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4. Changes in the Biomass of the California Current Ecosystem

ABSTRACT

California Current pelagic fishes have been monitored for 30 to 50 years, and a paleosedimentary record extends back 200 to 2000 years. Large natural fluctuations in abundance occur at all time scales. Overharvest of sardines removed a major component of the ecosystem; the extent to which it was replaced by other species (e.g., anchovy, rockfish) is not clear. Large predatory fishes have declined in abundance due to exploitation. Pinnipeds were depleted in the last century, but now are abundant and are increasing rapidly. Seabird reproductive success is closely related to availability of small forage fish such as anchovy. Despite a wealth of scientific information, species interactions are poorly understood, and are difficult to separate from independent differential responses to varying environmental conditions. The biological basis of fishery management is likely to remain single-species models in the foreseeable future. Ecosystem management requires coordinated consideration of both fished and non-fished species, but faces conflicting jurisdictions and other institutional difficulties.

INTRODUCTION

The California Current sweeps southward along the west coast of North America, with its main influence extending from about the Columbia River to central Baja California (Figure 4.1). A major eddy system occurs in the Southern California Bight (SCB) south of Point Conception, and a second eddy system occurs in Sebastian Vizcaino Bay, Baja California. Wind-driven coastal upwelling occurs along the more exposed sections of coastline, particularly at headlands, cooling the inshore area and adding nutrients to the already rich

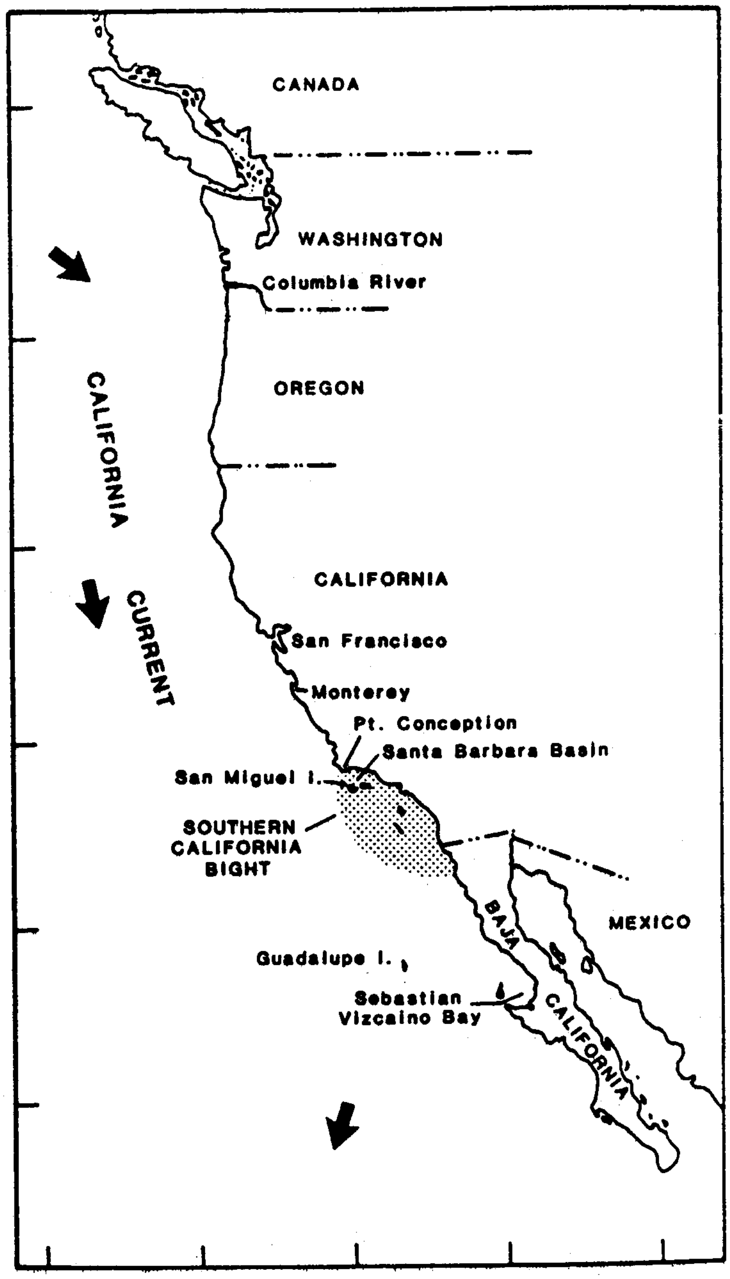

Figure 4.1. Map of the California Current region, with some place names which are referred to in the text.

waters being advected southward from the northeast Pacific. The SCB is a special habitat within this system, being warmer and influenced by numerous islands and banks. Most of the remainder of the California Current has little interaction with the seabed due to a relatively narrow continental shelf. Some useful reviews of California Current oceanography are Reid et al. (1958), Hickey (1979), and Parrish et al. (1983).

The main body of the California Current lies offshore and contains an abundance of lower trophic level organisms; this area has been studied extensively by biological oceanographers who have benefited from regular surveys made by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) since 1950. From the viewpoint of this volume, more emphasis must be placed on the inshore regions, especially the SCB, where higher trophic level organisms such as fish, marine mammals, and seabirds abound. It is these organisms that usually are of most concern to management, as they play a visible role in human culture and economy.

