Introduction

GAZING OUT FROM THE DECK of a steamer near the town of Huarmey, Peru, the ornithologist Robert Cushman Murphy stood in awe at the sight of "such multitudes of herrings as I had never previously beheld." He marveled at the dense school of "quivering, silvery creatures" swimming in the cold coastal current: they were "packed together like sardines in a tin . . . as their legion, which somehow seems more like an individual organism than a conglomeration of millions, streams through the gauntlet of its diverse and ubiquitous enemies."[1] Eighteenth- and nineteenth-century seafarers traveling along the South American Pacific coast had often remarked on the tiny fishes that swam in schools so massive that they visibly darkened the sea surface against the distant horizon.

The immense, quivering schools Murphy described were anchoveta (*Engraulis ringens*), an endemic species that thrives in the cold, plankton-rich waters of the Humboldt Current ecosystem. Their abundant populations are integral to the diets of many other marine fauna, including tuna, seals, and the innumerable seabirds that nest on rocky islands off the arid coast between northern Peru and central Chile. Murphy recalled the frenetic battle that ensued at the encounter between predators and prey: "I estimated that a hundred schools of anchoveta were within sight. At times, when the bonitos attacked them from beneath, large areas of the surface would be so broken by the leaping of the little fishes that the ocean hissed as though a deluge of rain were descending upon it. The most remarkable sight of all was the manner in which whole herds of sea-lions were lolling and frolicking among the anchovetas, gorging themselves to the limit of their capacity."[2] The feeding frenzy was a dramatic, if apocryphal, display of the anchoveta's key role in this marine ecosystem.[3]

Observing the scene from his perch above the sea surface, Murphy had a mere human's-eye view of the watery tumult.[4] But in any case, it was the multitudinous flocks of sea birds that drew his keenest interest at the time. Since the late nineteenth century, this region of the Peru-Chile coast had been a key field site for European and US marine ornithologists due to the global economic importance of the guano trade.[5] "The long files of pelicans, the low-moving black clouds of cormorants, or the rainstorms of plunging gannets probably can not be equaled in any other part of the world," the zoologist Robert E. Coker wrote in 1908, after nearly two years of study on the Peruvian coast.[6] Three endemic birds comprised what Murphy called the "great guano-producing triumvirate" of this eco-region: the numerous and "wonderfully specialized" *piquero* (*Sula variegata,* or Peruvian booby); the large and "most conspicuous" *alcatráz* (a species of pelican, *Pelicanus occidentalus,* frequently encountered in huge flocks); and, finally, that which he deemed "first in importance" and efficiency as a guano-making "machine": the *guanay* (Peruvian cormorant, *Phalacrocorax bougainvillii).*[7] In 1913, two US ornithologists identified a single species of petrel (*Oceanodroma hornbyi*) that was common to the entire length of the coast between the Gulf of Guayaquil (3°S) to central Chile (30°S). Such a large latitudinal range highlighted the distinctiveness of this "special faunal zone," Murphy asserted.[8] The broad contours of this oceanic system had been recognized by indigenous peoples of the littoral and mariners sailing what they knew as the "South Sea" for centuries, if not millennia.[9]

Oceanic winds generally blow counterclockwise in this region, pushing surface waters from the west and south toward the Equator, along the continent's western edge. In contrast to the notoriously stormy Caribbean, the tranquility of these cold, deep-blue waters is rumored to have inspired the name "Pacific" when Ferdinand de Magellan passed through in 1520.[10] By the seventeenth century, the Pacific Ocean had become a subject of interest among European scientists who sought to theorize the interrelationships among tides, winds, and ocean currents.[11] The Prussian naturalist Alexander von Humboldt helped to popularize knowledge of the coastal current system among Euro-Atlantic intellectual elites upon returning from his voyage to the Americas, where in 1802 he had measured and recorded the ocean and atmospheric conditions off the coast of Peru. Since the surface-level current clearly flowed northward, Humboldt attributed the cold sea surface temperatures to the waters' apparent origins in sub-Antarctic latitudes, but this proved inaccurate.[12] Instead, a strong coastal upwelling was the defining feature of the marine ecosystem and its biogeography in these waters.

