DRAFT

BRIEFING PAPER

AN INTRODUCTION TO HARVEST AND ITS EFFECTS ON SELECTED SPECIES OF FISH OF THE SAN FRANCISCO BAY/ SACRAMENTO-SAN JOAQUIN DELTA ESTUARY

Resources Agency, State of California
BAY-DELTA OVERSIGHT COUNCIL

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Preface

This briefing paper is one of a series of background reports prepared for the Bay-Delta Oversight Council (BDOC or Council). It describes the status and impacts of legal and illegal harvest of selected species of fish of the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. While an attempt has been made to be as comprehensive as possible, this paper should not be considered an exhaustive treatment of issues related to the harvest of fishery resources in the Estuary, nor of measures to control illegal harvest.

The initial draft of this paper was prepared for the BDOC through the joint effort of several resource managers within the Department of Fish and Game. Editorial assistance was provided by BDOC staff. BDOC staff solicited peer review of the initial draft from commercial fishing interests, water resource managers and other experts in an attempt to reflect the full spectrum of opinion regarding the issues addressed. Not surprisingly, the salmon section generated significant response while the balance of the paper did not. The critiques of the salmon section were addressed through incorporation and revision.

The Executive Summary provides an overview of the information presented. However, it should not be considered a substitute for the full text, as the characterization and context of the entire document cannot be replicated in such a summary.

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EXECUTIVE SUMMARY

Water supply operations within the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Estuary) are significantly impacted by management of the Estuary's fishery resources, and vice-versa. The harvest of Estuary fish (whether resident or transient) is of concern to fishery managers. The cumulative impacts of legal and illegal fishing are important variables affecting the overall population stability and resiliency of various species. The following is a brief sketch of harvest impacts associated with selected species in the Estuary. The species selected for discussion in this paper are subject to significant commercial and/or sport fishing pressures which either affect the sustainability of their populations, or contribute to uncertainty with respect to regulation of water project operations, or both. The conspicuous emphasis on salmon reflects its critical importance both as the basis of a commercial fishery and as the focus of regulation pursuant to the federal Endangered Species Act.

SALMON

There are four races or "runs" of chinook salmon in the Central Valley: fall-run, late fall-run, winter-run and spring-run (so named to identify the time of year they return upstream to spawn). The fall-run is the most abundant of the four races in the Sacramento River and the only race currently returning to the San Joaquin River. More than 90 percent of all spawners are fall-run fish.

Pursuant to the Magnuson Fishery Conservation and Management Act, the U.S. Department of Commerce regulates ocean harvest to protect against over fishing. In California waters, sport harvest is regulated by the California Fish and Game Commission, while the Legislature regulates the commercial fishery. Harvest regulations account for the effects of legal harvest (including impacts associated with releases of sub-legal fish), incidental take, illegal harvest and environmental variables both in inland and ocean waters. However, identifying the origin and race of any individual salmon caught in the ocean is problematic, as there are no distinguishing features to do so. Complicated procedures, which to some are problematic, are used to estimate catches, to determine which race of salmon is being taken and its stream of origin.

Within the Central Valley, salmon hatcheries have been built during the last 50 years to mitigate for the loss of salmon spawning areas. Because of reduced mortality early in life, hatchery salmon populations can withstand higher harvesting rates than wild stocks. As a consequence of this variance in susceptibility to over harvest, it is difficult to establish fishing regulations which allow full utilization of the total population without potential detrimental pressures on the wild stock population.

POPULATION ESTIMATES

Spawning surveys indicate quite different trends for the various races and particularly for fall-run salmon in different parts of the system. The largest stock of fall-run salmon is in the upper Sacramento River. Its abundance fell precipitously from the mid-1960s to the mid-1970s, and since then has consistently remained at about 1/4 to 1/3 of its abundance during the 1950s and early 1960s. Stocks in the lower Sacramento system have not experienced a similar decline, partly as a result of hatchery management practices. San Joaquin fall-run populations have been highly variable, with three peaks of 30,000 to 45,000 in average annual fish abundance followed by valleys of approximately 5,000 fish.

The three other races of chinook salmon in the upper Sacramento River have declined substantially since 1967.

HARVEST

Most harvest of Central Valley salmon stocks occurs in commercial and sport fisheries off the coast of central California. However, some salmon from the Central Valley are caught further north and some salmon from other areas are harvested off central California. Hence, no precise measure of total harvest exists.

The 5-year running average of estimated combined commercial catch in the San Francisco and Monterey bay areas fluctuated between about 250,000 and 300,000 fish from 1973 to 1987, but was over 400,000 fish in the 1988 - 1991 period (this catch includes some salmon originating in areas other than the Central Valley). The long-term trend in harvest rate indices appears to be increasing slightly, however, these indices at best are only a rough estimate of actual harvest.

The principal salmon sportfishing catch also occurs in the ocean. From 1967 through 1991, the sport catch equalled approximately one-third of the commercial catch. The Department of Fish and Game estimates sport catch of salmon in the Sacramento River averaged about one tenth of the average combined ocean sport catch in the San Francisco and Monterey bay areas.

Sport harvest has not been estimated in the San Joaquin system, but legal fishing has been largely restricted to the main stem of the San Joaquin River throughout the 1967-1991 period and has been prohibited entirely since 1991.

Illegal harvest of salmon occurs in the form of gillnetting, longlining and snagging. Fishermen using legal techniques contribute to illegal take when they exceed bag limits and keep fish shorter than the legal length. Illegal salmon harvest in the Estuary has been estimated to result in the loss of spawning stock (potentially as many as 500 adult female salmon) that would otherwise produce as many as 250,000 additional salmon smolts annually.

Considerable attention has been focused on the possible effects of concentrated (illegal) fishing by foreign boats off the Pacific Coast. The mid-Pacific high seas drift net fishery has impacted Alaskan and British Columbia salmon stocks (such as sockeye, chum, and pink). However, there is no evidence that the Central Valley salmon fishery has been similarly impacted. Central Valley salmon only rarely venture into international waters, and are thus not subject to significant legal foreign harvest.

In the Pacific Ocean, salmon shorter than legal length limits are often caught and released by both sport and commercial fishermen. The PFMC has adopted 31 percent and 13 percent as the best estimates of the proportion of released salmon which die from the stress of being caught and released by commercial and sport fishermen respectively. These mortalities are factored into the impact analyses provided to the PFMC as part of its regulation setting process.

The key salmon issues that are intended to be addressed by regulation are whether the harvest is sufficiently large to threaten the continued existence of some stocks and the relative impacts of the fishery and environmental variables upon spawning stock size. The answers to those questions determine whether the fishery is being regulated prudently.

The age structure of salmon spawning stocks is an important indicator of its sustainability. Today, spawning runs are dominated by three-year old fish, while five-year old fish are rare. Previous to the 1960s, there were more four- and five-year old fish in the system.

This change in age structure from previous years has several consequences. The lowered average age of spawning fish diminishes the reproductive potential of the stock because egg production increases with age. Also, dominance by a single age renders the stock more vulnerable to fluctuations in environmental conditions. Department of Fish and Game biologists do not believe, however, that the present age structure is unacceptable or a principal cause of measured abundance declines since 1970.

A harvest rate index has been developed as a principal measure used by the PFMC in regulating the fishery. The annual harvest rate index has fluctuated between about 0.4 and 0.8 during the last 40 years. Significantly, in examining harvest data, a scientific team reporting to the PFMC concluded that "since 1970, the ocean harvest rate index has been slowly increasing" and "the increasing trend may indicate a level of harvest too high to sustain" (PFMC, 1994).

The PFMC's management goal has been to set harvest limits that will maintain a spawning run of 122,000 to 180,000 fall-run adult fish in the Sacramento River system: the estimated optimum number of spawners -- accounting for hatchery production and the carrying capacity of the natural environment. This goal was met from 1970 through 1989 with only two exceptions. However, it was not achieved in 1990, 1991 and 1992. In 1993, the escapement goal was achieved, with preliminary data indicating the number of fish to be at the lower end of the goal's range.

The PFMC has refined its predictor models and continues to strive to regulate the fishery so as to attain the escapement goal of 122,000 to 180,000 fall-run salmon. The PFMC believes the analysis that originally concluded that the current numerical escapement goal is optimum for the basin still provides a sound management strategy.

While the PFMC escapement goal targets fall-run salmon, the regulations to implement it provide protection for all runs. Even before recent regulatory changes were implemented to curtail harvest of winter-run, the harvest ratio for winter-run was probably about 0.3. Even though the winter-run is harvested at a lower rate than the fall-run, some people believe that the 30% take of adult fish (including spawners) is too high and has contributed to the continuing depressed status of the winter-run.

Water industry representatives generally express reservations about the adequacy of the PFMC's approach. Marking all hatchery fish, so regulations could be directed toward selectively harvesting hatchery fish, is an idea supported by some commercial fishing interests and it would provide increased accuracy in regulatory calculations. However, there are concerns about mortality caused by marking. Some fishery experts go a step further and advocate reliance on terminal fisheries (harvest of returning fish *in the river*).

EFFECT OF HARVEST ON POPULATION

Various Central Valley salmon stocks have experienced quite different trends in the abundance of their spawning runs. Some have declined sharply, others have been relatively stable and still others have fluctuated dramatically.

Commercial and sport harvest of salmon, primarily by legal fisheries in the Pacific Ocean, are clearly large enough to have a substantial effect on the size of spawning runs. Several trends, including decreases in the average age of spawners, increases in harvest rates, and the recent failure to meet spawning escapement goals raise serious questions and concern as to whether salmon stocks are being over harvested. This is particularly the case for naturally spawning fish, as contrasted to hatchery stocks. At a minimum, the evidence would seem to dictate a need for more effective regulation of harvest to meet spawning escapement goals.

Some experts believe salmon abundance fluctuations in the San Joaquin system provide the best empirical evidence that fishing is not the principal factor limiting populations of Central Valley salmon stocks. Since the San Joaquin is dominated by naturally spawning fish, and is thus more vulnerable to being depleted by over fishing than the larger stocks of the Sacramento, one would not expect spikes in its populations to occur independent of dramatic harvest reductions. However, such increases have occurred and they are generally thought to be reflective of increased habitat value associated with instream flow increases caused by hydrologic conditions.

There is a widely held perception in the water community that water projects are too heavily constrained to mitigate for what are, in its opinion, fishery and other non-project impacts. On the other hand, the typical commercial fisherman perceives himself as bearing the burden of fishery declines caused by various sources of environmental degradation, particularly water development.

These perceptions demonstrate the breadth of the continuing controversy regarding potential fishery impacts upon the Central Valley salmon resource. Many issues are not well understood or are the subject of ongoing debate. There does seem to be general agreement, however, that effectively addressing the decline of Central Valley salmon will require a comprehensive regulatory program, addressing both water project and non-water project impacts. Only such a comprehensive program can achieve a sufficient level of confidence among *all* of the constituencies to successfully manage the resource. Though that necessary level of confidence does not exist today, there are encouraging signs that the importance of such an approach is gaining greater acceptance.

STRIPED BASS

Striped bass are not native to the Estuary and were introduced to it in 1879. By 1900, the commercial harvest alone exceeded 1 million pounds annually. The commercial fishery was ended in 1935 to protect the sport fishery.

The striped bass population has steadily declined since the mid-1960s. Studies by the DFG indicate that low annual recruitment of new fish has led to fewer adults spawning and producing eggs. Estimates of adult, legal-sized striped bass abundance for the Estuary show a steady decline from a high of 1.8 million fish in 1975 to a 1992 total of 600,000. It was estimated that the 1992 sub-adult population was 2.4 million fish.

With respect to illegal harvest, the Delta-Bay Enhanced Enforcement Project (DBEEP) estimated an annual take of 500,000 sub-legal striped bass before inception of its intensified enforcement effort. In 1993, DBEEP estimated the illegal take was 350,000 fish.

Since 1969, an average of 216,800 legal-size striped bass have been harvested annually. Additional restrictions were placed on the harvest in 1982. The 1991 harvest estimate in the Delta was 108,000 fish, which was below the most recent 10-year average of 154,000.

DFG biologists believe about 75 percent of the decline in adult striped bass abundance is attributable to fewer bass reaching legal size, with the other 25 percent caused by predation, pollution, poaching, etc. Although the percentage of the adult population being harvested has not changed dramatically, declines have continued. DFG believes this indicates other factors are to blame and existing angling regulations are appropriate. However, substantial numbers of sub-legal striped bass are harvested, which has probably contributed to the decline in population, but DFG has not been able to estimate the level of that contribution.

In the 1980s, to help reverse the decline of the striped bass fishery, the DFG advocated more restrictive angling regulations, improving environmental and habitat conditions in the Estuary, and undertaking a hatchery program.