PREINDUSTRIAL CONDITIONS

The natural state of the California Current ecosystem was almost certainly one of substantial variability at all time scales. Anaerobic sediments in the Santa Barbara Basin of the SCB contain a rich record of recent fossil remains, particularly fish scales from the past few centuries. The annual layering of these sediments allows precise dating, and enabled Soutar and Isaacs (1969, 1974) to compile time series of scale deposition rates which may be interpreted as rough indexes of abundance (Figure 4.2). While the process of scale deposition and relation to the source population is poorly defined, scale deposition rates tend to agree with well-documented changes in commercial fish abundance since 1930, providing some credibility for their interpretation (Soutar and Isaacs, 1974; Smith, 1978; Lasker and MacCall, 1983).

Another demonstration of long-term variability is given by Hubbs (1948), who interprets lists of fish species collected by the Pacific Railroad Survey in 1853-1857 and by Jordan and Gilbert in 1880. Many tropical species are shown which are exceedingly rare or unknown in modern experience; other species normally restricted to the SCB and southward are reported as being abundant in Monterey Bay, central California. Douglas (1980) has used tree-ring data to reconstruct past sea surface temperatures off California, and the period 1841-1859 appears anomalously warm. Northward faunal shifts are known to be associated with oceanic warming off Califonia (Hubbs, 1948; Radovich 1961), but

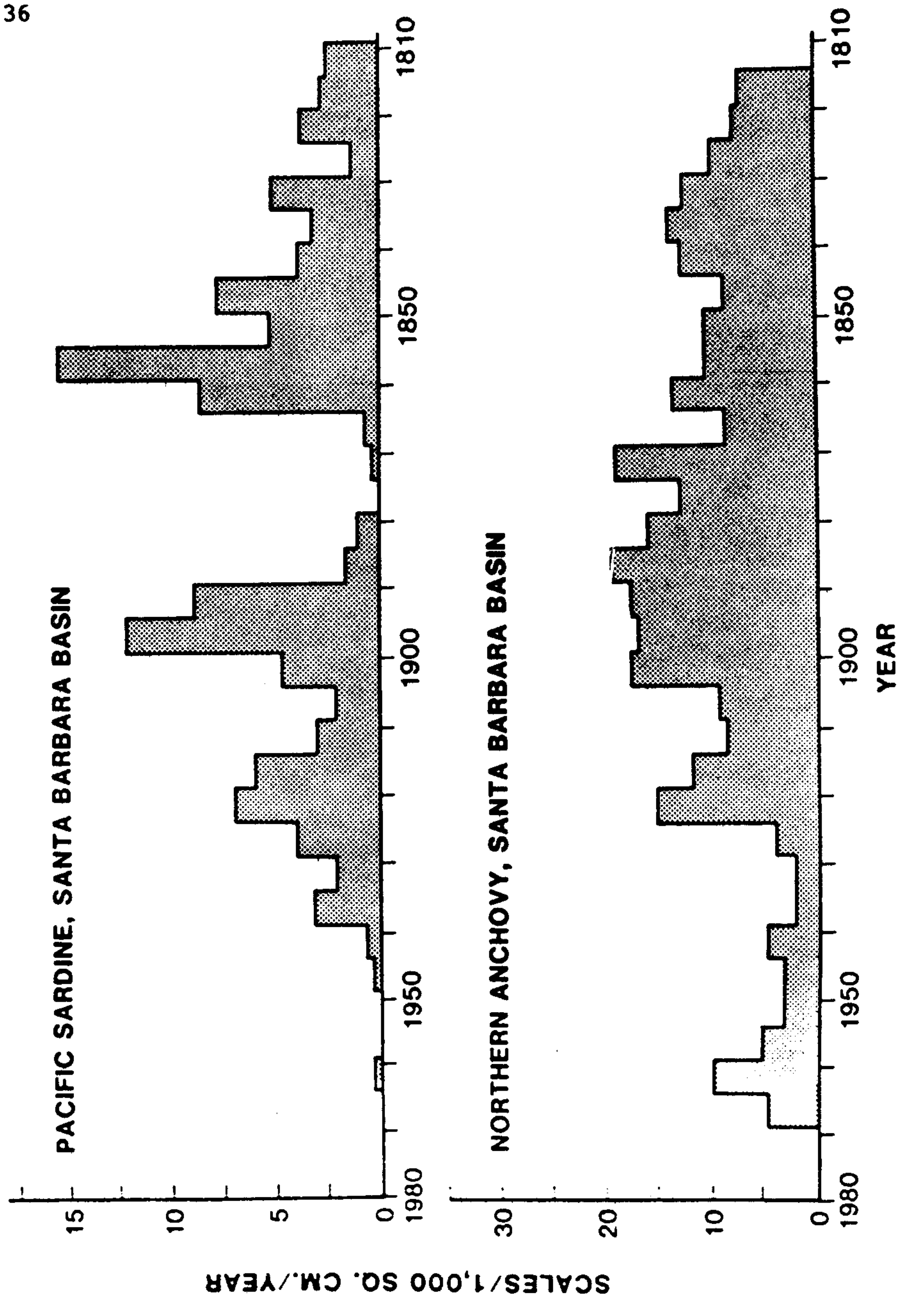

Figure 4.2. Recent scale deposition rates for Pacific sardine and northern anchovy (from Soutar and Isaacs, 1974).

nothing of the magnitude and duration experienced in the mid-1800s has been seen since then.