Together, these two intersecting realms—the oceanic-climatological, and the biotic-zoological—have comprised the driving forces of the Humboldt Current marine ecosystem.[13]

Coker, Murphy, and others documented the region's distinctive biogeography prior to the ravages of large-scale industrial fishing. Coker unequivocally declared the tiny anchoveta to be "the most valuable resource of the waters of Peru."[14] Murphy, who set out to investigate the ecological forces driving the extraordinary abundance of the marine ecosystem, reached a similar conclusion: finding only *Engraulis ringens* in the stomachs of the boobies (*piqueros*) he examined, he conceded that "this creature is probably the mainstay of [their] existence."[15] At the same time that these scientists recognized the importance of these fisheries and their food webs, however, their reports also promoted—in some cases explicitly—the industrial development of fishing in the areas they surveyed. Coker described indigenous Peruvians' practice of salting and sun-drying anchoveta as "an opportunity that is not now utilized" by fish-processing entrepreneurs: "This little fish of manifold uses is all the more significant because of the rare opportunity it offers for the preparation of an excellent preserved product."[16] In a 1923 article in *The Scientific Monthly*, Murphy also emphasized the underdevelopment of commercial Peruvian fisheries, reporting that there was "not a single organized fishing industry" in operation along the entire coast. "Few littoral waters of the globe teem with fish and with other edible products as do those of Peru," he remarked, "and yet in no other enlightened country are fisheries more restricted to methods which . . . are such as the Indians have followed from immemorial times."[17] Locals typically used wooden boats (*lanchas*) or traditional craft, such as reed rafts (*los caballitos de totora*), woven from the tall grasses of Peru's north coast wetlands near Huanchaco. These vessels were adequate for subsistence fishing and small-scale commercial activity, given the near-shore abundance of large fish shoals in this region prior to World War Two.

The experts' enthusiastic assessments of the potential for commercial production and export of Humboldt Current marine proteins had not been overstated: in the late 1950s, Peru and Chile emerged as two of the top-producing industrial fishing nations. Their primary export product, however, was not ultimately fillets or canned goods made from high-grade "table fish," but rather concentrated proteins in the form of fishmeal and fish oil—critical ingredients in the specially formulated animal feeds that fueled the rapid expansion of intensive poultry, hog, and fish farming during the second half of the twentieth century.[18] Expanding agricultural economies of scale and

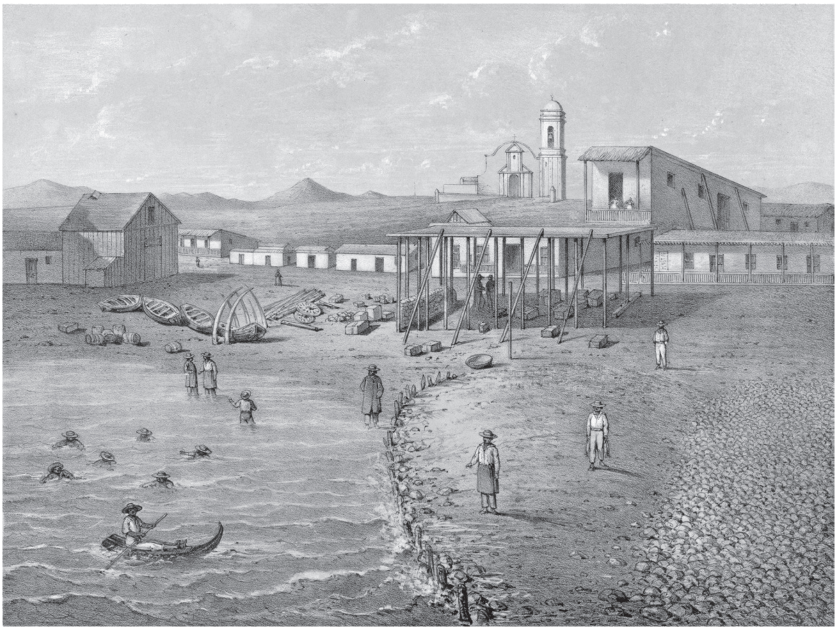

FIGURE 1. Huanchaco, Peru, in the late nineteenth century. Mateo Paz Soldán with Mariano Felipe Paz Soldán, eds., *Geografía del Perú* (Paris: F. Didot, 1862), Plate XIV. Prints and Photographs Division, United States Library of Congress.

"just-in-time" production models increased the demand for fishmeal and other high-protein feed commodities, one of the sector's most costly inputs.[19] Between 1950 and 2010, approximately 27 percent (an average of twenty million metric tons annually) of global marine fisheries landings became fodder for nonhuman consumers, and 90 percent of those fish were classified as food-grade.[20] During the same period, Peru and Chile together accounted for an average of 48.7 percent of total fishmeal and oil produced annually (33.8% and 14.9%, respectively).[21] Worldwide, fishmeal and oil producers have primarily targeted "forage fish"—small, oily species that form large schools and are important food sources for foraging marine predators—for industrial-scale "reduction" to more easily digestible, nutrient-rich substances. Cooked, pressed, and pulverized, they traveled across the oceans in jute sacks or cargo ships' bulk holds, ultimately arriving at the troughs of industrially farmed animals and fish, primarily in the United States, Northern Europe, and increasingly by the twenty-first century, China.

