Introduction

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The problem of environment

> With every day that passes we are acquiring a better understanding of these laws and getting to perceive both the more immediate and the more remote consequences of our interference with the traditional course of nature . . . the more this progresses the more will men not only feel but also know their oneness with nature, and the more impossible will become the senseless and unnatural idea of a contrast between mind and matter, man and nature, soul and body. . . . – Frederick Engels (1876)[1]

The pelagic, or open-sea, fisheries of California owe their productivity to the California Current, a stream of water roughly 350 miles wide that flows slowly along the coast from north to south. Off the central California coast and in the Southern California Bight, winds and currents interact seasonally to generate upwellings of deep, cold, nutrient-rich water to the lighted surface of the ocean. Blooms of plankton fertilized by this upwelled water feed the coastal pelagic schooling fishes – sardine, anchovy, and the like – which in turn provide fodder for still other fish and mammals higher on the food chain. What portion of this great, complex aggregation of living matter, or biomass, that does not leave the system in the bellies of migratory animals or fishing boats dies and drifts slowly to the ocean floor, only to be upwelled later to enter the cycle again. As coastal upwelling areas go, that off California is moderately productive; combined, all such areas account for about one-half of humanity's total fishery harvest.[2]

Life in California waters is as diverse as it is productive. The rocks and canyons that extend from the land down into the seafloor mix nearshore currents into complex patterns and provide homes for a great many different plants and animals. A sharp temperature gradient off Point Conception, roughly two-thirds of the way down the state's 1,100-mile coast, divides the nearshore zone into subtropical and subarctic regions (see Figure 1.1). To the south live tuna and other warm-water species, while to the north are salmon and other animals that prefer colder temperatures. The great forests of kelp that line the coast just offshore enhance the system's fertility and diversity still further as they provide food and shelter for a great many nearshore and intertidal species.