Marine mammal abundances were severely impacted by the influx of Europeans in the 1800s. The major fur bearers--northern fur seal (Callorhinus ursinus), Guadalupe fur seal (Arctocephalus townsendii), and California sea otter (Enhydra lutris)--were quickly reduced to near-extinction, as were the northern elephant seal (Mirounga angustirostris) and the California gray whale (Eschrichtius robustus) which were rendered for their oil. Other pinnipeds less sought for commercial purposes, such as the California sea lion (Zalophus californianus), suffered from prolonged hunting before concern turned to predator control for the marine fisheries.

Seabirds also were impacted by the influx of Europeans, particularly following the gold rush of 1849. Seabird eggs were harvested for food, and disturbance of the breeding colonies caused further reproductive difficulty. In 1854 common murres (Uria aalge) numbered about 400,000 on the Farallon Islands near San Francisco, judging by the magnitude of the annual egg harvest (Ainley and Lewis, 1974). As recently as 1959 these birds numbered only about 6,000, but their population has since recovered to 60,000 as a result of protection from disturbance (Sowls et al., 1980). Changes of seabird abundance in other locations are poorly documented, but most accessible colonies near human population centers were probably adversely impacted.

Except for the few fishes represented in Soutar and Isaacs' sedimentary record, it is particularly difficult to reconstruct the prehistoric state of the California Current ecosystem. Abundances of animal remains in prehistoric middens suggest that the Guadalupe fur seal may have been the dominant pinniped in southern California (Walker and Craig, 1979). Ironically this species does not presently reproduce in southern California although it has recovered somewhat on Guadalupe Island where it was "rediscovered" only 30 years ago (Antonelis and Fiscus, 1980). The northern fur seal has a southern rookery on San Miguel Island where waters are cool due to strong upwelling off Pt. Conception. Their prehistoric abundance at this location may have been high, and they probably were quite important in the northern part of the California Current, with large numbers of subadult females migrating southward from the Pribilof Islands. A major peak in Soutar and Isaacs' (1974) scale deposition rate for Pacific hake (Merluccius productus) coincides with peak harvests of fur seals at the Pribilof Islands in the late 1800s (Anon., 1977).

Aboriginal impacts on natural resources are usually thought of as being in approximate equilibrium. McEvoy (1979) concludes that aboriginal salmon harvests in northern California approached maximum sustainable yield (regulated by a variety of cultural mechanisms) and greatly exceeded harvests sustained by later industrial fisheries. Impacts on most other marine species were relatively small. An apparent exception is Chendytes lawi, a flightless marine duck with a well documented evolutionary lineage over the last 2 million years in California (Warter, 1978). The most recent remains from Indian middens have been dated at less than 3,780 years B.P. (Morejohn, 1976). As Morejohn observes:

> The high frequency of occurrence of bones of this species at one Indian midden clearly implicates early California aboriginal man as playing an important role in its extinction.

RESOURCE VARIABILITY IN THE 20th CENTURY

Commercial fisheries in California have been studied and monitored closely since the early part of this century, but they have been managed very little. Recreational fisheries, which have a major impact on many California fish stocks, have been monitored since the late 1940s, although substantial fishing pressure has existed for much longer. Mexican fisheries probably had a small impact on California Current fish stocks prior to the 1960s, and some segments of that industry have grown substantially in the last decade. Marine mammals and seabirds were not extensively monitored or studied until the 1970s when public awareness increased and several environmentally oriented acts were promulgated by the U.S. and California legislatures. This section discusses the variability of these California Current resources, and the subsequent section discusses their management.

The collapse of California's Pacific sardine (Sardinops sagax caerulea) fishery in the late 1940s set a well-documented pattern later followed by many of the world's coastal pelagic fisheries. However, the appearance of collapse may be an artifact of scale: A logarithmic plot of historical sardine abundances (Figure 4.3) indicates a prolonged exponential decline with a remarkably constant average rate of decay, about -0.2/yr. MacCall (1983) interprets this as a constant average rate of overexploitation, with harvests exceeding replacement levels by about 18% over the entire history of the fishery. Also, the variability about the trend in Figure 4.3 is of roughly constant magnitude indicating constant proportional variability

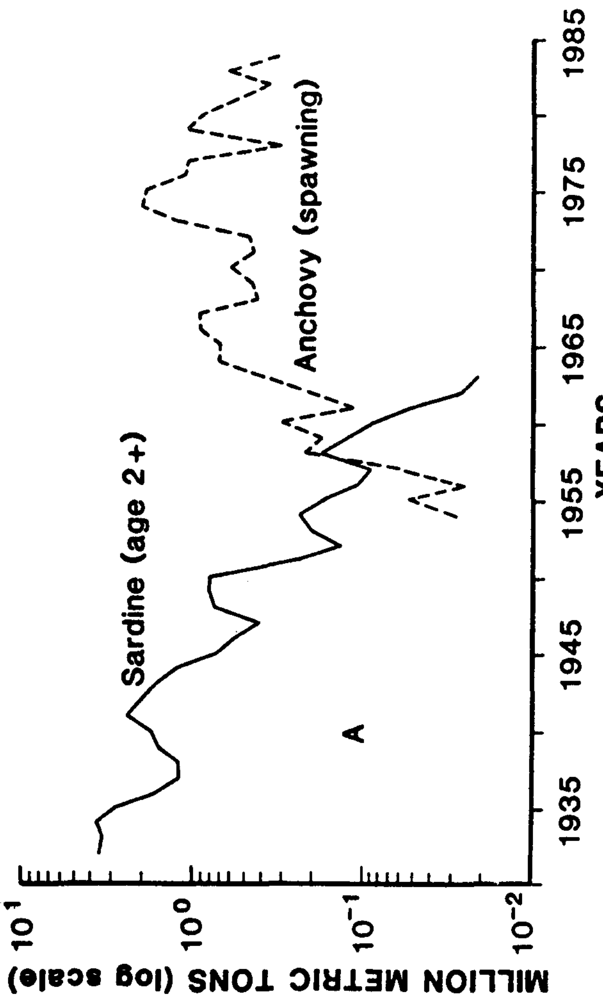

Figure 4.3. Time series of sardine (age 2+) and anchovy spawning biomass (log scale) off California and northern Baja California. "A" denotes approximate anchovy spawning biomass in 1940-1941 (interpreted from Smith, 1972). Sardine biomasses are from Murphy (1966) and MacCall (1979); anchovy biomass are from MacCall and Methot (1983).