Global fishmeal and fish oil production became major components of what fisheries biologist David H. Cushing has called the "second industrialization" that occurred in world fisheries between 1950 and 1977, as the application of new technologies and the expansion of traditional fishing grounds exponentially increased the rate at which humans extracted biomass from marine ecosystems.[22] While the first phase of fisheries industrialization occurred in three relatively more limited areas—the North Sea, the North Atlantic (between Cape Hatteras and the Gulf of St. Lawrence), and off the Northwest Pacific Coast of the Americas—the second phase increased pressure on fish stocks worldwide.[23] During the second phase, European, Japanese, and Russian long-distance factory trawlers incorporated refrigeration and freezing technologies to process their catch on-board (and away from land-based regulations). Sonar, echo-sounding, hydraulic power blocks, and nylon nets further revolutionized humans' ability to detect, observe, and extract underwater resources, delivering seemingly endless supplies of cheap fish to ever-hungry consumers, both animal and human. Equipped with these tools, purse seine fleets depleted stocks of herring, sardines, anchovies, and mackerel between the 1940s and late 1960s in multiple ocean regions.[24] They included the coasts of British Columbia, California, Japan, the US Atlantic and Gulf Coasts, South Africa, Namibia, and in the North Sea.[25] As humans traversed the maritime "techno-frontier" in the second half of the twentieth century, the world's oceans became more legible—and their resources more accessible—to scientists, governments, and industrialists on a planetary scale.[26]

Central to this emerging global industrial food web, the humble anchoveta became "the most heavily exploited fish in world history" after a rapid period of expansion in Peru and northern Chile during the 1960s.[27] Seafood, agribusiness, and pharmaceutical concerns invested in fishing vessels and processing plants in both countries during the boom years. Overall, schooling fishes of the Humboldt Current supplied an estimated 55.8 percent of all fishmeal produced between 1950 and 2010, including the anchoveta (*Engraulis ringens*, at 33.7%), sardine (*Sardinops sagax,* at 16.6%), and jack mackerel (*Trachurus murphyi*, at 5.5%).[28] In the early twenty-first century, this region continued to yield up to 10 percent of the total world marine fisheries catch in an area spanning less than 1 percent of the world's ocean surface.[29]

The variabilities of the Humboldt Current marine ecosystem have punctuated the global history of this commodity, most notably in 1972, when an incursion of unusually warm waters coincided with a decades-long peak in the intensification of industrial fishing and fishmeal production in Peru. The remarkable impact caused by this ocean-atmospheric phenomenon, known as El Niño, attracted great attention from international scientists and industrialists alike. The ensuing collapse in the fishery severely disrupted global flows of marine proteins, impacting farmers in distant markets. Without the anchoveta, supplies of fishmeal and oil dried up almost overnight, wreaking havoc for brokers with contracts to fill.[30] But Chilean industrialists continued to produce and export fishmeal using newly abundant sardine and mackerel species, incorporating technologies that created a higher-grade product with less raw material, while Peru struggled to restructure the industry and its gigantic bureaucracy. Along with the estimated 35 percent of the world's land-based agricultural harvest that is used to feed livestock, oceanic ecosystems and littoral societies have been key suppliers of nutrients to the industrial food web during the past century.[31] Their histories are therefore crucial to understanding the environmental and human dimensions of modern food production.

THE GLOBAL ENVIRONMENTAL SIGNIFICANCE OF THE HUMBOLDT CURRENT ECOSYSTEM

Between 5,800 and 3,600 years ago, in the desert valleys of what is now the northern coast of Peru, humans built what were once the largest settlements in the Western Hemisphere. In addition to cultivating several food crops (including beans, squash, avocado, sweet potato, and peanuts), along with cotton, in irrigated fields, they subsisted on protein taken from the sea, and kept no domesticated animals. This society lived a "unique evolutionary experiment," adapted to the particular ecological conditions of the desert coast, which was carved by episodes of severe flooding and tectonic shocks. The ridges such events formed in the land are discernible today to paleoarchaeologists in several locations offshore, including near the mouth of the Santa River (9°S), just north of Chimbote.[32] The west coast of South America was (and remains) one of the most seismically active regions on Earth.

Oceanographically, three major characteristics broadly shape the Humboldt Current System (HCS): its coastal flows and counterflows; a strong upwelling of nutrient-rich water; and the inherent variability of these conditions, both spatially and temporally. Under normal conditions, the surface-level current sweeps northward along the western edge of the South American continent, "literally bathing the shores" from southern Chile (45°S) to equatorial latitudes near Guayaquil (4°S), before turning sharply