thermocline. Seabirds may concentrate nitrates in nearshore waters and coral reefs. They feed over vast areas of the ocean, eating prey whose bodies are full of nitrates. When the birds defecate on the islands, their nutrient-rich guano is eventually washed by rain into nearshore waters.

Some areas are enriched by upwellings, eddies, and fronts. On a global scale, locations where upwellings bring nutrient-rich deep water to the surface can be ten times as productive as otherwise similar waters. Enriched waters are often sites for important fisheries such as those found in the Humboldt current off the west coast of South America and the Benguela current off the coast of Namibia, where currents and winds drive surface waters away from the coasts and cold, deep water rises to replace them. On a localized scale, eddies and upwellings are common on the leeward sides of islands and over submerged banks, where deep-water currents collide with submerged volcanic ridges. Uncharted fronts occur in tropical and subtropical waters where water temperature and depth change abruptly. Fronts are associated with increased water turbulence and upwelling, which produce localized concentrations of plants and animals so abundant that the water can have the consistency of soup. In *The Arcturus Adventure*, William Beebe described such a phenomenon in the equatorial Pacific midway between Panama and the Galápagos:

> Again and again I was impressed with one outstanding feature of the Current Rip, this uncharted zoologists' paradise—the narrowness of its limits and the sharpness with which these limits were defined. It was a world, not of two, but to all intents and purposes, of a single plane—length. From first to last we followed its course along a hundred miles, and yet ten yards on either side of the central line of the foam, the water was almost barren of life. The thread-like artery of the currents' juncture seethed with organisms—literally billions of living creatures, clinging to its erratic angles as though magnetized.

Fronts, upwellings, and convergences may greatly enhance the productivity of Hawaiian waters. They are difficult to detect by routine scientific sampling because they are small and seem to occur randomly. During the 1980s biological oceanographers began to believe that the subtropical waters north of Hawaii might be two or three times as productive as earlier researchers had estimated because their sampling ignored such isolated pulses of high productivity. Production varies in the water column and increases substantially near the thermocline, just above the cold, nutrient-rich waters.

The Food Chain

Floating microscopic phytoplankton forms the base of food production in the ocean. These single-celled algae use carbon dioxide, water, and energy from sunlight to photosynthesize carbohydrates. Analogous to green plants on land, they are the primary producers in the marine food web. Because of nitrate limitations, primary productivity in Hawaii is a low 330 metric tons per square kilometer per year, although recent studies imply that this may be an underestimate. Productivity is somewhat higher in summer than in winter and is significantly higher in the Northwestern Hawaiian Islands than in the main islands. It is also greater in waters close to the islands than in offshore waters: the lagoon at French Frigate Shoals produces almost ten times as much phytoplankton as an equivalent volume of water in the open ocean.

The annual primary productivity of the open ocean near Hawaii may be only one-third of that in temperate coastal zone areas and one-tenth of that in open-ocean upwellings. In contrast to the fairly constant levels of productivity of Hawaiian waters throughout the year, production poleward of the tropics and subtropics varies dramatically by season. In arctic and temperate waters phytoplankton suddenly proliferates in spring, providing a vast supply of food for the marine ecosystem. Hawaii has no such spring bloom. Some estuarine and coral reef waters are so productive that in two days they can outproduce the entire annual yield of an equivalent water mass in Hawaii.

The smallest of the creatures that make up plankton, from protozoans to larval fishes, graze on the algae. These primary consumers are in turn eaten by secondary consumers, either carnivorous zooplankton or fish. The position of any species in a food web—whom it eats and who eats it—defines its trophic level. Plants are the first, herbivores the second, primary carnivores the third, and so forth. Tropical and subtropical waters are usually considered to have five trophic levels, the fifth including the largest predatory fishes, such as sharks and tunas.

The five-trophic-level model for Hawaiian waters generally describes the interactions among its thousands of marine plant and animal species, but the actual situation is far more intricate. Trophic levels are more poorly defined in the ocean than they are on land. A predator may feed on three trophic levels during the same day. At different stages in its life cycle, a fish may occupy several trophic levels, consuming zooplankton as a fry and large predatory fishes as an adult. A blue-gray noddy can consume a larval blue marlin and, if unwary, can itself become a snack for its prey's parent minutes later. Interactions among the 11,000 species of fish, 6,000 species of crustacea, and 700 species of squid in the world's oceans can be vastly complex.