from environmental fluctuations, and suggesting that difficulties experienced near the end of the fishery were not unusually severe. Removal of a major component such as the Pacific sardine (unexploited biomass averaging about 3 million tons) from the California Current food web would presumably have measurable effects on other components of the ecosystem. It is surprisingly difficult to identify those putative effects.

The northern anchovy (Engraulis mordax) is commonly thought to be a competitor with the sardine. The circumstantial evidence of similar food habits and a large increase in anchovy abundance following the decline of the sardine (Figure 4.3) has often been cited as proof of competitive replacement (e.g., Odum, 1971). However, the increase in anchovy abundance lagged the sardine decline by nearly a decade, and Smith's (1972) evidence of a relatively large anchovy biomass in 1940, when sardines were abundant, is often overlooked. A direct interaction between the two species has been demonstrated by Santander et al. (1983) in Peru, where anchovies and sardines are mutual predators on their eggs and larvae; a similar relationship should occur in California. Possible competition for food is suggested by Lasker and MacCall (1983), who showed that anchovy scales from Soutar and Isaacs' anaerobic sediments are significantly smaller (implying smaller anchovies) when sardine scale deposition rate is high. However, recent observations weaken the hypothesis of strong interaction between the two species: Mean size of anchovies has declined drastically since the mid-1970s due to causes that cannot be attributed entirely to the increased fishing pressure. At the same time, Pacific sardines are showing signs of increase, but are still very scarce. If sardines were more abundant, the increase in sardine abundance would be thought to be the cause of the decline in anchovy mean size, but because sardines are presently an insignificant component of the trophic system, these phenomena must be independent results of another, presumably environmental influence. As Daan (1980) concluded in a general review of replacement phenomena, the case is very unclear for anchovy having competitively replaced the sardine in California.

Due to a string of very strong year classes, abundance of Pacific mackerel (Scomber japonicus), elsewhere known as chub mackerel, in the 1930s may have greatly exceeded average virgin stock levels (Figure 4.4). Over the following years spawning success (recruits per spawner) varied with a distinct 6- to 7-yr cycle which ended with severe depletion of the resource about 1965. A moratorium on fishing during the 1970s was successful in rehabilitating the resource, which

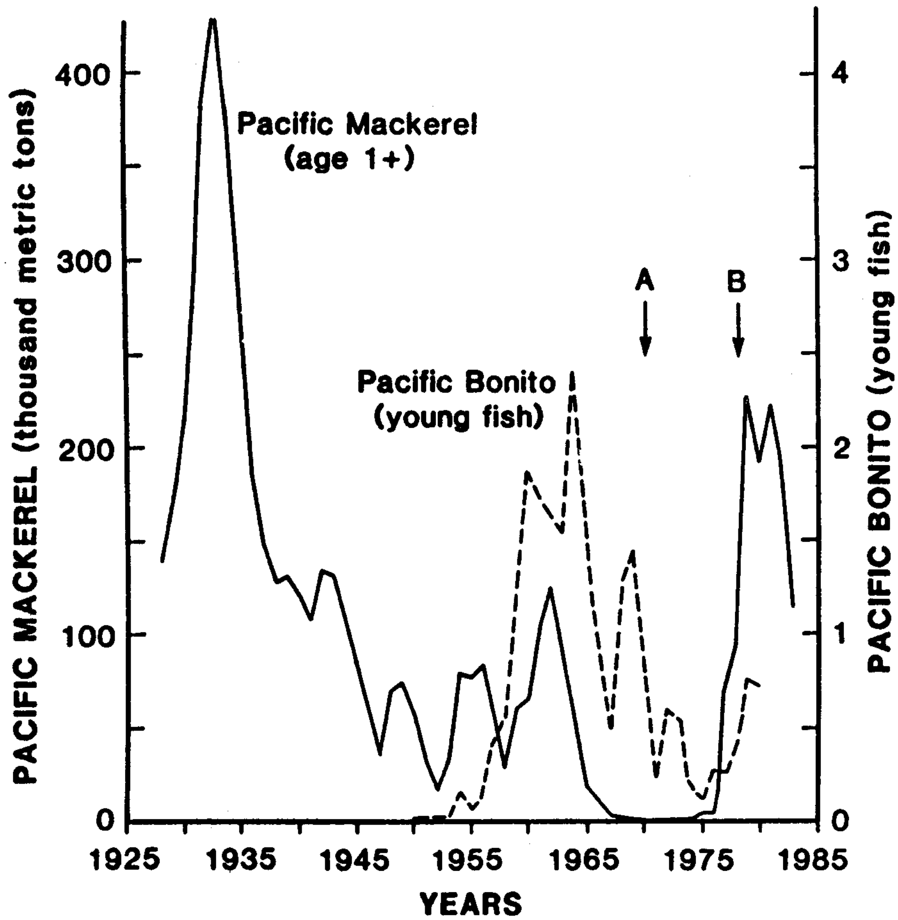

Figure 4.4. Time series of Pacific mackerel total biomass (age 1+) and Pacific bonito recreational catch per effort (fish per angler-trip). "A" denotes beginning of Pacific mackerel fishing moratorium, and "B" denotes re-opening of the fishery. Pacific mackerel biomasses to 1969 are from Parrish and MacCall (1978); bonito catch per effort is from Collins et al. (1980).

rebounded by producing the largest year class (1978) in the history of the fishery (Klingbeil, 1983). Surprisingly, the cyclic spawning success seen consistently in the 30 yr prior to collapse has not been evident in the erratic pattern of the recovered resource.