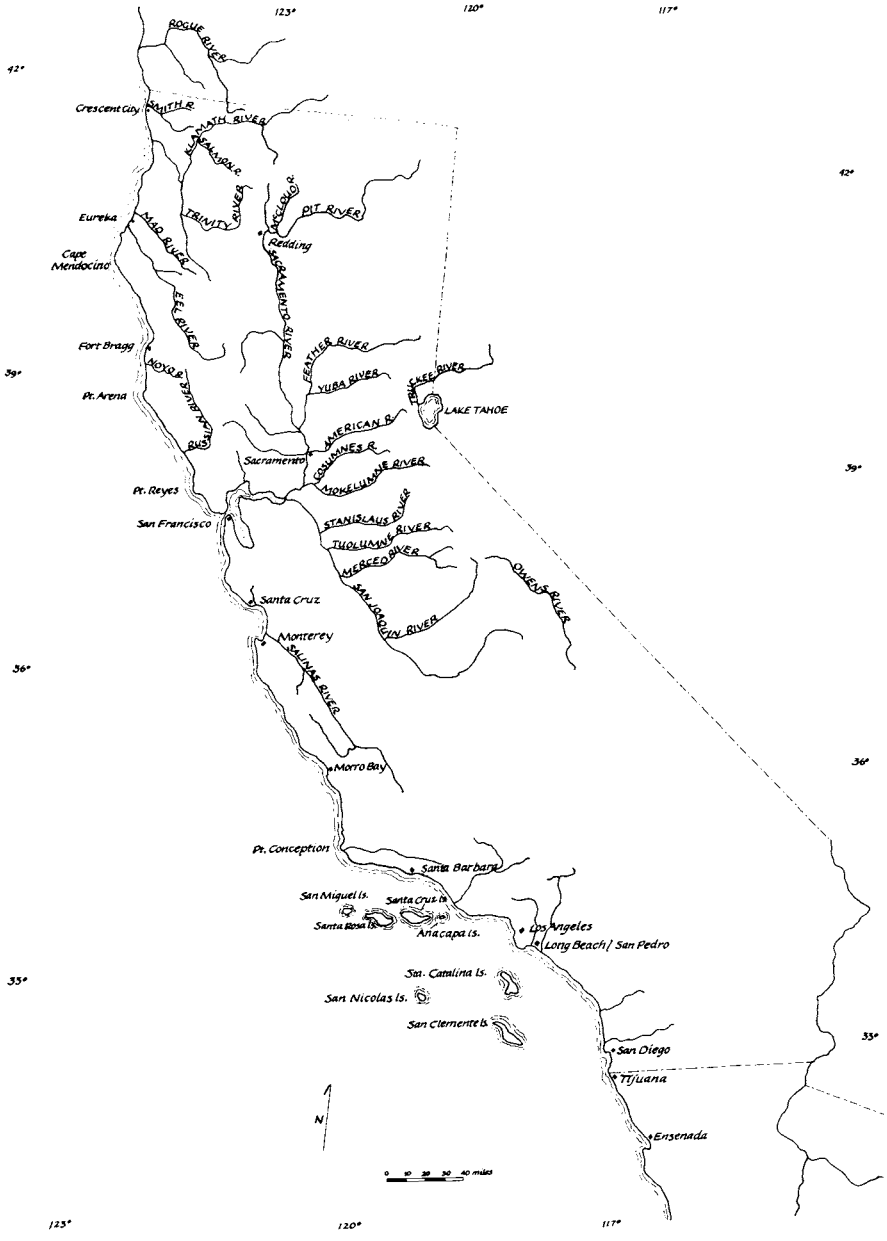

Figure 1.1. California, showing major waterways and fishing ports. Map drawn by Ann Bartz and C. M. Martin.

Estuaries, among the most fertile environments on the planet, are few and far between in this geologically youthful and restless region. Those that have formed, however, are vitally important to the ecology of nearby waters, providing food for animals living in them as well as nursery for many that spend most of their lives in the open ocean. Premier among California estuaries is the outflow of the Sacramento–San Joaquin river system, which includes Suisun, San Pablo, and San Francisco Bays. Before 1850, the salt marshes and mudflats that ringed the three bays may have held, at high water, as much as two-thirds of all the water flowing in and out of the Golden Gate with each tide. Twice daily, immense quantities of water washed over these tidelands and retreated, by turns fertilizing them and carrying off algae and detritus to supply an important share of the food consumed by animals both inside and outside the Gate.[3]

Inshore, the rivers that drain the Coast Range and the Sierra Nevada are home to a wide variety of freshwater fishes, as well as to salmon and other anadromous species that spend most of their lives in the ocean but return inland to spawn. The largest of these is the Sacramento–San Joaquin system, which reaches back into the great Central Valley of California and beyond into the Sierra Nevada, and the Klamath–Trinity system in the northwestern corner of the state. Each of these river systems lies at the ecological heart of its watershed. Fish in them feel the pulse of every significant change in the ecology of the surrounding lands. Together, these two watersheds encompass most of the land area of California. The changing fortunes of their fish, then, provide an index to the ecological history of much of the state.

The Sacramento–San Joaquin drainage is second in size only to the Columbia among western U.S. watersheds. The Sacramento, largest of the two rivers, arises from a vast network of tributaries in the Sierra Nevada, each of which is home to its own genetically unique population of salmon. Downstream, before the Central Valley was reclaimed for agriculture, the Sacramento flowed through a finely adjusted system of natural sloughs and levees that allowed the river to overflow during the heaviest winter floods, thereby inundating a broad plain that extended as far north as present-day Chico. Partly covered with swamps and marshes, the floodplain stored overflow water for a time and then gradually released it back into the river's main channel, while settling debris and sediment carried down from the mountains. The visible product was some of the finest grassland that early explorers had ever seen.[4]

In its lower reaches, the Sacramento merged with the Cosumnes, the Mokelumne, and the San Joaquin Rivers in a huge expanse of freshwater marsh, dotted with islands and laced with endless winding sloughs and channels, all teeming with life. Tides extended as far upstream as the mouth of the Feather River, north of Sacramento City. In 1850, delta lands may have encompassed some 533 square miles and contained perhaps two-thirds

of all marshland in the entire watershed. The delta further regulated and filtered the flow of water through it as well as providing homes for infinite indigenous and migratory birds, mammals, and fish.