Most blue offshore waters in Hawaii are an impoverished biological desert where food chains tend to be long, complex, and inefficient. Each transfer of energy between trophic levels in Hawaii squanders nine-tenths of the original energy, in part because predatory animals spend much more time and energy searching for food than their counterparts in more productive waters. As a result, of every 10,000 units of energy produced by Hawaiian phytoplankton, only one unit winds up in a yellowfin tuna after four energy transfers through five trophic levels. In contrast, productive areas off the coast of California with higher ecological efficiencies and shorter food chains produce four hundred times more energy to top-level predators, such as large fishes, seabirds, porpoises, and humans. At localized upwellings or fronts, Hawaiian productivity may approach California levels. Obviously such oases of food and energy are especially important to the Hawaiian ecosystem and are sought out by hungry predators.

An important phenomenon in the Hawaiian food chain is the daily vertical migration in the water column of planktonic creatures. Unlike phytoplankton, zooplankton is not restricted to the sunlit upper hundred meters of the ocean, but can be found at all depths. Many of these creatures undertake extensive migrations, usually moving toward the surface during the night and descending hundreds of meters during the day. Such movements can be observed as deep scattering layers on ships' echo sounders, though frequently the sophisticated electronic equipment actually detects a school of lanternfish, hatchetfish, or bristlemouths pursuing zooplankton rather than the zooplankton per se. Crustaceans and squid move similarly in the water column. Migrations enable the organisms to feed in the productive euphotic zone yet hide in deep water during the day, when the risk of becoming a meal is greatest. Vertical migration seems to be an important means by which food is transported from the surface to the deep ocean. Deep-water animals consume prey near the surface which otherwise might have remained there to be recycled in surface waters. When the predators descend, they are hunted by resident deep-water creatures. Vertical migrations have influenced the feeding habits of several Hawaiian seabirds.

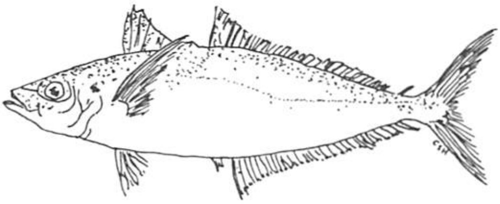
Some Marine Fauna That Are Important to Hawaiian Seabirds

Only a few of the 700 species of fish and thousands of other marine organisms that live in Hawaiian waters are directly important to foraging Hawaiian seabirds. The amount of fish larvae in surface waters seems to influence seabird life cycles. Fish larvae, especially those of inshore and reef species, are most abundant in surface waters during summer, an indication that fish in Hawaii tend to spawn during the summer months. Larvae are almost twice as abundant in the Northwestern as in the main Hawaiian islands. Common larval fishes include anchovies, lizardfish, skipjack tunas, yellowfin tunas, flyingfishes, goatfishes, lanternfishes, sauries, and dolphinfishes. Lanternfish larvae are particularly abundant at night, an indication that even the young of this family migrate vertically in the water column. Anchovies and Pacific sauries are found primarily in the northwestern portion of the Hawaiian archipelago. Such differences in fish fauna between the cool, subtropical northwest waters and the warmer, tropical southeast waters emphasize the transitional nature of Hawaiian waters. North of Kure Atoll the waters become too cool to support coral reefs.

The nine flyingfish species in Hawaii are of special interest because they are commonly consumed by many Hawaiian seabirds. Flyingfish have unusually large pectoral and central fins that can be used as wings, allowing them to skim hundreds of feet above the ocean's surface to flee from porpoises, tunas, dolphinfish, or swordfish. This means of escape from the mouths of predators from below increases their vulnerability to hungry seabirds, which capture flyingfish near the surface or in mid-air. Errant flyingfish occasionally propel themselves onto the decks of ships. Flyingfish attach their eggs to flotsam such as seaweed, pumice, fishing line, and plastic. Most species breed during winter near the equator, but some lay eggs at least as far north as Midway. All flyingfish are migratory. They seek warm water, and their distribution is limited by the temperature of the surface water. Flyingfish are found in all tropical seas and their presence is almost diagnostic of subtropical or tropical waters. They are common at 23 and abundant at 25 degrees centigrade, moving in winter toward the equator and in summer toward the poles, where they feed on crustaceans such as copepods and amphipods. Their migrations bring many of them to Hawaiian waters during summer but far fewer are found in winter. Larval flyingfishes are common in Hawaii all summer.