Pacific bonito (Sarda chiliensis) have long been seasonal visitors to California waters, with large northwardly migrating adults appearing in the SCB in the late summer and fall. However, an apparently self-sustaining population seems to have established residence in California only since the late 1950s, perhaps as a result of the oceanic warming of 1958-1959 (see Collins et al., 1980, for a complete review). Abundance has declined since the early 1960s (Figure 4.4). Some of that decline must be attributed to the commercial fishery which began harvesting bonito in 1966, but sustainability cannot be expected from a resource which has only recently come into existence. The bonito stock in the SCB seems to be a marginal population that hovers near the edge of viability. One hypothesis for its existence is that warm-water discharges from power generating stations have provided overwintering refuges for fish that would normally migrate southward (Collins and MacCall, 1977).

No substantial fishery has developed for jack mackerel (Trachurus symmetricus) in California or Mexico. A small fishery for young fish has existed since 1950 but the industry has had difficulty marketing the product. Much of the biomass consists of large adults inhabiting oceanic waters from the tip of Baja California to the Aleutian Islands, and as much as 1500 km offshore. These fish may exceed 30 yr of age, and stock size may be around two million tons (MacCall and Stauffer, 1983). Nearly all the spawning occurs in offshore oceanic waters, but subsequent young fish appear mainly in the SCB which serves as a nursery ground for a few years. Recruitment strength is highly variable (Figure 4.5), with seemingly periodic strong year classes tending to be isolated by several weak year classes. Age compositions for recent catches are unavailable, but the 1976 year class seems to be prominent, maintaining the pattern.

There are about 60 known species of rockfishes (Sebastes spp.) in the California Current, most of which are demersal and reside north of the U.S.-Mexican boundary (Miller and Lea, 1972). Some of the more pelagic rockfishes such as shortbelly (S. jordani), bocaccio (S. paucispinis), and chilipepper (S. goodei) potentially interact with shallow schooling pelagic fishes such as anchovy and sardine. Abundance of rockfish larvae has been monitored by the CalCOFI ichthyoplankton surveys since the early 1950s, and a few species such as shortbelly and bocaccio are

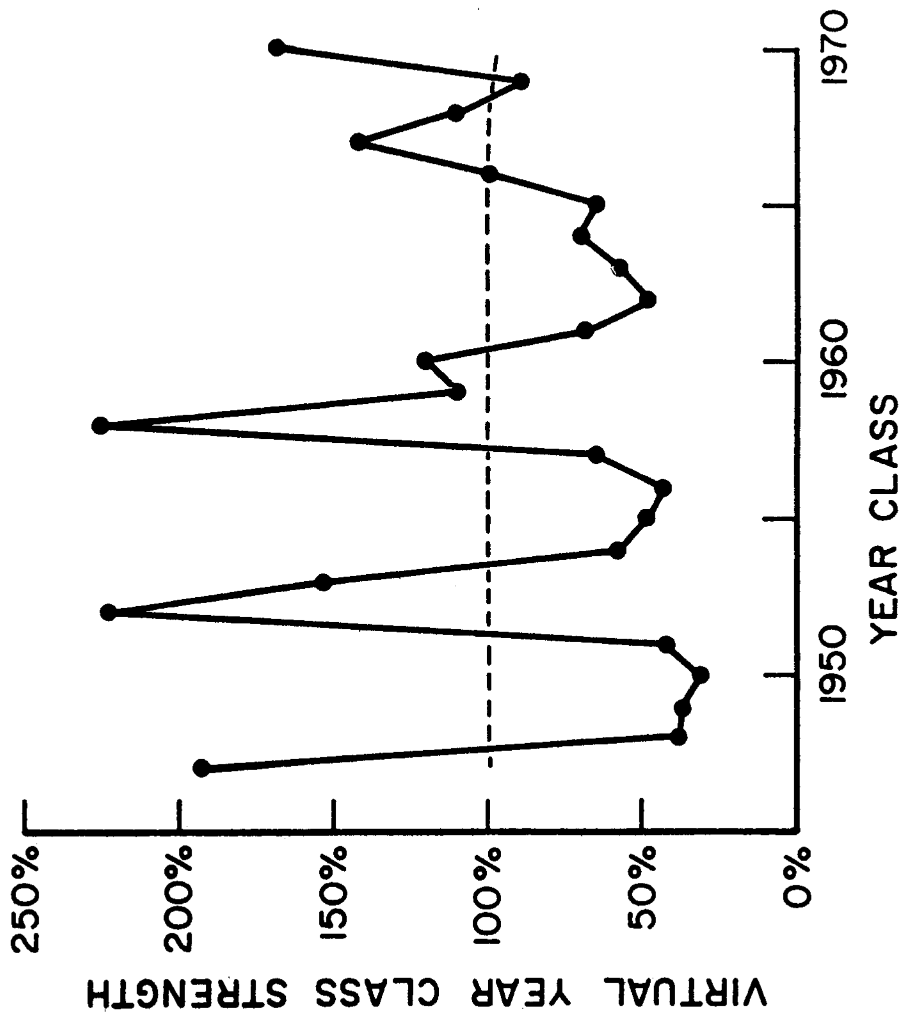

Figure 4.5. Relative recruitment strengths of jack mackerel year classes in southern California (From MacCall and Stauffer, 1983).