The commercial development of California's lush and varied fisheries has followed a repetitive pattern of boom and bust, one typical of fisheries the world over. Usually, after a few pioneers demonstrate a fishery's profitability, capital and labor rush into it, and the harvest increases exponentially for a time. At some point, unable to bear the strain of exploitation indefinitely without sacrificing its ability to replenish itself, the resource begins to yield less and less to economic effort. As depletion erodes its productivity, a fishing industry may even improve its technical ability to find and catch fish, thereby sustaining profits for a time but drawing ever more effort into the harvest and ever more life out of the stock of fish. Ultimately, harvesting so depletes the resource as to cripple it.[5]

A stock of fish is a renewable resource: It sustains itself by breeding or "recruiting" enough new adults to balance its losses to predators and other causes from year to year. A fishing industry is simply another predator added to the environment. According to the so-called sustained yield theory, the amount of fish that any given level of harvesting effort will yield over the long term is a function of both the intensity of fishing and the capacity of the stock to reproduce. At some maximum sustainable yield (MSY), fishers take exactly as many fish as the stock recruits in a season and so do not impair the resource's long-term productivity. Less fishing, of course, will produce fewer fish. A higher level of effort, however, will also produce fewer fish in the long run by leaving fewer adults to breed. The task of fishery management under this rudimentary model, then, is to calculate each stock's MSY and limit the take to that point.[6]

Developed gradually over the first half of the twentieth century, the sustained-yield model guided most scientific thinking about fisheries, game animals, timber, and other living resources until the 1960s. It represented a considerable improvement over earlier thinking, which held that oceanic fisheries at least were so vast in relation to the harvest as to be practically inexhaustible. If certain grounds lost productivity from time to time, fishers would simply move to new ones and give them time to replenish. Regulating the harvest in that case simply made no sense.[7] This idea, perfectly in keeping with late nineteenth-century laissez-faire ideology, made the very important assumption that there existed a radical dichotomy between the fishing industry and the ecology of its resources: Nature, in the form of the stock of fish, was a passive object to be exploited at will and without significant consequences either for the resource or for the industry itself.[8]

For its part, the sustained-yield theory rested on the important postulate that the stock of fish existed in isolation from its environment; that is, that the only influence on its productivity was the number of breeding adults

left after harvest. Most fisheries, however, do not behave as neatly as the theory suggested because, like any other biological resource, fish live in a complex and constantly changing environment. Thus, for a given level of fishing effort, any stock's sustainable yield shifts constantly and for all practical purposes at random in response to conditions in its habitat. Targeting a conservative yield from a real fishery is thus a problem in stochastic, or random-variable, analysis – more like predicting the weather or the outcome of an election than, say, the sustainable yield of guppies from a well-maintained aquarium.

Some species reproduce less efficiently at lower levels of population, so that recruitment is not a simple algebraic function of breeding stock. It only takes two whales of the appropriate sex, for example, to make more whales, but if there were only two in an entire ocean they might not be able to find each other. Similarly, a schooling fish like the sardine must spread its spawn over a large expanse of ocean to ensure that enough offspring find conditions favorable to their survival. A fishery under intensive harvesting pressure may thus be more brittle and vulnerable to collapse than an unexploited one.[9]

Some environmental changes that impinge on the productivity of fisheries occur in nature without reference to human activity, as when currents shift or the weather changes. Fish are much more sensitive to such changes than are organisms that live in the air. Scientists now believe, for example, that environmental conditions during the first year of life have a larger role in the recruitment of sardine and other herring-like fishes than does the size of the parent stock, although, again, environmentally induced recruitment failure will have a much more catastrophic effect on a heavily fished stock than on an abundant one.[10] A sudden drop in temperature can blanket a coast with tides of dead sardines or anchovies. The Spanish explorer Vizcaino observed this phenomenon at the southern end of Baja California in 1602; Monterey newspapers reported another such incident the last week of May 1858.[11] More subtle shifts in climate may drastically influence the migration and survival of larger fish such as albacore or salmon as well.

In general, the effects of climatic or other ecological change will be more pronounced if a fishery is under stress and more so at the margins of the stock's range than near its center. California fisheries are the more responsive to ecological change, then, because many species taken on either side of the climatic boundary at Point Conception live near the limits of their tolerance for heat or cold. Very slight shifts in conditions will cause wide fluctuations in the behavior of many of California's fishes, with dramatic economic consequences for the industries that harvest them. Such remote events as the El Niño–Southern Oscillation, a complex oceanic–atmospheric interaction that takes place in the equatorial Pacific every six years or so, can have a significant impact on fisheries in California waters.[12]

Army and Weather Service records of temperature and precipitation for many parts of California date back to the 1840s. Records for two representative locations, Sacramento in the Central Valley and San Diego on the Southern California Bight, are reproduced in Appendix A. The influence of weather on riverine ecology, hence on inland fisheries, is quite direct. Because coastal air temperatures correlate closely with those of adjoining seas, the atmospheric data give evidence of changes in the ocean environment as well.[13] Shifts between warm and cool periods correspond with historical records of shifts in the range of northern and southern species as much as several hundred miles up and down the coast. Shifts between "marine" climates, characterized by high rainfall, cool summers, and moderate winters, and "continental" climates marked by drier weather and greater seasonal variation in temperature, correspond roughly to periods of high and low productivity, respectively, in the salmon fishery. All of these changes, both in the long and short term, have had a discernible impact on the development of California fisheries and on political controversies over their use.