The average harvest rate for striped bass was 15 percent from 1980-91, as compared to 17 percent in 1976-79. Despite this reduction in harvest rate, populations continued to decline. DFG believes that this further illustrates the reduction in striped bass populations is related to factors other than harvest.

In a 1990 study, the DFG concluded that even significant additional angling restrictions, dramatically increasing overall egg production, would only have a limited positive benefit to striped bass populations. A 68 percent increase in egg production was estimated to result in less than an 8 percent increase in the stable striped bass population. A doubling of egg production was expected to result in only a 10 percent increase. This study illustrates the significance of the other factors, independent of population management measures, affecting striped bass abundance. DFG believes that particularly key factors are the levels of project exports and Delta outflows.

DFG studies have also shown that less than 25 percent of the declines in striped bass population can be attributed to adult mortality (legal/illegal take, toxics, etc.). Improving recruitment through habitat enhancement and other measures is seen as the answer to increasing populations, not additional harvest restrictions that provide only marginal improvement.

While some have broached the idea of following the example of the Chesapeake and closing the striped bass fishery for some fixed period of time to allow replenishment of stocks, the DFG considers this comparison inappropriate because the Chesapeake's harvest rates were much higher than those in the Delta.

WHITE STURGEON

White sturgeon is an anadromous fish native to the Estuary, which does not reach sexual maturity until approximately 14 years of age. From the 1860s through 1917 there was a commercial fishery for white sturgeon in the Estuary. Because the population was so decimated, it was illegal to take sturgeon in the Estuary from 1918 through 1953. In 1954, a heavily regulated sport harvest was reinstituted. Today, there is a one fish per day bag limit.

White sturgeon population dynamics have been monitored only intermittently since the sport fishery re-opened in 1954. However, population estimates have been made in recent years, with extremely high variability. A peak of 120,000 fish was estimated in 1984, 86,000 in 1987, and 29,000 in 1990. The 1991-93 estimates are not yet available.

Illegal harvest of white sturgeon in the Estuary has not been measured, and records of illegal catch are not kept by the DFG.

The DFG has only periodically monitored the legal harvest of white sturgeon. Until 1984, harvest rates stayed below 8 percent. This rate rose to nearly 11 percent in 1985, which DFG believed might be high enough to threaten over exploitation of the population. New regulations were promulgated in 1990 which reduced the legal harvest to less than 5 percent of the population.

AMERICAN SHAD

American shad were introduced from the east coast to enhance sport fishing opportunities. There are no annual population estimates for American shad in Central Valley rivers and streams, except for 1976 (3.04 million) and 1977 (2.79 million).

Although the commercial American shad fishery was closed in 1957 to reduce the incidental take and associated mortality of striped bass and salmon, there is a recreational fishery.

Illegal harvest of American shad is not monitored to the extent that an estimate can be made of total losses.

There are only two three-year periods during which sport catch was monitored: From 1976-78 a combined average of approximately 180,000 shad were taken on the Yuba, Feather, American, and Sacramento rivers. During the 1990-91 season, close to 46,000 fish were caught and released, the 1991-92 season total was 54,700 and the 1992-93 total was 80,500. These 1990s figures are based upon catch data from the mainstem of the Sacramento River stretching from the Carquinez Bridge to Redding. According to DFG, estimates of sport harvest of American shad are low compared to estimated abundance levels and lower than the historic commercial harvest.

American shad historically spawned throughout the Delta and its upstream tributaries. Today, spawning is limited to the upper edge of the north Delta.

LEOPARD SHARK

The extent of the leopard shark fishery is difficult to measure, and its population has not been estimated. While catch data are used to make rough estimates of the population, environmental conditions are thought to affect it as well.

It is important to note that the leopard shark, as compared to other fish in the Estuary, has a low reproductive rate of only 4 to 29 pups per year.

The National Marine Fisheries Services tagged 948 leopard sharks in San Francisco Bay in 1979; of those, roughly 82 percent of the 108 recoveries were returned by sport anglers, while only 18 percent were returned by commercial fishermen. This indicates, assuming there were no tagged fish that were not returned, that the sport fishery is a significant factor impacting population.

In 1983, the commercial harvest of leopard shark was 101,283 pounds. The commercial fishery has been expanding in southern California and declining north of Monterey.

Additional sport fishing regulations limiting the take of leopard shark were instituted in 1994.

PACIFIC HERRING

California's commercial herring fishery began in 1972. San Francisco Bay is the largest and most productive spawning ground for Pacific herring in California. Tomales Bay is the next most productive spawning area. Each bay is managed separately to ensure that the stock in each is protected from over harvest. Harvest quotas are usually set at approximately 15 percent of the total herring biomass estimates in each bay. According to DFG, commercial harvest of Pacific herring does not appear to be having a negative effect on the sustainability of the population.

There is currently no data regarding the extent of the illegal harvest of this species.

LARGEMOUTH BASS

The largemouth bass is a warm water fish that was introduced to the Estuary in the late 1800s.

The extent of the illegal take of largemouth bass has not been monitored in the Delta.

There is very little information available concerning sport harvest and population size of largemouth bass in the Sacramento and San Joaquin rivers. However, based upon tagging studies carried out in the mid-1980s, the DFG estimates annual harvest to be no more than 30 percent of the population in the Delta, which is a rate less than that of many other largemouth bass populations which are known to be stable. Consequently, DFG believes that sport take is well within acceptable levels.

INTRODUCTION

This document has been prepared in response to a request from the Bay-Delta Oversight Council for information on the status and impacts of fish harvest within and beyond the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Estuary), and its potential effects on aquatic resources. In addition to describing the harvest of selected species, the information presented is intended to facilitate a better understanding of the degree to which harvest, legal and/or illegal, may affect fishery benefits to be derived from management measures directed toward solving other problems within the Estuary.

Over 200 species of shrimp, crab, and fishes live in the Estuary. Nearly 100 species of fishes occupy the more brackish to marine portions of the Estuary (Table 1), while the brackish to freshwater portions offer habitat for 35 species of fishes (Table 2). Six species of anadromous fish spawn, rear in, or pass through the Estuary. The species selected for discussion in this paper are subject to significant commercial and/or sport fishing pressures which either affect the sustainability of their populations, or contribute to uncertainty with respect to regulation of water project operations, or both.

Efforts to protect and recover the winter-run chinook salmon, delta smelt, and other depleted fishery resources, primarily in response to mandates imposed by the federal Endangered Species Act, have resulted in restrictions on State Water Project and federal Central Valley Project operations. Such project constraints have affected the ability of California's Department of Water Resources and the U.S. Bureau of Reclamation to fulfill water management objectives for direct human use and other beneficial uses. Some observers have expressed concern that limits have been imposed without fully understanding how other, non-water project factors impacting the Estuary's ecological balance may limit or preclude the recovery of species, as well as the protection and enhancement of the broader ecosystem. Other factors identified as probable contributors to environmental and fishery declines in the Estuary include commercial and sport harvest, entrainment in in-Delta diversions, invasive and disruptive non-native species, pollution, toxics, and reduced ocean productivity.

This paper, which examines the impact of harvest, complements information already provided to the Council in the September, 1993 briefing paper titled; "Briefing Paper on Biological Resources of the San Francisco Bay/Sacramento-San Joaquin Delta Estuary" -- particularly the section, "Factors Controlling the Abundance of Aquatic Resources in the Sacramento-San Joaquin Estuary." In that briefing paper, the effect of human harvest was generally portrayed as a relatively minor factor affecting the Estuary's fishery resources when compared to the influence of water flows into the Delta, Delta outflows, and water export operations. Some biologists and water managers strongly disagree with that judgment and believe sport and commercial fish harvest are likely contributors to fishery declines. They argue that a better understanding of the impacts of harvest on the interrelationship between fisheries and water management needs to developed as part of any strategy to manage the various beneficial uses served by the Delta.

[NOTE: In addition to this paper, as part of an effort to provide the Council with a comprehensive view of the factors affecting the Estuary, the BDOC staff has produced a briefing paper discussing the impact of introduced species; "Briefing Paper on Introduced Fish, Wildlife and Plants in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary," (May, 1994). Additionally, a briefing paper describing the effects of pollution and toxics in the Estuary is currently in process. The fishery impact of in-Delta entrainment is the subject of ongoing DWR and DFG studies. Investigation of variables affecting ocean productivity of particular fish species is beyond the scope of the BDOC program.]

Table 1. Marine and Brackish Water Fish Species that Occur in the San Francisco Bay/ Sacramento-San Joaquin Delta Estuary.

Pacific lamprey	brown rockfish	C-O sole
river lamprey	yellowtail rockfish	curlfin sole
sevengill shark	black rockfish	hornyhead turbot
Thresher shark	blue rockfish	sand sole
brown smoothhound	red Irish lord	California tonguefish
leopard shark	brown Irish lord	ocean sunfish
spiny dogfish	Pacific staghorn sculpin	plainfin midshipman
Pacific electric ray	fluffy sculpin	smooth ronquil
big skate	cabezon	blue lanternfish
bat ray	bonehead sculpin	barred surfperch
Pacific herring	scalyhead sculpin	calico surfperch
Pacific sardine	tidepool sculpin	shiner perch
whitebait smelt	white croaker	black perch
surf smelt	queenfish	spotfin surfperch
longfin smelt	halfmoon	walleye surfperch
night smelt	senorita	silver surfperch
delta smelt	kelp greenling	rainbow seaperch
Pacific tomcod	lingcod	dwarf perch
Pacific hake	painted greenling	white seaperch
northern lampfish	Pacific sandlance	rubberlip seaperch
northern anchovy	rockpool blenny	pile perch
Pacific argentine	topsmelt	chameleon goby
California lizardfish	jacksmelt	blackeye goby
Pacific saury	medusafish	longjaw mudsucker
threespine stickleback	Pacific pompano	bay goby
bay pipefish	Pacific barracuda	yellowfin goby
showy snailfish	striped mullet	cheekspot goby
spotted cusk-eel	onespot fringehead	arrow goby
Pacific blacksmelt	striped kelpfish	goby type II
red brotula	monkeyface prickleback	arrow/cheekspot goby
northern clingfish	penpoint gunnel	Pacific sanddab
pygmy poacher	saddleback gunnel	speckled sanddab
chub mackerel	starry flounder	

Table 2. Resident Fish Species of the Brackish and Freshwater Portions of the San Francisco Bay/Sacramento-San Joaquin Delta Estuary.

Centrarchidae

*Sacramento Perch
Largemouth
Smallmouth Bass
Bluegill

Redear Sunfish
Green Sunfish
Warmouth
Black Crappie
White Crappie
Pumpkinseed
Sunfish Hybrids

Other

*Delta Smelt
*Sacramento Sucker
*Tule Perch
*Threespine Stickleback
*Riffle Sculpin
Prickly Sculpin
Bigscale Logperch
Inland Silversides
Mosquitofish
Threadfin Shad
Yellowfin Goby

Cyprinidae

*Sacramento Squawfish
*Hitch
*Sacramento Splittail
*Sacramento Blackfish

*Hardhead
Golden Shiner
Goldfish
Carp
Flathead Minnow

Ictaluridae

Channel Catfish
White Catfish
Brown Bullhead
Black Bullhead

*Indicates native species

CHINOOK SALMON

INTRODUCTION

There are four races or "runs" of chinook salmon in the Central Valley: fall-run, late fall-run, winter-run and spring-run (so named to identify the time of year they return upstream to spawn). Approximately 80 percent of all four races are produced in the Sacramento River system (P. Chadwick and P. Herrgesell, DFG, 1993). The fall-run is the most abundant of the four races in the Sacramento River and the only race currently returning to the San Joaquin River. More than 90 percent of all spawners are fall-run fish.

All races are harvested to varying degrees by sport and commercial fishing in the Pacific Ocean and by sport fishing in inland waters.

Pursuant to the Magnuson Fishery Conservation and Management Act, the U.S. Department of Commerce regulates the level of harvest in the ocean to protect against over fishing. The Pacific Fishery Management Council (PFMC) recommends regulations to the Department of Commerce. The PFMC includes representatives from state and federal agencies as well as commercial and recreational fishing groups. In California waters, sport harvest is regulated by the California Fish and Game Commission, while the Legislature regulates the commercial fishery. The Legislature, however, has given authority to the Director of the Department of Fish and Game (DFG) to conform State regulations with federal regulations. When setting harvest limits, regulators include in their calculations the effects of legal harvest (including impacts associated with releases of sub-legal fish), incidental take, illegal harvest and environmental variables both in inland and ocean waters. While environmental conditions in inland waters have received the most attention, major variations in survival are also traceable to environmental conditions in the ocean.

All races of Central Valley chinook salmon mix in the ocean amongst themselves and with salmon from other river systems. As a result, except for tagged fish, identifying the origin and race of any individual fish caught in the ocean is problematic. Complicated and relatively uncertain procedures are used to estimate catches from the various rivers and to determine which race of salmon is being taken.