identifiable as small larvae. Abundance of adult shortbelly rockfish appears to be several hundred thousand tons, based on acoustic-trawl surveys (inferred from Lenarz, 1980), and, as this species contributes about one-tenth of all Sebastes larvae in the CalCOFI surveys, total rockfish abundance must amount to several million tons. Relatively few species of rockfish are sufficiently abundant, vulnerable, and desirable, to be the object of major commercial or recreational fisheries.

Abundance of rockfish larvae has varied substantially over the last 30 yr. In southern California, where sampling has been the most consistent, the data show three distinct periods (Figure 4.6). The early and recent periods appear fairly stable, with a suggestion of higher abundance recently. The anomalous middle period is initiated by the oceanic warming of 1958-1959 when larval abundances dropped severely. Unlike most other fish species, rockfish larval abundances did not recover immediately following the return to normal oceanic conditions in the early 1960s, but took about ten years to recover to previous levels. It is unclear to what extent the depressed larval abundances were due to decreased adult abundance or to decreased fecundity of those adults. There is no trend in shortbelly rockfish larvae (Figure 4.6) despite large changes in abundance of potentially competing anchovy and sardine. Abundance of bocaccio larvae (Figure 4.6) seems to parallel changes in abundance of anchovy, but the reason is not known; however, adult bocaccio are large fish, and are probably predators of anchovy.

Most of the larger predatory fishes are migratory. The temperate tunas, bluefin (Thunnus thynnus) and albacore (T. alalunga) visit the California Current as 1- to 3-yr-old fish in late summer during their transpacific migrations. Catch rates of both species have declined from peak levels of the 1960s (Hanan, 1983; Laurs, 1983). Many predatory fishes migrate along the coast, wintering in Baja California waters, and moving northward into California waters in the summer. Most of these species are now at low abundance relative to those of the early 1900s. Intense commercial and recreational fisheries on white seabass (Atractoscion nobilis) and California barracuda (Sphyraena argentea) have resulted in very low abundance of these species. A contraction of range is evident for white seabass, which formerly supported a commercial fishery in San Francisco, but now occurs only south of Pt. Conception (Methot, 1983; also see reviews by Collins, 1981; and Vojkovich and Reed, 1983, for white seabass; and Schultze, 1983, for barracuda). Yellowtail (Seriola

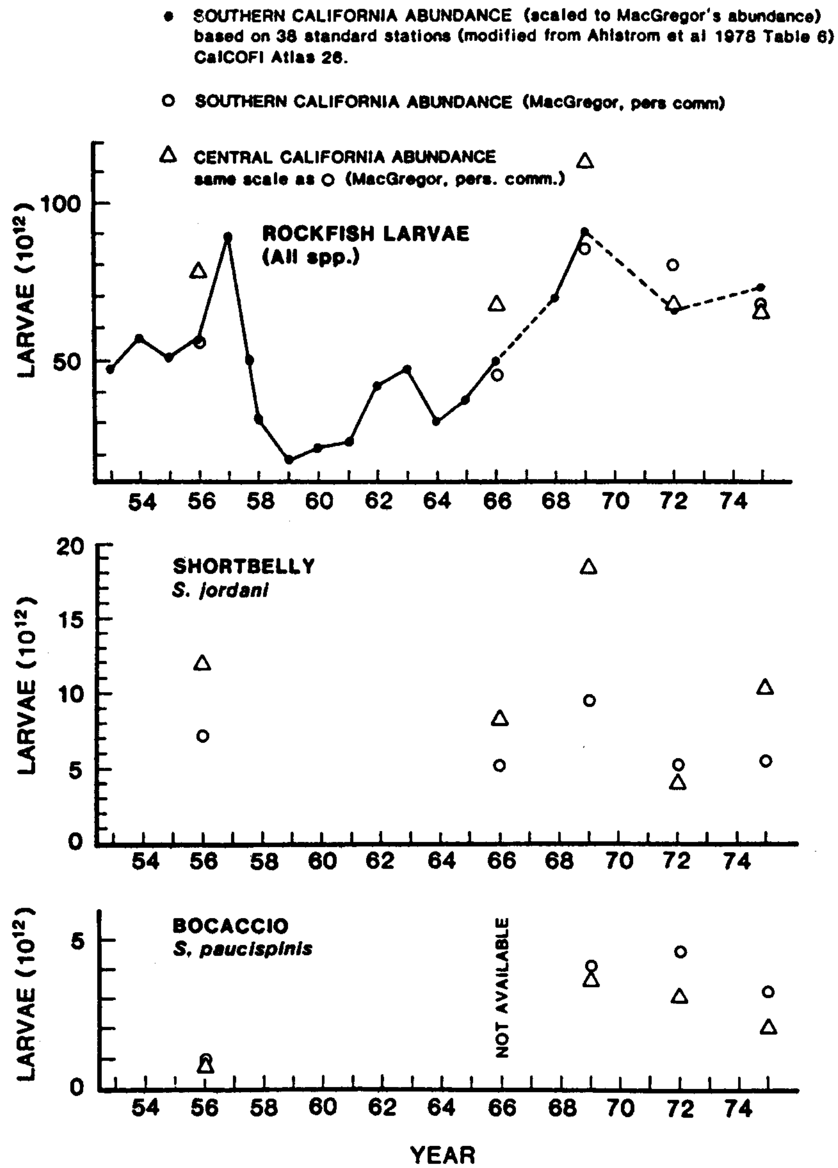

Figure 4.6. Abundances of larval rockfishes off California. Abundance indexes were provided by J. MacGregor, Southwest Fisheries Center, La Jolla, CA.