Some of the most fascinating evidence in the ecological history of California waters derives from the geology of the ocean floor. Where upwelling occurs, as it does off Baja California and in the Southern California Bight, water at the seafloor contains very little oxygen and consequently very few creatures to disturb the orderly accumulation of sediment on the bottom. Winter deposits, augmented by runoff from the coast, are darker and thicker than summer ones. Cylindrical cores extracted from the seafloor thus provide an annulated record, in the fashion of tree rings, of plankton, fish scales, and other detritus deposited by the California Current ecosystem over the centuries. By counting the scales from different kinds of fish in each cross section and calibrating the counts to modern estimates of their populations, scientists at the Scripps Institution of Oceanography at La Jolla, California, have compiled a census of sardines, anchovies, and other coastal schooling species that reaches back some two millenia. Because these fishes are fodder for most of the larger animals in the system, the record provides a rough index of the productivity of the system as a whole. That productivity has fluctuated widely for as long as the record exists.[14]

Biomasses of sardine and anchovy, moreover, fluctuate with respect to each other. The two species are ecologically quite similar, except that the anchovy has a shorter life and breeds at a higher rate than does the sardine. In any ecological system, unsettled conditions tend to favor species such as the anchovy, which turn their population over more rapidly. A relatively high ratio of sardine to anchovy thus indicates stable environmental conditions, whereas a low ratio evinces environmental instability and consequently a more volatile fishing industry. Data for the nineteenth and twentieth centuries appear in Appendix B. Over the long term, as one biologist put

it, "if ecological theory concerning high reproductive rate holds, this means that the California Current area is one of almost continual environmental disturbance favouring the anchovy."[15] Changes in the stability and overall productivity of the system clarify otherwise opaque historical data on the fisheries, including newspaper accounts, contemporary scientific observations, fishers' testimony about their luck and, most importantly, records of political conflict in the industry.

Human activity can also alter the productivity of fisheries in ways other than by harvesting them. All fish occupy places in a food chain, so that human impact on a stock's prey, its predators, or its competitors for food and space can increase or decrease its potential yield. Some such impacts, moreover, stem from human activities only remotely related to the fisheries themselves. Any economic activity that uses water – which includes most of them – or that alters the character of the seabeds, tidal areas, or rivers in which fish live will have some impact on the ecology, hence on the productivity of a resource. Mining, agriculture, and urban development have all had a major impact on the development of California fisheries and on controversies over their use and management.

Nature is a very careful accountant. Because evolution has built such a complex pathway for energy and materials to follow on their way through the food chain, every change in one part of an ecosystem sooner or later has some effect, however minute, on every other part. Human beings and their industries are no less part of the ecosystems in which they work than are the plants and animals they harvest. Human economies, however, account for the costs and benefits of their activities through the market mechanism, which unfortunately is much less efficient a transmitting medium than an ecosystem is. The injuries that fishers impose on each other by overharvesting, for example, or that water polluters inflict on the fishing industry as a whole, do not normally come to account because the market diffuses them too broadly – too many victims each suffering a little bit – for any one person or coherent group to demand compensation for them in the marketplace or in the courts. They are what the economist R. H. Coase called "social costs," that is, costs that fall to society at large because the expense of making and enforcing contracts to pay them is too great to make the effort worth anyone's while.[16] Fish are remarkably efficient builders of protein, fat, and other good things for people but are themselves unable to bid the price of their services up to their comparable value in the market. They are free for the taking because they neither strike, nor sue, nor vote.

A self-preserving fishing industry would respect the biological limits of its resource's productivity, limiting its seasonal take to some safe minimum so as to guarantee future harvests. Fishing industries, however, do not generally manage their affairs in such a rational way. This is primarily because fishery stocks are "common property" resources; that is, although many different

individuals or firms may compete with each other for fish, no one of them owns the resource so as to keep others away from it. As a result, everyone has an incentive to keep fishing so long as there is any money to be made in the effort, whereas no one has an individual incentive to refrain from fishing so as to conserve the stock. Every harvester knows that if he or she leaves a fish in the water someone else will get it, and the profit, instead. This is what economists call "the fisherman's problem": In a competitive economy, no market mechanism ordinarily exists to reward individual forbearance in the use of shared resources.