Regulation is also complicated by the existence of salmon hatcheries. Within the Central Valley, salmon hatcheries have been built during the last 50 years to mitigate for the loss of salmon spawning areas destroyed by dam construction on the Sacramento, Feather, American and Mokelumne rivers. A small hatchery also exists on the Merced River. Because of reduced mortality early in life, and thus more fish making it to the ocean, hatchery salmon populations can withstand higher harvesting rates. Hence regulations designed to optimize harvest of hatchery fish might result in over harvesting wild stocks.

One critical deficiency is the absence of an ability to distinguish between hatchery and wild fish, as fish produced in hatcheries often spawn in the wild and some natural fish spawn in hatcheries. The probability of such exchanges is enhanced by releasing many hatchery produced fish in the Estuary, which increases straying (returns to "wrong" rivers), and by occasionally moving salmon from one river to another within the Central Valley to bolster stocks in the receiving river.

Consequently, it should not be surprising that substantial uncertainties and gaps exist with respect to the information needed and used to regulate the salmon fishery. Also, this uncertainty contributes to strong differences of opinion as to the wisdom of various management actions.

POPULATION ESTIMATES

Historically, chinook salmon stocks were monitored through the use of commercial catch records. This method has generally been replaced with spawning surveys, involving mark-recapture techniques, fish ladder counts, and aerial redd (nest) surveys (T. Mills and F. Fisher, DFG, 1994).

Annual fall-run spawning surveys, which began in 1953, provide the longest salmon stock abundance record available. Dead fish on spawning grounds throughout the Central Valley are counted and an estimate of the fall-run population is extrapolated.

Completion of Red Bluff Diversion Dam in 1967 permitted counting of the three other runs as they migrate past the dam. Those counts, and some aerial surveys of redds, have provided abundance measures for the other three runs in the upper Sacramento River since 1967.

Spawning surveys indicate quite different trends for the various races and for fall-run salmon in different parts of the system. The largest stock of fall-run salmon is in the upper Sacramento River. Its abundance fell precipitously from the mid-1960s to the mid-1970s, and since then has consistently remained at about 1/4 to 1/3 of its abundance during the 1950s and early 1960s (Figure 1). Although overall fall-run abundance in all three of the Sacramento's lower tributaries (Feather, Yuba and American rivers) has not experienced a similar decline (Figure 2), the number of naturally produced fish has diminished during the last six years, coincident with the drought. Population increases and decreases in different areas of the Sacramento system, which are partially caused by changes in hatchery production, tend to fluctuate independently of one another and often cancel each other out with respect to the stability of the total population in the system (Figure 3). [See Glossary for method of five-year running average calculation.]

The three other races of chinook salmon in the upper Sacramento River have each declined since 1967. The decline has been greatest for the winter-run (Figure 4). The late fall- and spring-run populations have also been reduced (Figure 5), with the spring-run declining to very low levels recently.

Population trends for fall-run salmon in the San Joaquin system are dramatically different than those in the Sacramento. In the San Joaquin, three peaks of 30,000 to 45,000 in average

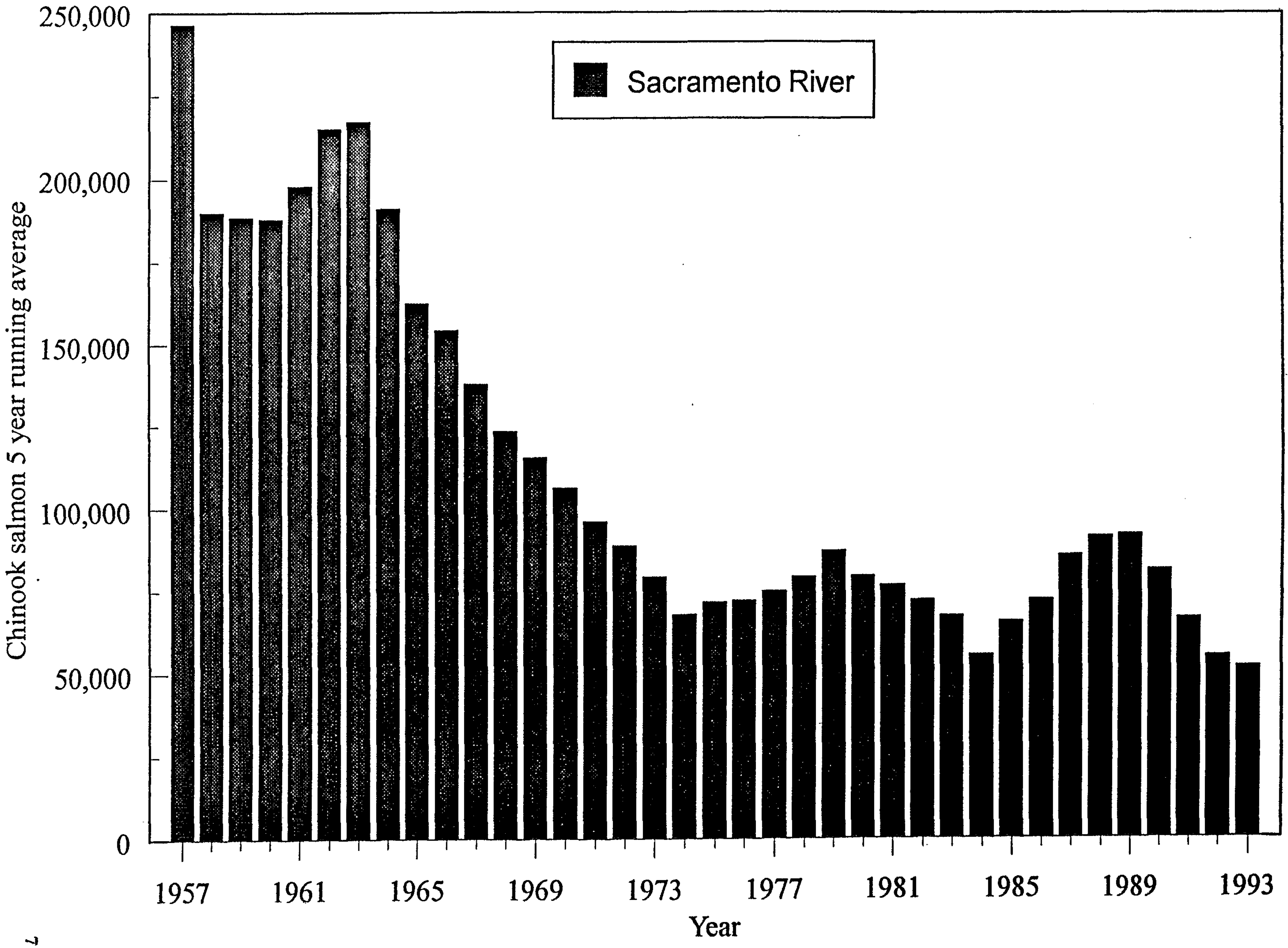

Figure 1. Five-year running average of Sacramento River fall-run chinook salmon population estimates above the mouth of the Feather River (1957-1993).

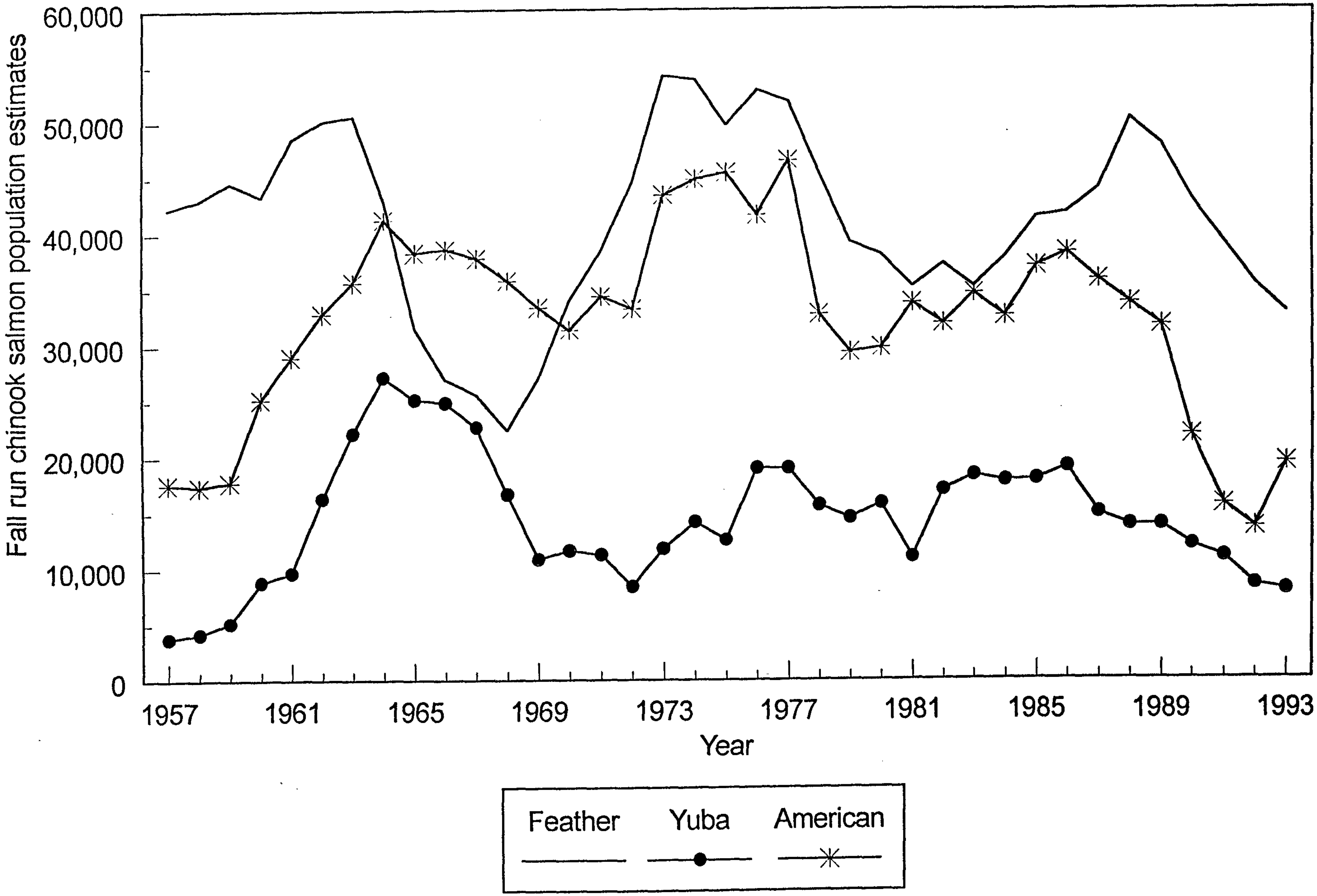

Figure 2. Five-year running average of fall-run chinook salmon population estimates for the Feather, Yuba, and American rivers (1957-1993).