lalandei) is a popular target of southern California recreational fishermen who take mainly the northward migrants that reach the SCB. Yellowtail appeared to have increased in abundance since the end of the commercial fishery in the 1950s (MacCall et al., 1976), but have recently declined due to several years of poor recruitment (Crooke, 1983). Intense fisheries for thresher sharks (Alopias vulpinus) and bonito sharks (Isurus oxyrinchus) have developed recently (Cailliet and Bedford, 1983), and may be expected to reduce rapidly the abundance of those low fecundity species (cf. Holden, 1977). The pre-fishery abundance of predatory fishes is difficult to estimate, but should be severalfold larger than their peak historical harvests, perhaps by one or two hundred thousand tons. Their present-day abundance is probably 10 to 25 percent of the original level, and the corresponding reduction in prey consumed should have had a beneficial effect on net productivity of the latter species.

Many other species play important roles in the California Current ecosystem. For example, market squid (Loligo opalescens) supports a commercial fishery, and is a major component of many predators' diets. Unfortunately, little is known about the abundances and variability of these species.

MULTISPECIES CONSIDERATIONS

Our knowledge of multispecies interactions is surprisingly limited in view of our extensive knowledge of the California Current. As was suggested in the preceding discussion, it is difficult to assess the impact of the loss of the sardine from the ecosystem. Both natural variability and fisheries have affected other components of the ecosystem, and responses are often indirect and confounded. Our knowledge has been gained mostly since the beginning of the CalCOFI Program in 1950, a period in which the sardine has had little biological influence. While it seems reasonable to assume that loss of the sardine has had a significant impact on the ecosystem, the alternative hypothesis should also be considered: The ecosystem may be well adapted to a highly fluctuating sardine abundance, and its disappearance may have had relatively few identifiable effects.

In a few cases, predator requirements have been defined quantitatively. The brown pelican (Pelecanus occidentalis californicus) is a designated "endangered species" due to pesticide contamination and associated reproductive failure about 1970, a condition from which the California colonies have largely recovered (Anderson et al., 1975; Anderson and Gress, 1983). The relationship between pelican breeding success and anchovy abundance (its main prey) is well-established (Figure 4.7, also see Anderson et al., 1980, 1982). If sardines once again become abundant, brown pelicans are likely to include them in their diet and should enjoy higher breeding success and less dependence on the anchovy (cf. Crawford and Shelton, 1978). In this context it is relevant that brown pelicans ceased breeding effectively at Pt. Lobos, near Monterey, at the same time that the Pacific sardine fishery failed (MacCall, in press). The relationship between brown pelican breeding success and anchovy abundance is recognized explicitly in the Northern Anchovy Fishery Management Plan developed by the Pacific Fishery Management Council (MacCall et al., 1983). Direct relationships between seabird reproduction and anchovy abundance have been shown also for western gulls (Larus occidentalis) and Xantu's murrelets (Endomychuura hypoleuca) by Hunt and Butler (1980), and for elegant terns (Sterna elegans) by Schaffner (1982). Despite their relatively high metabolic requirement, seabirds probably are not abundant enough in the California Current to have a major long-term impact on abundance of prey fishes. However, at times, seabird impact on forage may be large. For example, Wiens and Scott (1975) estimate that the millions of sooty shearwaters (Puffinus griseus) passing along the Oregon coast during their late summer southward migration may consume over 450 tons of anchovies per day, and larger quantities may be assumed for the much longer California coastline.

Pinnipeds consume large quantities of fish, and are increasing at a rapid rate in California. The approximately 70,000 California sea lions have been estimated to consume 100,000 to 300,000 tons of fish, and the 40,000 elephant seals may annually consume 400,000 to 1,000,000 tons, mostly of demersal fish (DeMaster, 1983). Daily rations are well known for pinnipeds, due to experience with captive animals, but the response to fluctuations in abundance and species composition of forage in the ocean is poorly known. Per capita reproductive rates of pinnipeds appear relatively constant except for severe declines during oceanic warmings such as 1982-1983.

A particularly difficult issue is the relationship between anchovy abundance and catch rates of large predatory fish. California's recreational fishermen strongly feel that abundant forage is necessary to attract large fishes to the region. Anchovies are certainly important to recreational fishing operations, being used as live bait, and anchovy schools provide visual clues to the location of predator fishes. The importance or value of these uses of anchovy is very difficult to quantify, but recognition of the large