All three species of mackerel scads in Hawaii are eaten by Hawaiian seabirds. These spindle-shaped fishes are resident, remaining in Hawaiian waters throughout the year, often schooling in large numbers. Young fish shoal near the reef and shoreline, while adults move into deeper water offshore. Mackerel scads usually feed on zooplankton such as amphipods, copepods, and juvenile forms of pelagic crabs. They fall prey themselves to migratory skipjack tunas and are an important source of food to the tunas during summer. Probably the pressures of predation from tunas drive schools to surface waters, where seabirds are more likely to encounter them. Spawning occurs from spring to late summer, peaking from May to July, when fish fry are most in demand by fledgling seabirds and tunas.

Ommastrephid squids are a surface-dwelling family that are common and widespread in all warm oceans. These long, slender mollusks are migratory, traveling thousands of kilometers into warming waters during summer, then retreating toward the equator in winter. Some species in Japan migrate toward



Mackerel scad

shore during April and May to lay eggs on the ocean floor. The migrations and precise breeding seasons of the four common ommastrephid squid in Hawaii are poorly known. Squid produce vast numbers of young, which usually mature within two years. The great frequency with which seabirds, tunas, and porpoises eat juvenile ommastrephid squid implies that squid are a very important component of the Hawaiian marine ecosystem, despite the fact that fishermen and scientists have difficulty catching them. Ommastrephid squid are rapacious and use their hard beaks to attack and devour fish their own size. They also take copepods and small fishes, but they shred their food so thoroughly that it is difficult for biologists to learn the specifics of their diets. Two of the common squid in Hawaii, *Ommastrephes bartrami* and *Sthenoteuthis oualaniensis*, are called flying squid because of their ability to leap from the water as though propelled by submarine cannons when they wish to avoid submerged predators.

Tunas' extensive migration in the Pacific basin poses special problems in international fishery management. Three species are of particular interest to Hawaiian seabirds—skipjack, yellowfin, and little tunas. As we shall see in later chapters, many Hawaiian seabirds feed in association with tuna schools. Tunas forage during the day and apparently make prey available to birds by driving it to the surface: flyingfish and flying squid leap from the water to avoid the tunas. Offshore, skipjack tunas are associated most frequently with bird flocks. The tendency of adult yellowfin tunas to feed well below the surface in Hawaii breaks the linkage with seabirds, but Hawaiian birds occasionally feed with schools of juvenile yellowfin on the surface. Nearshore, bird flocks sometimes congregate over schools of nonmigratory little tunas. Little tuna schools remain fairly close to the shoreline and only rarely venture far offshore. Migratory tunas are most abundant in Hawaii during spring and summer, and fishermen land large amounts of pelagic tunas then. Larval forms are common in Hawaiian waters during summer but rare in winter. Apparently tunas spawn and larvae are present only when the water is 23 degrees centigrade or above. Where waters are cooler, they rarely spawn. The number of tuna larvae near the Northwestern Hawaiian Islands declines from French Frigate Shoals to Midway in concert with declining surface water temperatures.

All marine wildlife depends on the marine ecosystem for sustenance. The natural characteristics of the physical environment provide the ground rules under which all life forms compete to survive. Tropical marine creatures, unlike those in cool northern waters, have the additional challenge of surviving in an impoverished environment that is limited by a lack of nutrients at the base of the food web. Food supplies tend to be patchy, and species that exist millennium after millennium must adapt to take advantage of occasional feasts and survive frequent famines. Seabirds live much of their lives above and in the ocean in search of food. But they are terrestrial expatriates, having originated on land and, like marine turtles and monk seals, must return to terra firma to reproduce. Seabirds have never evolved into true marine creatures because they have never successfully created floating nests at sea. The tie to land is their Achilles' heel.