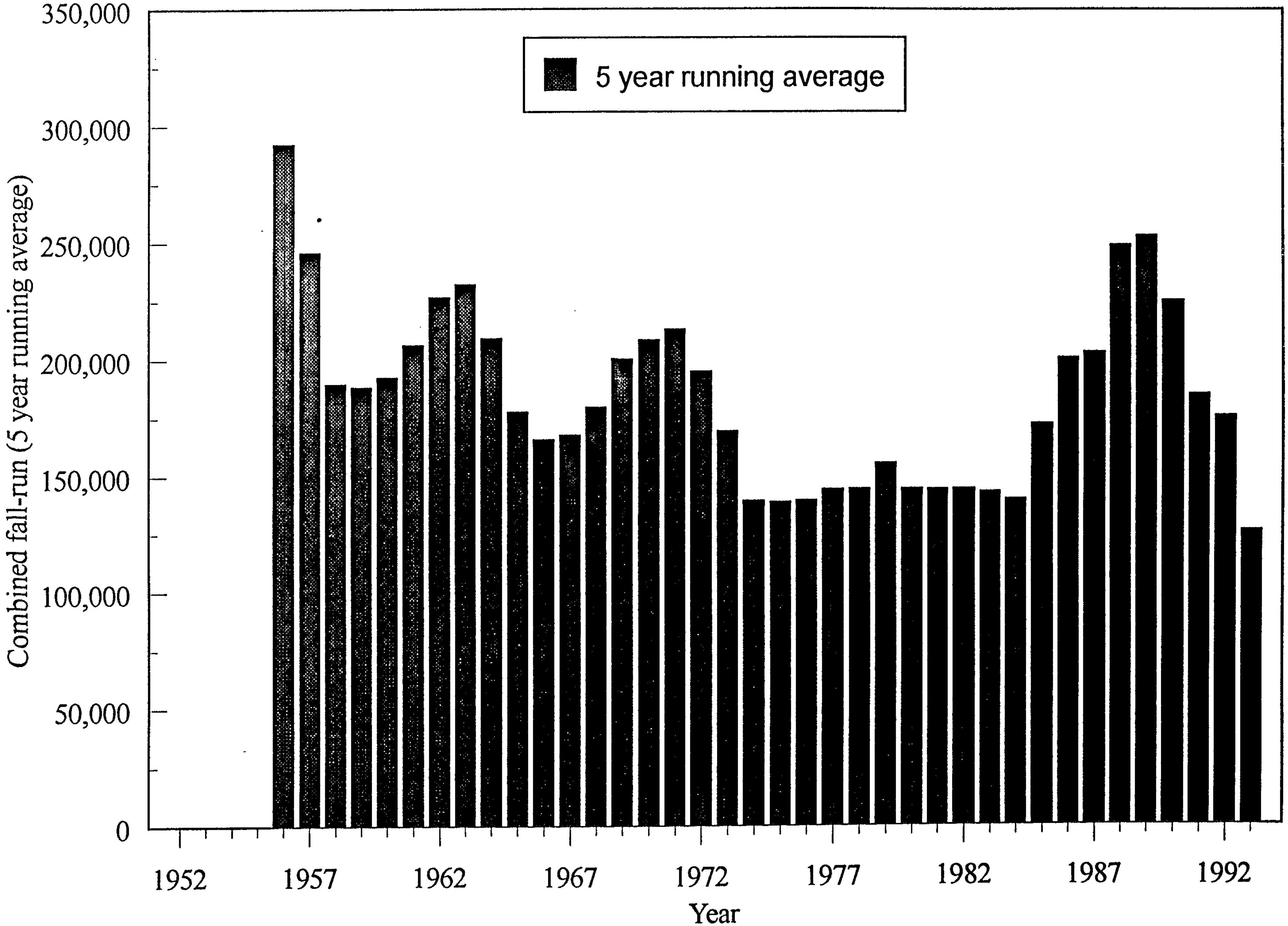

Figure 3. Five year running average of combined fall-run chinook salmon population estimates for the Sacramento River and its major tributaries (1956-1993).

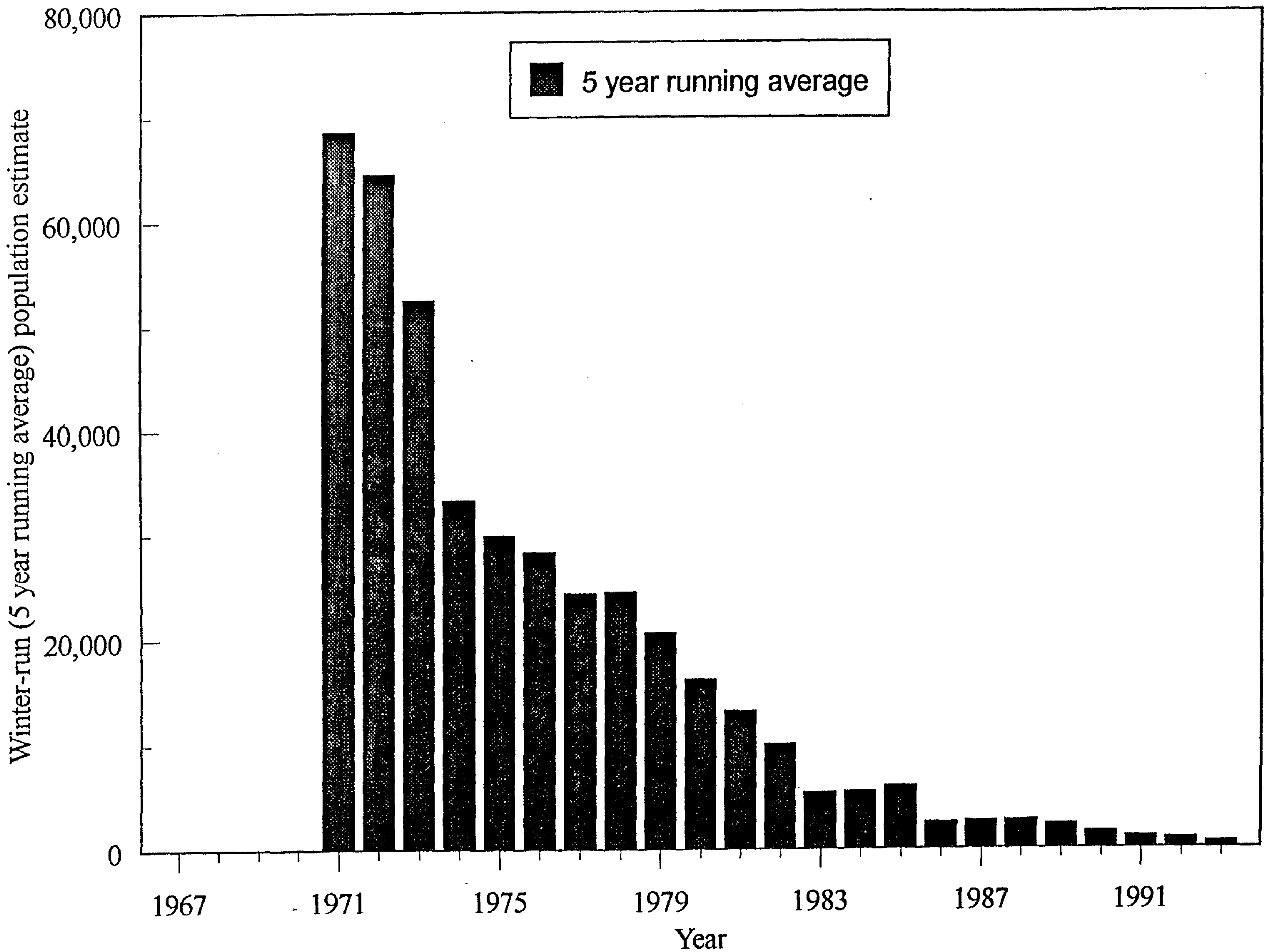

Figure 4. Five-year running average of winter-run population estimates in the Sacramento River.

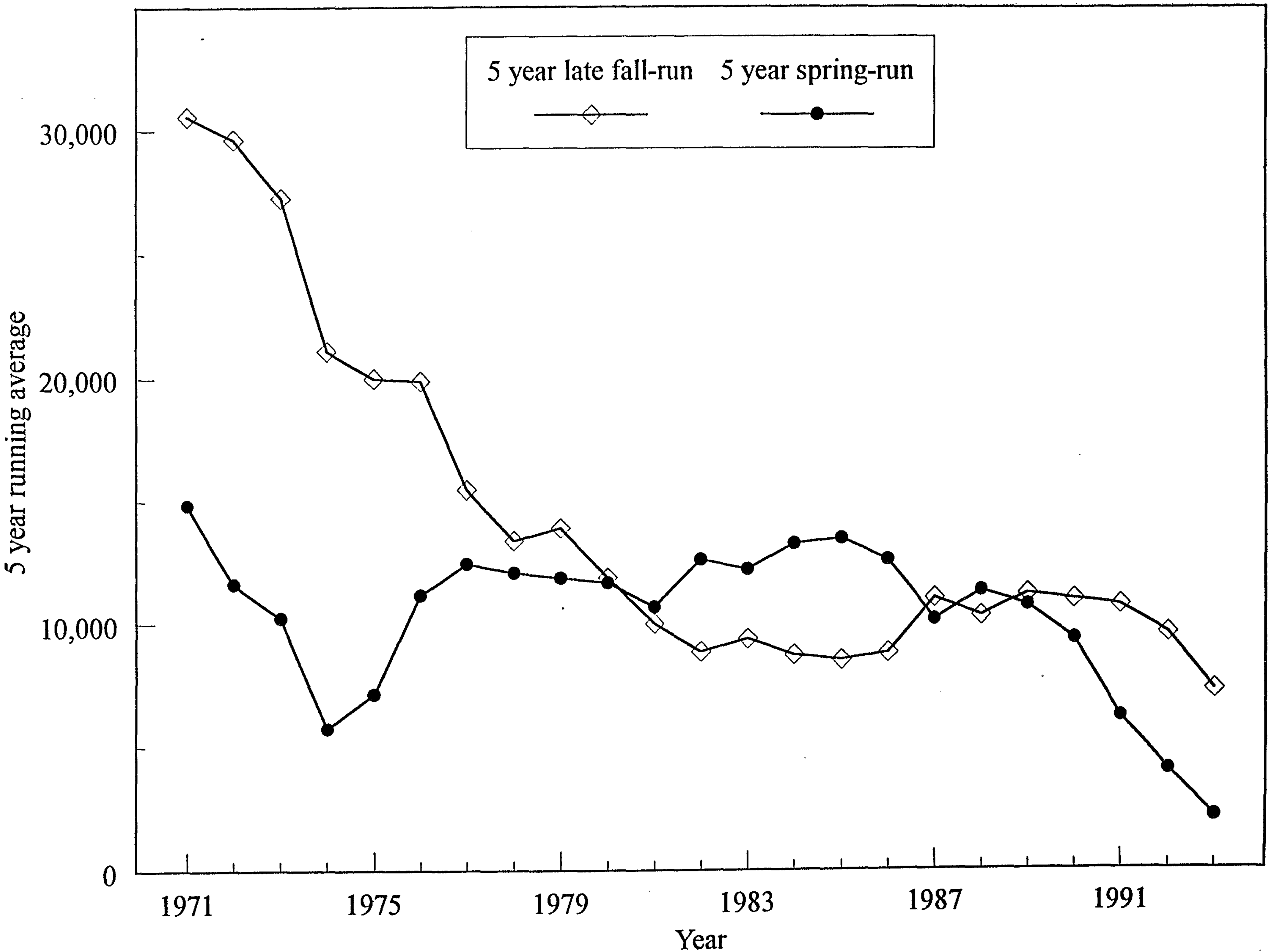

Figure 5. Five-year running averages of late fall- and spring-run population estimates in the Sacramento River.

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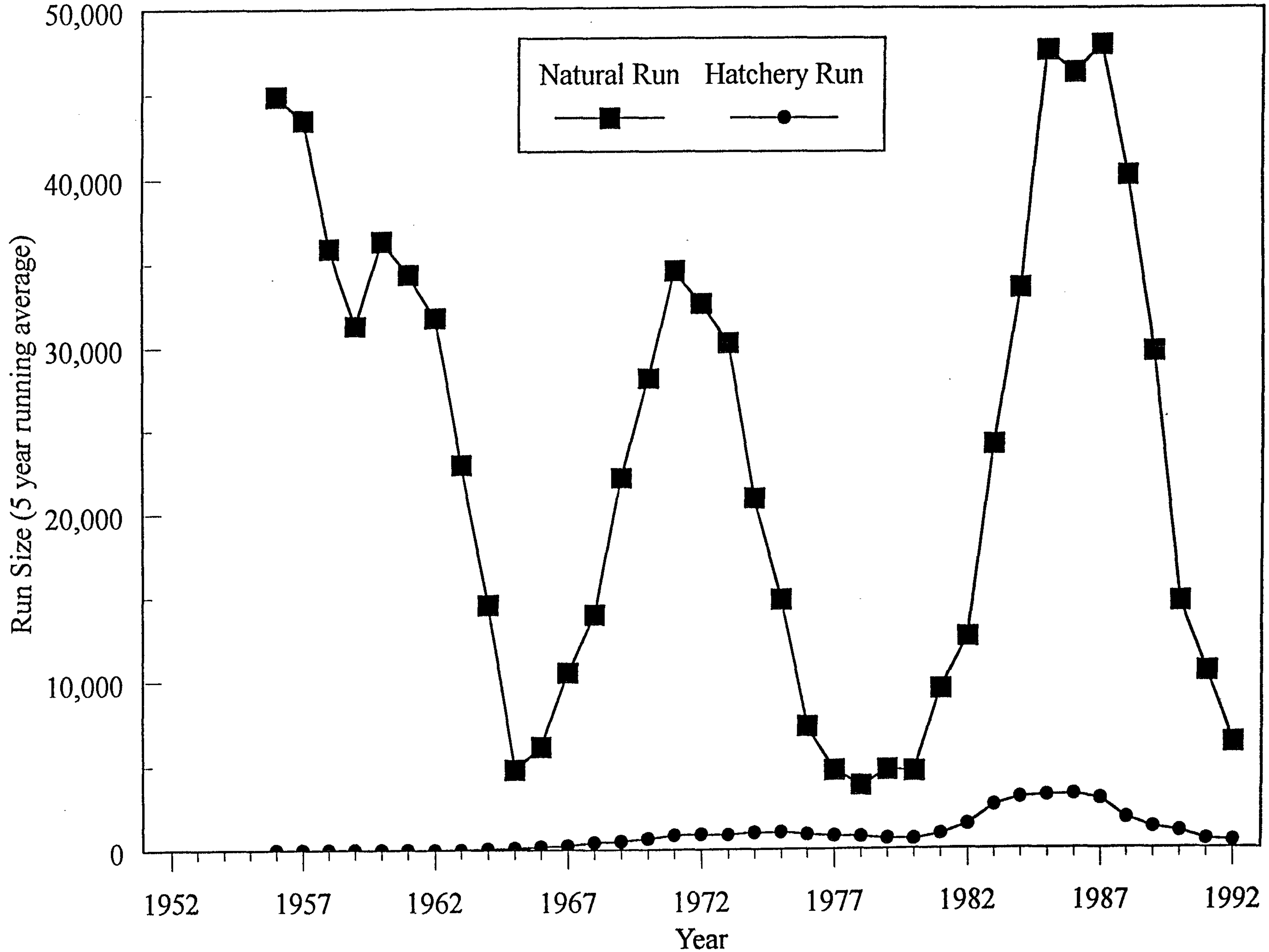

Figure 6. Five-year running average of fall-run natural and hatchery population estimates in the San Joaquin River.

annual fish abundance have been followed by valleys of approximately 5,000 fish (Figure 6). Based on records dating back to the 1930s, those fluctuations in abundance generally coincide with variations in the magnitude of spring river flows in the San Joaquin system (Chadwick and Herrgesell, 1993).