It falls to government to consider the interrelated environmental effects of economic activity, to set safe standards for resource use, and to regulate the behavior of resource users so as to protect the community's long-term interest in its natural endowment.[17] One of the first scholars to point out the importance of legal and institutional arrangements for fishery conservation was an economist, H. Scott Gordon. In a 1954 article criticizing the sustained-yield theory of fishery management, Gordon analyzed fishery problems as the inevitable result of the industry's legal and economic organization rather than in terms of biology or population dynamics. The sustained-yield theory, he wrote, "overlooked essential elements of the problem" by neglecting the powerful incentives to overfish that operated in a common-property regime.[18]

Gordon proposed maximizing the economic return from fishing rather than the raw yield of fish, demonstrating in theory that a fishery would always produce its highest financial yield at a lower, hence safer, level of fishing effort than that required to produce its MSY. This was because the cost of fishing rises proportionally with the amount of effort expended, but sustainable yield reaches a maximum at some point and then begins to decline. The *marginal* return from fishing at MSY, then, is zero. A good businessperson tries to maximize revenues over costs and will cease fishing at precisely the point at which the price of one extra fish exactly balances the cost of catching it, well before the total yield reaches MSY and the marginal yield reaches zero. Fishing at the sustainable maximum produces more fish but costs disproportionately more money and so produces less profit. An unlimited fishery typically produces no income over costs at all, Gordon wrote, because as long as anyone who wants to can enter the fishery, new effort will go into the business until total costs equal total yields and the *average* return from fishing equals zero, at some point beyond and below the sustainable maximum. This, as economists are fond of pointing out, is why fishers are in financial trouble most of the time.[19]

In Gordon's model, if the industry lowers its cost of fishing by developing more efficient gear, it produces more income for a time but only draws more effort into the harvest until total yields again equal total costs. By fishing the stock harder, it also produces fewer and fewer fish in the long run. Such

economic irrationalities as subsidies designed to keep fishers solvent or hungry people fed and the traditional reluctance of fishers to leave their chosen line of work can push a fishery well past the point at which earnings no longer cover costs and on toward commercial or even biological extinction. Gordon's idea was that market forces, properly channeled under a limited-entry rather than a common-property regime, would tend to reward ecologically prudent behavior and thus work automatically to conserve the resource. He concluded that imposing such a regime on a fishery would require making it "private property or public (government) property, in either case subject to a unified directing power" able to exclude outsiders and adjust harvesting effort to maximum advantage.[20]

Although he used the fisheries as a model, Gordon thought his conclusions "applicable generally to all cases where natural resources are owned in common but exploited under conditions of individualistic competition."[21] In 1968 the biologist Garrett Hardin fit the theory to a wide range of environmental issues in a popular article whose title, "The Tragedy of the Commons," subsequently became an inclusive symbol of environmental problems generally.[22] Hardin cast the fisherman's problem in terms of a group of farmers grazing cows on a common pasture. Because no one farmer owns the pasture, each finds it more profitable to graze one more cow than the pasture can feed in the long run because all the profit from the extra cow goes to the individual farmer, while each bears only an average share of the cost of ruining the pasture. Eventually, everyone goes broke. Collectively and inevitably – tragically, to Hardin's mind – industry degrades and eventually destroys resources owned in common but used competitively. The model, Hardin believed, applied not only to rangeland and to fish and other wildlife. It also applied to national parks and the air and water that citizens "own" in common but pollute as competitors, to underground aquifers, which collapse because competing users draw out more water than natural flow can replenish, and even to the planet's ultimate capacity to support the ever-increasing numbers of new people that individual families produce.

Hardin asserted that the fisherman's problem had "no technical solution." He observed that throughout history, as human population had increased and environmental degradation proceeded apace, some form of private property had supplanted "the commons" in one resource area after another. By itself, however, privatization was no answer: Pointing to Coase's "social cost" problem, Hardin allowed that the Anglo-American concept of private property actually encouraged people to pollute their neighbors' air and water. Concluding his article, Hardin could only point to what he called "mutual coercion mutually agreed upon" to restrain people from destroying the planet. Nature ran a closed economy, he reasoned, so that the utilitarian notion of providing "the greatest good for the greatest number" was ecologically absurd. It was simply not possible to maximize both environmental