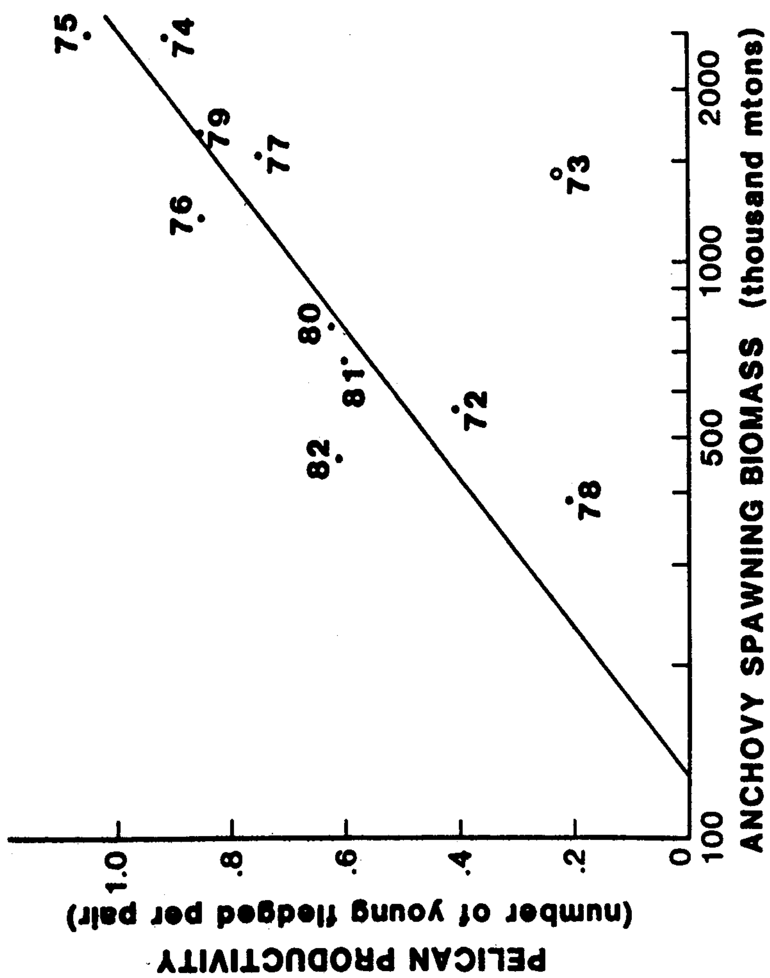

Figure 4.7. Relation between brown pelican productivity (Anderson et al., 1980, 1982) and anchovy spawning biomass (from MacCall et al., 1983). The 1981 and 1982 productivity values are unpublished data.

recreational fishing constituency in California has influenced anchovy harvesting policy, and constrained U.S. commercial fishery development in the early 1970s. More recently, the Pacific Fishery Management Council has chosen to pursue a harvest policy which seeks a moderate, relatively constant allowable anchovy harvest, and establishes a minimum level of anchovy abundance below which non-bait uses are curtailed (MacCall et al., 1983).

Multispecies considerations are operationally important to management of many species in California, although the biological basis of management remains single-species models. Incidental catches of non-target species are regulated, especially in the case of depleted stocks such as sardine and Pacific Ocean perch (Sebastes alutus). In order to prolong fishing opportunities, some fishing seasons have been established interactively. For example, in California, the anchovy reduction (fish meal) fishery ends on June 30, when summer live bait demand is high. The Pacific mackerel fishery opens on July 1, preserving continuity of opportunity for the California purse seine fleet (Klingbeil, 1983).

OUTLOOK

Developments in the California Current ecosystem and its management during the remaining years of the 20th century should be very interesting. The Pacific sardine recently has shown signs of increase (Bedford et al., 1983), although the resource presently remains severely depleted in the California Current. Recovery of depleted coastal pelagic resources often occurs suddenly, with production of a large year class. Examples are the strong 1976 and 1978 year classes of Pacific mackerel in California (Klingbeil, 1983) and the recent increase in sardines off Japan (Kondo, 1980). If recovery of the sardine is rapid, ecosystem effects may be somewhat easier to assess than they would be for gradual changes.

The major U.S. anchovy fishery produces fish meal, a high protein animal feed supplement which has declined in demand due to replacement by enriched soybean meal (Thomson, 1984). The Mexican fishery has grown since the mid-1970s, and Mexican domestic demand for fish meal is expected to remain strong. Consequently, the major harvest of anchovy now occurs south of the U.S.-Mexican border, where harvests are unregulated.

Pinniped populations are increasing rapidly, with some species increasing at over 10 percent per year, and interactions with fishermen are increasing disproportionately. Marine mammals are presently protected by the U.S. government under the Marine Mammal

Protection Act, but return of management to the individual states is being promoted. The debate between the preservationists and the fishermen is highly emotional, and the future course of marine mammal management in the California Current should be interesting to watch.

The greatest difficulty facing ecosystem management is the multitude of jurisdictions, often overlapping and conflicting, and each with its own objectives, responsibilities, and responsiveness. The portion of the California Current south of the U.S.-Mexican border is under Mexican jurisdiction, where some fauna such as marine mammals are protected, but fishery regulation is minimal. Access to Mexican waters by U.S. commercial fishermen has been severely restricted since 1982, which should have reduced fishing pressure on many species off Baja California. In California some species are managed by the federal government through the Pacific Fishery Management Council, while others are managed by state institutions, including the California legislature (most commercial fisheries) and the California Fish and Game Commission (recreational fisheries and some commercial fisheries). Marine mammals are managed by the U.S. Department of Commerce (and may be returned to state control), but seabirds are under the authority of the U.S. Department of the Interior. Despite this seeming confusion, coordination has been moderately successful when pursued on a single-species basis. Actual ecosystem management, if it were technically feasible, would be difficult to achieve unless management authority were better consolidated, with provisions for local representation and responsiveness. Such a consolidation appears unlikely in the foreseeable future.

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