HATCHERY PRODUCTION

Within the San Joaquin system, the Merced hatchery contributes some fish, but trends in salmon abundance have clearly been driven by wild fish (Figure 6).

The situation in the Sacramento system is quite different as a consequence of mitigation hatcheries in the upper Sacramento, Feather and American rivers. Particularly in the American and Feather rivers, rearing salmon to a relatively large size in hatcheries and trucking the entire production for release downstream of the Delta is generally credited with being a major factor in maintaining the runs. Nevertheless, the precise role of hatcheries remains uncertain.

HARVEST

Commercial Harvest

Today, California's commercial salmon harvest is accomplished by deep water trolling in the Pacific Ocean. Commercial troller harvest landed at ports in the San Francisco and Monterey bay regions have respectively averaged approximately 209,000 and 92,000 fish annually from 1967 through 1991 (Table 3). The 5-year running average of combined catches fluctuated between about 250,000 and 300,000 fish from 1973 to 1987, but was over 400,000 fish in the 1988 - 1991 period (Figure 7). The San Francisco and Monterey catches include some salmon from areas other than the Central Valley. A relatively small number of Central Valley salmon are harvested off the coasts of far northern California, Oregon and Washington. Consequently, the catch data cited provide only an index of the harvest of Central Valley salmon stocks. No precise measure of the actual total harvest exists.

Other commercial fisheries, principally the mid-water trawl fishery for Pacific whiting, take salmon incidentally. Incidental harvest is very low (an estimated 5,000 fish annually from California to Washington), and the number of Central Valley salmon taken is thought to be only a small fraction of that total.

Sport Harvest

The principal salmon sportfishing catch also occurs in the ocean. From 1967 through 1991, the San Francisco and Monterey regions averaged about 111,000 fish per year in recreational catch (Table 3), a number equal to approximately one-third of the total commercial catch. The 5-year running average of the recreational catch indicates a peak of about 150,000 fish in the early 1970s, a trough of less than 100,000 fish from 1978-86, and another peak of about 125,000 fish in recent years (Figure 8).

Table 3. Commercial and Recreational Harvest (number of fish) of Chinook Salmon In Monterey and San Francisco bays and the Sacramento River 1967-1991. Mills and Fisher 1994 (3rd Draft).

Year	Sacramento River Harvest	Ocean Harvest Landed in San Francisco Bay		Ocean Harvest Landed in Monterey Bay		Total
		Commercial	Recreational	Commercial	Recreational	
1967	12,258	69,533	58,503	17,549	7,650	165,493
1968	18,628	167,953	123,807	58,255	25,095	393,738
1969	19,750	176,749	113,517	103,613	14,737	428366
1970	13,839	163,097	97,300	63,732	13,838	351,806
1971	17,778	125,755	145,879	24,944	20,448	334,804
1972	12,303	189,558	176,503	40,238	11,089	429,691
1973	13,157	242,412	167,017	180,283	13,886	616,755
1974	9,156	222,785	130,242	59,895	11,348	433,426
1975	14,883	160,434	84,977	73,927	7,717	341,938
1976	18,381	138,231	63,760	99,626	4,807	324,805
1977	8,443	185,164	72,595	78,675	4,006	348,883
1978	6,816	158,158	64,085	132,842	1,809	363,710
1979	8,173	180,087	102,547	54,060	5,929	350,796
1980	6,172	211,778	73,093	82,524	4,020	377,587
1981	6,179	199,910	70,084	89,995	3,743	369,911
1982	5,905	281,761	116,910	136,678	5,586	546,840
1983	5,133	75,019	49,717	103,215	3,243	236,327
1984	7,150	167,668	73,233	53,992	5,437	307,480
1985	18,682	175,681	112,475	36,637	9,276	352,751
1986	19,665	302,302	86,255	200,154	28,558	636,934
1987	11,350	355,615	119,526	91,231	33,320	611,042
1988	12,768	642,693	114,455	187,818	15,919	973,653
1989	7,856	255,817	93,659	107,955	37,248	502,535
1990	5,835	199,147	77,562	137,072	35,053	454,669
1991	10,663	174,831	37,274	79,798	24,830	327,396
Averages	11,637	208,886	96,999	91,788	13,944	423,254

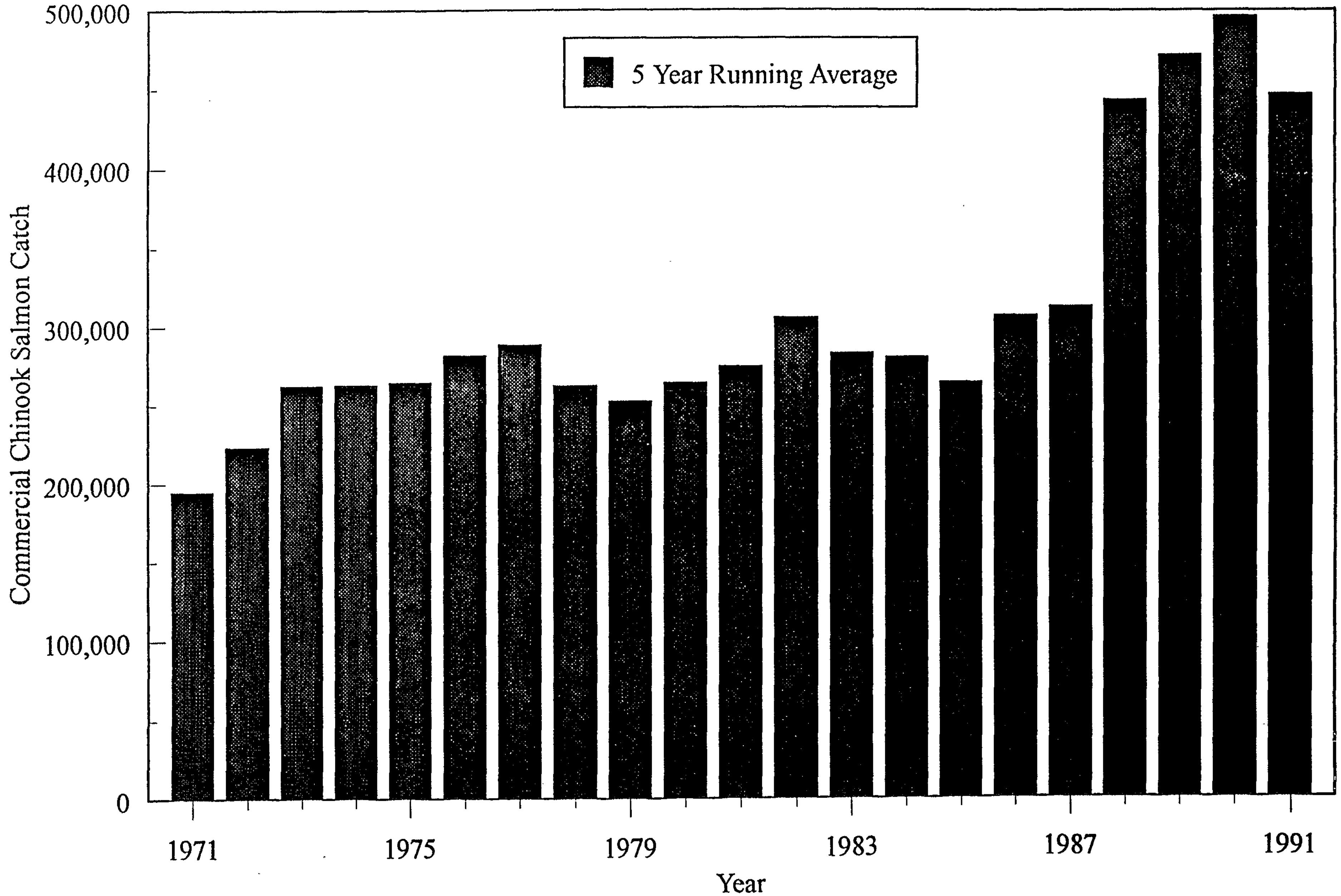

Figure 7. Five-year running average of commercial landings of salmon in the San Francisco and Monterey bay regions.

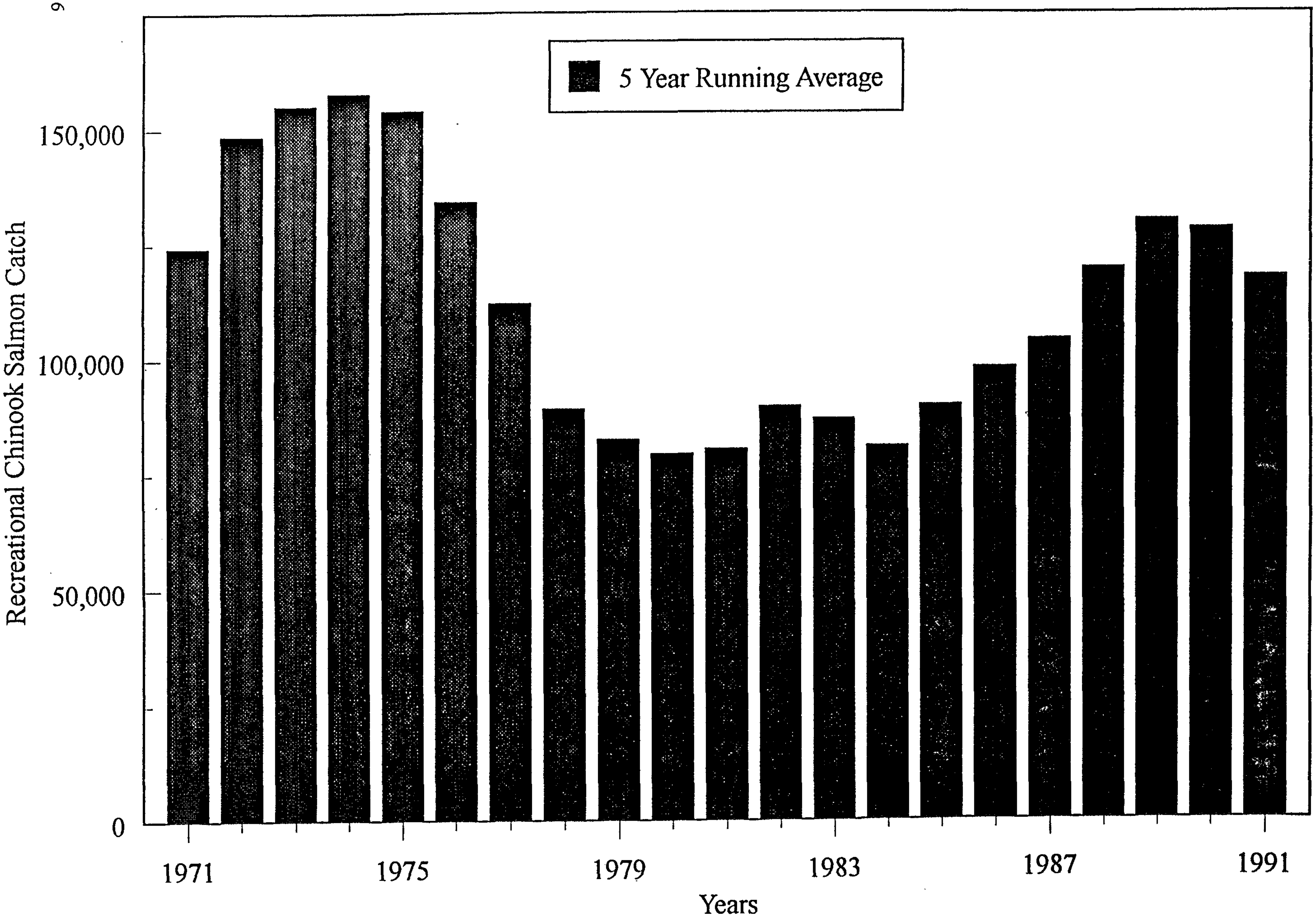

Figure 8. Five-year running average of recreational catch of salmon in the San Francisco and Monterey bay regions.

Based on extrapolations from very limited sampling, the DFG estimates that the sport catch of chinook salmon in the Sacramento River averaged about 12,000 fish, or one tenth of the average ocean sport catch off San Francisco and Monterey. An exception to the normal level of inland sport harvest concerns the inland catch of winter run. Since this race was listed pursuant to the federal endangered species Act, salmon fishing closures have been instituted in all sections of the Sacramento River above the Carquinez Straits during the time adults are present. These closures have effectively reduced inland sport take of winter run to near zero.

Sport harvest has not been measured in the San Joaquin system, but legal fishing has been largely restricted to the main stem of the San Joaquin River throughout the 1967-1991 period, and has been prohibited entirely since 1991. Considering those restrictions and the smaller spawning stocks, legal sport harvest in the San Joaquin is estimated to have been only a small fraction of that in the Sacramento River.

Illegal Harvest

Methods of illegal salmon take include gillnetting, longlining, snagging, exceeding bag limits, and keeping fish shorter than the legal length.

Illegal harvest of chinook salmon in the Estuary has been estimated to result in the loss of spawning stock (potentially as many as 500 adult female salmon) that would otherwise produce as many as 250,000 additional salmon smolts annually (F. Fisher, DFG pers. comm.). [The estimated smolt loss was calculated in the following manner: a single female typically produces 5,000 eggs, the rate of survival of those eggs to the fry stage is approximately 20%, and survival to the smolt stage is approximately 50%. The estimate of spawner loss was based, in part, on previously gathered citation data, the number of illegally caught salmon seized by DFG wildlife protection staff, and an estimated interdiction rate of two percent.]

Considerable attention has been focused on the possible effects of concentrated (illegal) fishing by foreign boats off the Pacific Coast. The mid-pacific high seas drift net fishery has impacted Alaskan and British Columbia salmon stocks (such as sockeye, chum, and pink). However, there is no evidence that the Central Valley salmon fishery has been similarly impacted. Foreign fishery vessels are not allowed to fish inside the United States' 200 mile Exclusive Economic Zone, a prohibition enforced by National Marine Fisheries Service, Coast Guard and DFG patrols. Central Valley salmon only rarely venture over 200 miles from the coast, and are thus not subject to significant legal foreign harvest (A. Baracco, DFG, pers. comm.).

CATCH AND RELEASE

In the Pacific Ocean, salmon shorter than legal length limits are often caught and released by both sport and commercial fishermen. Some of the released fish die as a result of stress associated with their capture and release. The PFMC has adopted 31 percent and 13 percent as the best estimates of the proportion of released salmon that die from such stresses in the commercial and sport fisheries respectively. These mortality rates are incorporated by PFMC staff in analyses of alternative fishing regulations. Thus, they are considered explicitly when the PFMC recommends regulations to achieve their spawning escapement goal.

EFFECT OF HARVEST ON POPULATION

As with any fishery, the harvest of salmon diminishes spawning populations. The pertinent questions are whether the harvest is sufficiently large to threaten the continued existence of some stocks and what are the relative impacts of the fishery and environmental variables upon spawning stock size. The answers to those questions determine whether the fishery is being regulated prudently.

Age Structure

The age structure of the population is an important indicator of its sustainability. According to the U.S. Department of the Interior, "In the 1940's approximately 50 percent of the Sacramento San Joaquin salmon return [ed] from the sea as adult salmon to spawn during their fourth year. The remainder return [ed] in decreasing order of abundance, as five-year fish, three-year fish, and two year fish." (USDOI, 1948). Today, the spawning run is dominated by three-year old fish. Five-year old fish are rare.

A major contributor to the relatively recent change in salmon age structure is that the primary method of harvest is no longer a gill net fishery in the Estuary. That fishery harvested only mature fish returning to spawn. In contrast, the modern ocean fishery harvests fish longer than a minimum size limit, so older fish are vulnerable to the fishery longer and have a higher harvest rate. The gill net fishery was gradually restricted over a period of years and closed in 1957.

Increased harvest rates (described below) have also contributed to alterations in age structure.

This change in age structure has several consequences. The lowered average age of spawning fish diminishes the reproductive potential of the stock because egg production increases with age. Dominance by a single age class renders the stock more vulnerable to fluctuations in environmental conditions. This occurs because unusually good or bad environmental conditions affecting spawning and rearing in one year will essentially affect the entire stock, rather than having sufficient numbers of other age groups to cushion the effect. Also, older salmon would likely have greater reproductive success than younger fish because they place their eggs deeper in gravel, making them less vulnerable to mortality resulting from bed load movement (D. Vogel, fisheries consultant, pers. comm.)

DFG biologists recognize that changes in age structure have made Central Valley salmon stocks more vulnerable to harm. They do not believe, however, that the present age structure is unacceptable or a principal cause of abundance declines since 1970 (A. Baracco, pers. comm.).

Harvest Rate

Harvest rate is traditionally set as a fraction of the estimated population alive at the beginning of the measuring year. For Central Valley salmon, however, there are no estimates of population size at the beginning of any year being studied. Furthermore, as has been

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described, individual salmon from the Central Valley, except for tagged fish, cannot be identified in the ocean so there is no precise measure of catch with respect to race and run.

As a substitute for the traditional counting method, a harvest rate index has been developed that divides the total commercial and sport catch landed in the San Francisco and Monterey bay areas by that catch plus the annual spawning escapement (the number of fish returning upstream to spawn) to the Central Valley. Sources of potential bias in the index include annual variations in: natural mortality; the fraction of Central Valley stock residing off the coast in the San Francisco and Monterey bay regions; the numbers of other stocks residing in the same areas; the amount of inland harvest; and, the age composition of the stock. Nevertheless, this index provides a useful indication of trends in the proportion of the population being harvested in the ocean and is a principal measure used by the PFMC in regulating the fishery.

The annual harvest rate index has fluctuated between about 0.4 and 0.8 during the last 40 years (Figure 9). Based on the annual indices in Figure 9, fluctuations are the dominant feature and no trend over time is obvious. The same data, however, when plotted as a 5-year average was not more than 0.6 in any year prior to 1976, while it has been greater than 0.6 in eleven subsequent years; with a particularly obvious increase since 1988 (Figure 10).

In examining these data, a scientific team reporting to the PFMC concluded that "since 1970, the ocean harvest rate index has been slowly increasing" and "the increasing trend may indicate a level of harvest too high to sustain" (PFMC, 1994)

MANAGEMENT STRATEGY

The PFMC's management goal has been to set harvest limits that maintain a spawning escapement of 122,000 to 180,000 fall-run adult fish in the Sacramento River system: the estimated optimum number of spawners -- accounting for hatchery production and the carrying capacity of the natural environment. The PFMC goal was met from 1970 through 1989 with only two exceptions. However, it was not achieved in 1990, 1991 and 1992 (Figure 11). In 1993, the escapement goal was achieved, with preliminary data indicating the number of fish to be at the lower end of the goal's range.

The PFMC concluded that overestimates of population sizes had contributed to the failure to achieve predicted escapement in 1990-1992. The overestimates resulted from a failure to account for poor inland production associated with the drought and low ocean survival. In addition, the PFMC underestimated actual harvest rates in those years (PFMC, 1994). In response to these failures to meet its escapement goals, the PFMC refined its predictor models and continues to strive to regulate the fishery so as to attain the escapement goal of 122,000 to 180,000 fall-run salmon. The PFMC believes the analysis that originally concluded that the current numerical escapement goal is optimum for the basin still provides a sound management strategy (A. Baracco, pers. comm.).

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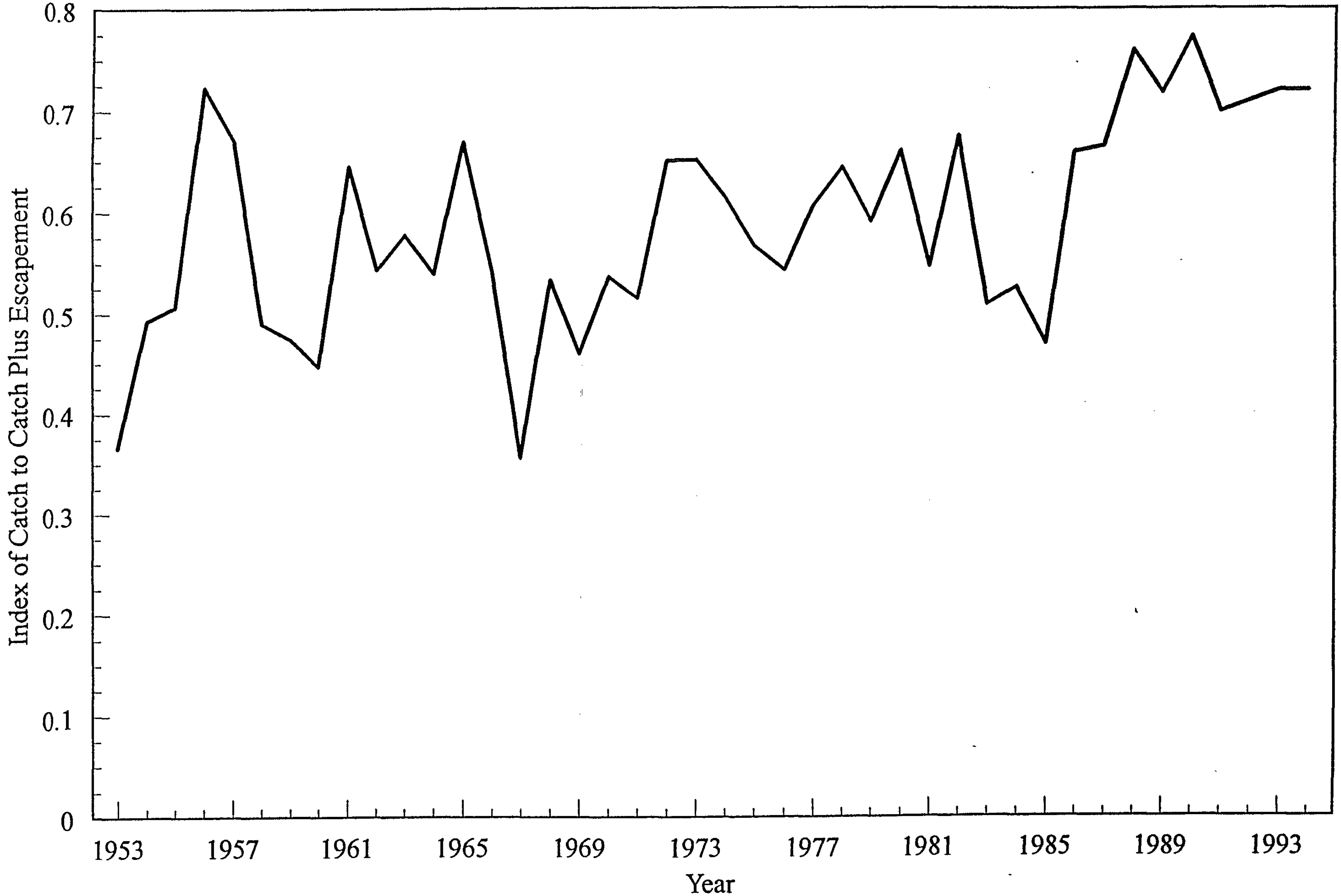

Figure 9. Harvest rate index for Central Valley fall-run chinook salmon (1953-1991). [Index of catch divided by index of catch plus escapement] ---catch includes recreational and commercial harvest; escapement includes natural and hatchery spawners.)

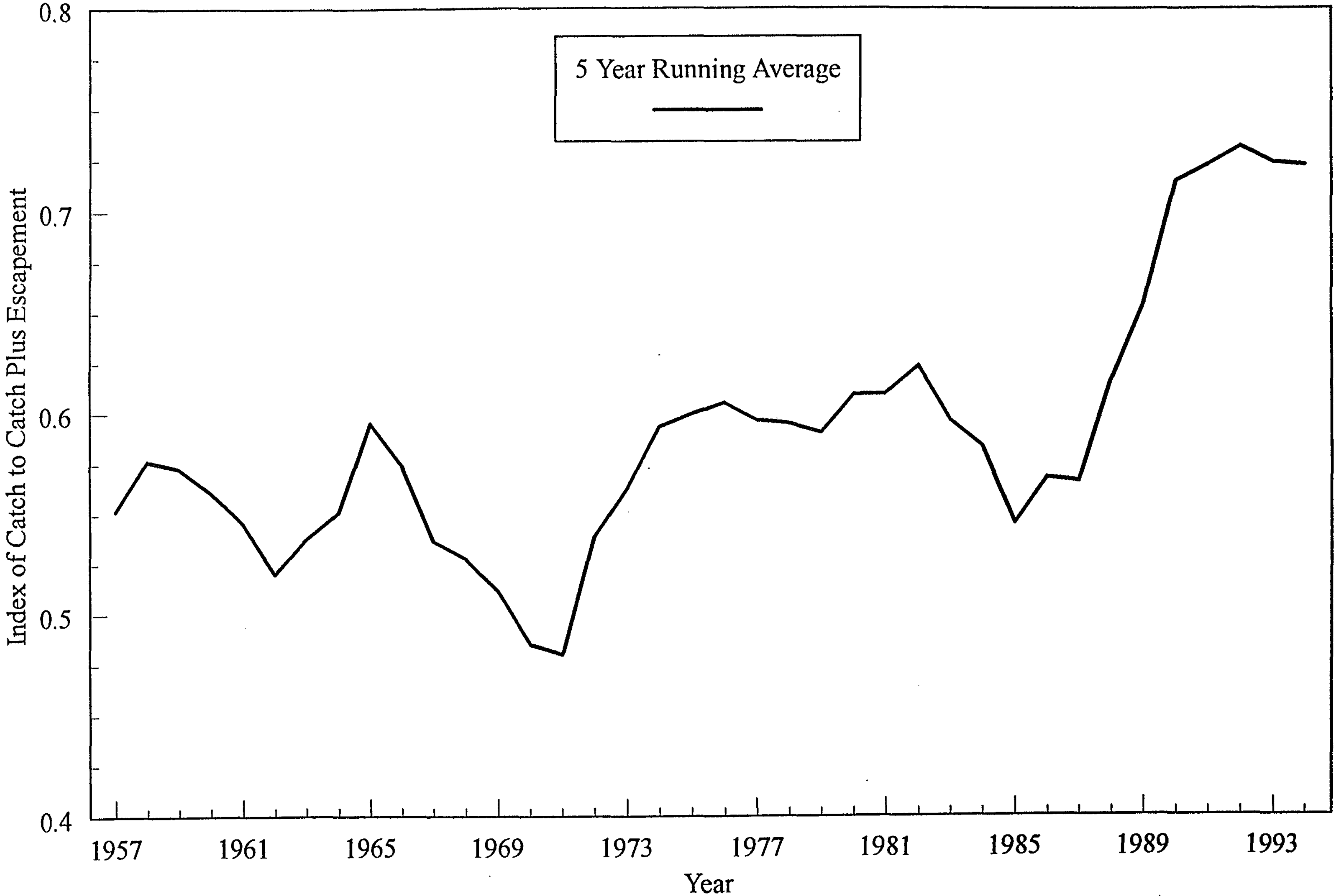

Figure 10. Five-year running average of harvest rate index for Central Valley fall-run chinook salmon (1953-1991). [Index of catch divided by index of catch plus escapement] ---catch includes recreational and commercial harvest; escapement includes natural and hatchery spawners.)

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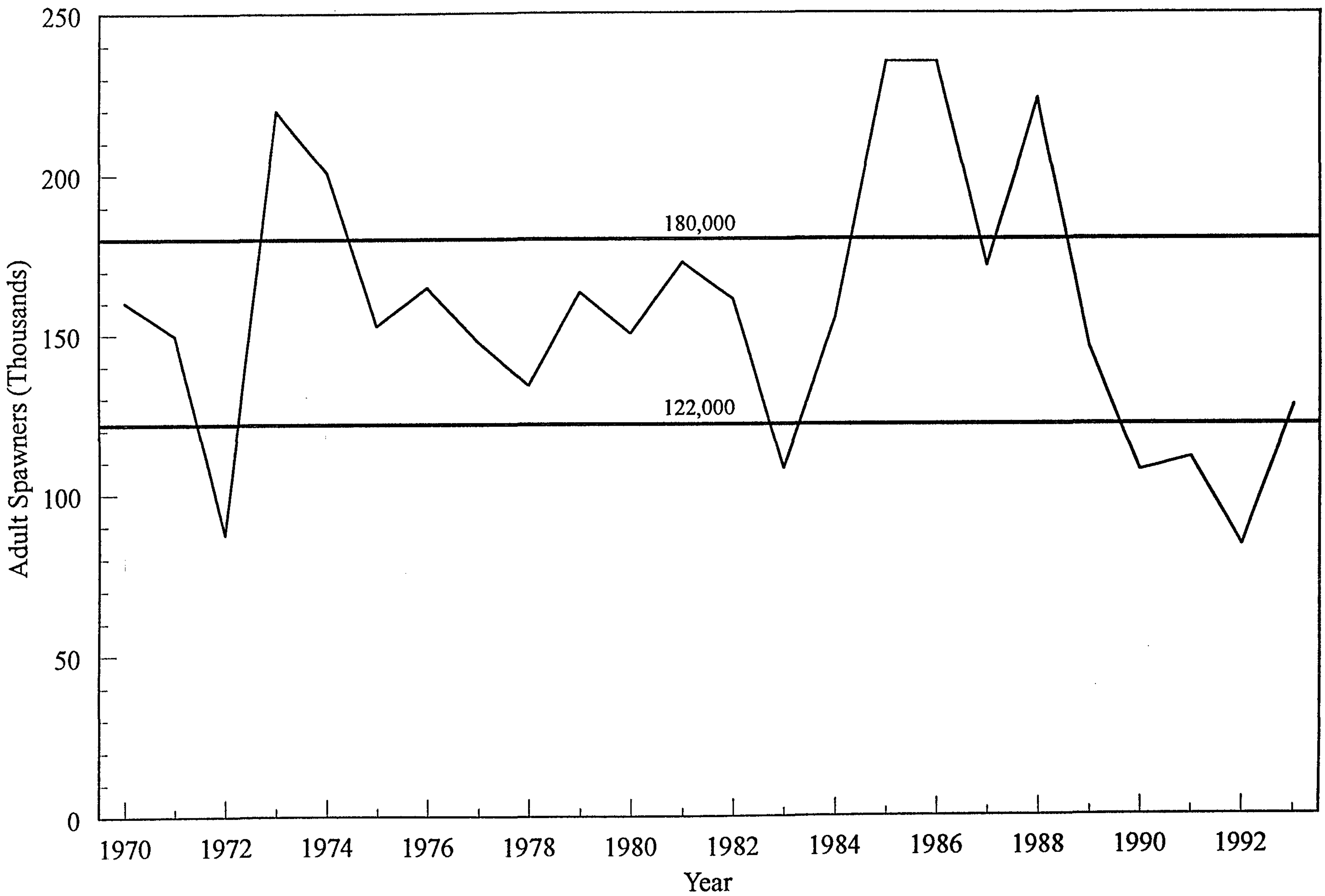

Figure 11. Spawning escapement of fall-run chinook salmon in the Sacramento River (1970-1993).

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While that goal targets fall-run salmon, the regulations to implement it provide protection for all runs. It is generally accepted that harvest rates for the various salmon races descend in intensity in the following order: fall, late fall, spring and winter. The four races are subject to variations in vulnerability to the fishery because of differences in their age structures and the timing of spawning migrations. Most winter-run and a high proportion of spring-run salmon reach minimum commercial size and return to spawn after the fishery is closed for the year and before the next season opens. Even before recent regulatory changes were implemented to curtail harvest of winter-run, the harvest ratio for winter-run was probably about 0.3 (A. Baracco, pers. comm.) Even though the winter-run is harvested at a lower rate than the fall-run, some people believe that the 30% take of adult fish (including spawners) is too high and contributes to the continuing depressed status of the winter-run.

Water industry representatives generally express reservations about the adequacy of the PFMC's approach. Some state that decreases in the age structure of Central Valley salmon indicate that a harvest index of about 0.8 is too high for wild stocks, though it may be maintained for stocks heavily supported by hatcheries (R. Brown, pers. comm.). Marking all hatchery fish, so regulations could be directed toward selectively harvesting only hatchery fish, is an idea supported by some commercial fishing interests and would provide increased accuracy in regulatory estimates and calculations. Such marking is not done today because: (1) the expense would be great; (2) there are concerns about increased mortality resulting from handling; and, (3) the sheer logistics of marking millions of smolts are problematic.

While sharing concerns about regulations designed to protect hatchery stocks leading to an over harvest of wild stocks, other experts also contend that the PFMC has a history of allowing harvest at levels above those that would conserve the stock (R. Bailey, pers. comm.). Reducing mortality is most important when stocks are low. Obviously, that is the time when effective implementation of the PFMC's escapement goal needs to produce the lowest harvest mortalities to be effective. This did not occur during the 1990-92 period.

Some advocate a more restrictive policy and believe a return to terminal fisheries (harvest of returning fish <u>in the river</u>) would be beneficial. (R. Bailey, fisheries consultant, pers. comm.). This was the historical practice in the Central Valley prior to 1957 when it was prohibited by state law. Such an approach has some obvious advantages for management and the attainment of escapement goals, but it also has some disadvantages. Differences between sport and commercial fishermen, which led to the closure of the commercial fishery in the Estuary, and a more recent ballot initiative banning gill netting in California waters, make it at best questionable whether a return to such an approach is viable.

DFG believes the best empirical evidence that fishing is not the principal factor limiting populations of Central Valley stocks are fluctuations in salmon abundance in the San Joaquin system (Chadwick and Herrgesell, 1993) (Figure 6). Since the 1930s, salmon abundance in the San Joaquin has been driven by environmental factors associated with the volume of spring runoff. Within the last 30 years, salmon populations have twice increased by an order of magnitude or more within two generations following droughts. San Joaquin stocks are dominated by naturally spawning fish and thus are more vulnerable to over fishing than the larger stocks in the Sacramento system.

Another piece of evidence suggesting that Central Valley salmon are vulnerable to powerful impacts which are independent of the fishery is the recent decline in the number of winter-run fish. This deterioration in the winter-run population has occurred even though it is subject to a harvest rate only about a third of the rate for fall-run. While it is conceivable that such a difference could be due to intrinsic differences in productivity making winter-run more vulnerable to fishing, it seems more likely that well documented habitat changes are the dominant cause of the decline.

SUMMARY

Commercial and sport harvest of salmon, primarily by legal fisheries in the Pacific Ocean, are clearly large enough to have a substantial effect on the size of spawning runs. Several trends, including decreases in the average age of spawners, increases in harvest rates, and the recent failure to meet spawning escapement goals raise serious questions and concern as to whether salmon stocks are being over harvested. This is particularly the case for naturally spawning fish, as contrasted to hatchery stocks. At a minimum, the evidence would seem to dictate a need for more effective regulation of harvest to meet spawning escapement goals.

Just as there is debate over hydrodynamic changes and resulting ecological impacts attributed to operation of the state and federal water projects in the Delta, there is similar controversy regarding potential fishery impacts on the salmon resource. In each case, much is not understood or subject to dispute. There does seem to be general agreement, however, that effectively addressing the decline of Central Valley salmon will require a more comprehensive regulatory program, focused on water project *and* non-water project impacts. Only such a comprehensive program can achieve a sufficient level of confidence among *all* of the constituencies to successfully manage the resource. Though that necessary level of confidence does not exist today for many, there are encouraging signs that the importance of such an approach is gaining greater acceptance.

PERSPECTIVES

As the foregoing illustrates, regulation of the sport and commercial salmon fishery is subject to significant uncertainty, and a recent PFMC report acknowledges a need for improved regulation (PFMC, 1994) . Still, many are confident that the PFMC, utilizing the best available techniques, is reasonably protecting the resource from over exploitation by the commercial fishery. Moreover, the DFG does not consider the inland sport fishery to be of concern when considered as a component of the total take. Both entities believe their regulatory schemes are sufficiently stringent and responsive to changing conditions to effectively insulate salmon populations from the potential of over harvest.

Despite this relatively high confidence level among fishery managers, many in the water industry remain highly skeptical. Much of this skepticism may be traced to a widely held perception in the water community that water projects are too heavily constrained in order to mitigate for what are, in its opinion, partially fishery and other non-water project impacts.

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Additionally, there is a feeling that a regulatory double-standard is being applied. While there remain significant uncertainties with respect to the actual and relative impacts of the fishery and the projects, the project operators believe that that uncertainty is addressed through over-regulation of the projects and equivocal regulation of the fishery.

On the other hand, the typical commercial fisherman, many of whose compatriots have been put out of business by increasingly stringent fishing regulations, perceives himself as bearing the burden of fishery declines caused primarily by various sources of environmental degradation; particularly water development.

STRIPED BASS

Striped bass were introduced to the Estuary in 1879. By 1889 there was a thriving commercial fishery supplying San Francisco fish markets. In 1900, the annual commercial harvest exceeded a million pounds. The commercial striped bass fishery was ended in 1935 in order to protect and sustain the burgeoning sport fishery from over harvest (Chadwick and Herrgesell, 1993).

Since the mid-1960s, the striped bass population has gradually declined. Striped bass research efforts have focused on factors affecting survival of young bass during the first year, accurate measurement of adult population size, and annual recruitment. From 1969 to 1991, the DFG tagged striped bass during their spawning migration. Following this tagging effort, a creel census in the San Francisco Bay area was conducted to measure how many of the tagged fish were taken by sport anglers. The tagging and creel census projects indicated low annual recruitment of new fish, resulting in fewer adults, which, in turn, results in fewer eggs spawned each year (Stevens, et. al., 1985; Kohlhorst, et. al., 1991).

POPULATION SIZE

Adult striped bass abundance has been estimated using tag-recapture methodology since 1969: a modified Petersen estimator (N=M (C+1)/(R+1) is used -- where N=bass abundance, M= number of tagged fish released, C = number of fish examined for tags, and R= number of tagged fish in the recapture sample.

The DFG uses gill nets and fyke net traps to capture striped bass during their spawning migration in the Delta and Sacramento River. These striped bass are tagged with numbered disc-dangler tags and released. The population is sampled during a year-round census of angler catches and during the following year's tagging process in the spring.

The 1969-1992 population estimates of adult, legal-sized striped bass abundance in the Estuary have declined steadily from a high of over 1.8 million fish in 1975 to a 1992 total of approximately 624,000 (Table 4) (D. Kohlhorst, DFG, pers. comm.). In addition to these mature fish, an estimated 2.4 million sub-adults, yearlings and two year old fish were part of the 1992 population.

HARVEST

Sport Harvest

Sport angling for striped bass in the Estuary consists of fishing with a rod and reel on a party boat, private boat, or from shore. Fishing in the Delta and in the Sacramento River is typically most successful during the April/May spawning migration.

Since 1969, an annual average of about 217,000 legal-size striped bass have been harvested by sport anglers. In an effort to further protect declining populations, restrictions to reduce daily maximum catch per angler from 3 fish to 2 and to increase the legal length from 16" to 18" were introduced in 1982 (Stevens, et. al., 1985). The 1991 harvest estimate for striped bass in the Sacramento-San Joaquin Delta was approximately 108,000 fish, which was a decline from the most recent 10-year average of 154,000 fish (Table 5) (D. Kohlhorst, DFG, pers. comm.).

Illegal Harvest

Illegal harvest occurs when anglers take more than the 2 fish limit, take striped bass shorter than the minimum size limit of 18 inches, and when they use illegal fishing methods; such as gillnetting and longlining.

To reduce poaching, the DFG, utilizing funding from DWR, initiated the Delta-Bay Enhanced Enforcement Project (DBEEP) in 1992. Prior to the inception of DBEEP, DFG estimated that approximately 500,000 sub-legal striped bass were taken annually, assuming a two percent interdiction rate. If this estimate was correct, illegal take at that time could have represented 20 percent of the population of sub-legal striped bass one year of age and older.

During the first year of the DBEEP program, there was a five-fold increase in citations. Citations have declined steadily since then, which indicated a probable decrease in illegal take. Still, in 1993, DBEEP seized 7,038 sub-legal striped bass, of which 100 were seized from gillnetters and released (J. Gonzalez, DFG, pers. comm.). Using the same two percent interdiction rate, an illegal take of approximately 350,000 striped bass was estimated.

Poaching of sub-legal size striped bass was thought to be sufficient to decrease long term adult abundance when the DBEEP began. Unfortunately, historical trend data are not available to estimate changes in illegal take over time. Consequently, the contribution of poaching sub-legal bass to the overall decline in abundance cannot be determined.

Table 4. Population Estimates of Legal Size Striped Bass in the Sacramento-San Joaquin System.

Year	Total Number Legal Size Striped Bass
1969	1,646,026
1970	1,727,395
1971	1,599,716
1972	1,882,907
1973	1,637,159
1974	1,477,213
1975	1,849,771
1976	1,581,077
1977	924,301
1978	1,151,643
1979	1,155,701
1980	1,115,999
1981	911,300
1982	825,126
1983	1,009,748
1984	1,048,244
1985	1,038,126
1986	1,064,142
1987	1,037,617
1988	967,290
1989	873,065
1990	662,942
1991	799,913
1992	624,168
Average	1,243,939

Table 5. Combined Striped Bass Harvest in the Sacramento and San Joaquin Rivers, the Delta, and San Francisco Bay (1969-1991).

Year	Percent Harvest	Total Number Legal Size	Catch
1969	17.1	1,646,026	281,775
1970	12.1	1,727,395	209,258
1971	17.1	1,599,716	274,071
1972	17.0	1,882,907	320,299
1973	16.7	1,637,159	274,016
1974	22.9	1,477,213	338,001
1975	24.0	1,849,771	443,808
1976	20.8	1,581,077	329,051
1977	17.0	924,301	157,110
1978	16.3	1,151,643	187,718
1979	15.5	1,155,701	179,134
1980	12.3	1,115,999	137,268
1981	11.0	911,300	100,243
1982	15.9	825,126	131,195
1983	23.7	1,009,748	239,310
1984	22.3	1,048,244	233,758
1985	19.8	1,038,126	205,549
1986	16.3	1,064,142	173,455
1987	15.2	1,037,617	157,718
1988	13.3	967,290	128,650
1989	8.7	873,065	75,957
1990	12.6	677,942	83,531
1991	13.5	799,913	107,988
Average	17.3	1,272,792	216,767

Estimates of the magnitude of the illegal catch of legal-sized striped bass are also not available. While some poaching with illegal nets occurs, and is also a target of the DBEEP, it probably represents only a very small fraction of the legal catch. Changes in poaching during the last 25 years is included as part of the estimated 25 percent of the striped bass decline attributed to increased adult mortality (discussed below).

Striped bass are not considered vulnerable to harvest by foreign fishing vessels because the generally do not venture into international fishing grounds off California's coast (D. Kohlhorst, DFG. pers. comm.).

EFFECT OF HARVEST ON POPULATION

DFG biologists have concluded that about 75 percent of the decline in adult striped bass abundance results from fewer fish reaching legal-size. The other 25 percent of the decline is caused by increased mortality of adult bass. Among the possible causes of the other 25 percent of the decline are predation, sport fishing, pollution, and poaching. The percentage of the adult bass population legally harvested by anglers has remained steady (Table 5), which lends credence to the view that legal sport fishing is not responsible for increased mortality. There has not yet been an estimate of the proportional contribution of each of the other factors to the observed decline.

Historical Perspective

The relative, current influence of legal take on the observed decline in striped bass abundance can best be assessed by exploring the historic response to concerns of potential over harvest.

In the late 1970s and early 1980s, warnings were raised that the striped bass population reproducing in the Estuary and its tributaries had declined substantially since 1976. From 1969 to 1976, there had been about 1.7 million legal-sized striped bass (at least 16 inches long) in the Estuary; but by the late 1970s, that number had been reduced to about 1 million.

In addition to the reduction in adult bass numbers, young bass abundance had been very low since 1977. This suggested that recruitment to the legal-sized population would continue to be low, and that the adult population would likely remain depressed for several years unless remedial action was taken.

At that time, without the availability of recently developed mathematical models, the DFG hypothesized that the decline in abundance of legal-sized striped bass since 1976 probably reflected reduced survival of adults. Although the analysis was not conclusive, conservative resource management dictated restricting angling regulations to reduce harvest. If no action was taken, it was feared the fishery would probably continue to be depressed and the time required for recovery would increase. In the event its analysis was incorrect, more restrictive regulations would still increase adult bass survival, which, in turn, would further increase abundance and regulations could be liberalized later to take advantage of that population growth.

The DFG believed a contributing factor in population and recruitment declines was the deteriorating environmental condition of the Estuary. The evidence, in the DFG's view, suggested that the accelerated decline in the abundance of young bass (and subsequent abundance of 3-year-old recruits) after 1976, was probably attributable to a reduction of total egg production resulting from the decline in overall adult abundance (Stevens, et. al., 1985). The DFG associated each of these declines with environmental factors in the Estuary, related principally to water flows and hydrodynamic influence.

In the early 1980s, to reverse the decline of the striped bass fishery, the DFG advocated altering angling regulations, improving environmental conditions in the Estuary, and undertaking artificial propagation of striped bass. The tightening of angling regulations was expected to achieve at least a 25 percent reduction in catch. This, by itself, was predicted to increase adult populations by 60 to 85 percent in 10 years. In combination with the other actions, the DFG believed that recovery would occur even more quickly.

To achieve the goal of a 25 percent reduction in harvest, season closures, changes in bag limits, and changes in minimum size were considered. The following alternatives were evaluated to accomplish that goal: 1) increase minimum size to 20 inches; 2) reduce limit to one fish; 3) close season for one month in the spring and one month in the fall; 4) increase minimum size to 18 inches; and, 5) various combinations of increasing minimum sizes, reducing bag limits, and imposing fishing closures.

A reasonable, immediate goal in managing the striped bass population through changes in angling regulations was to return the population, and the fishery, to its mean abundance level existing from 1969 to 1974. Quantitatively, that translated to 650,000 spawning females ($\geq$ age 4) providing 290 billion eggs annually and an estimated population of about 1.7 million legal-sized fish.

Under all flow scenarios, the data suggested that there would be little change in the status of spawning stocks with a harvest rate of 17 percent, the average rate from 1976 to 1979. A 25 to 30 percent reduction in harvest rate would cause the spawning stock to increase about 60 to 85 percent (depending on the water outflow patterns) in 10 years, but it would still be 25 to 35 percent below the goal of 650,000 spawners. With a 50 percent reduction in harvest, the goal would be essentially achieved in 10 years, with estimated spawning stocks ranging from 87 to 103 percent of the mean 1969-74 level.

Regulations had allowed harvest rates as high as 24 percent in the past. At that level of harvest for the next 10 years, spawning stocks were predicted to decrease 34 to 45 percent. This was highly undesirable. To prevent such a decline, the Fish and Game Commission adopted more stringent regulations in 1982.

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Despite an average harvest rate of 15 percent from 1980 to 1991, a reduction from the average 1976-1979 level of 17 percent, the legal-sized striped bass population continued to decline (Table 5). Despite harvest reductions in response to the regulation changes, the average population of legal-sized striped bass in 1980-91 fell 21.3 percent from that of the 1976-1979 period, to about 947,000 fish. The average population in 1990 and 1991 of 739,000 represented a reduction of 38.6 percent from the 1976-1979 level. These declines occurred despite the reduction in harvest rate, thus supporting the contention that the decline of striped bass populations are primarily related to factors other than harvest.

Recent Studies

Further recommendations for angling changes were analyzed in 1990. Organized angling groups and others, expressing increased concern about the continued decline in the striped bass fishery, proposed that the DFG evaluate the need for even more severe angling restrictions. The DFG, working with Dr. Louis Botsford of U. C. Davis, completed that evaluation.

The analysis was composed of two stages:

1. Dr. Botsford estimated the relative catch and egg production of a year class over its life span based on size distribution, harvest rate, and natural mortality rate data provided by the DFG.

2. Egg production data was run through a sustained adult abundance model developed by DFG to evaluate the impacts of alternative freshwater outflow and water export levels on striped bass.

The alternative angling regulation changes evaluated were: 1) an increase in the minimum size limit from 18 inches to 24 inches; 2) an increase in the minimum size limit to 28 inches and initiation of a maximum size limit of 38 inches; and, 3) a 5 percent decrease in the harvest rate (which DFG tag return data suggested would result from prohibiting night fishing from boats in Suisun Bay and the Delta).

The first two alternatives would produce substantial changes in catch and egg production. Dr. Botsford's analysis indicated that an increase in the minimum size limit to 24 inches would decrease catch from a year class by 48 percent and increase egg production over the life of that year class by 27 percent. Minimum and maximum size limits of 28 and 38 inches, respectively, would decrease catch by 69 percent and increase egg production by 68 percent. Eliminating night fishing by boat anglers in Suisun Bay and the Delta would result in only a 4 percent decrease in catch and a 4 percent increase in egg production.

The DFG's model was then used to predict population consequences of these changes in egg production. The model predicted adult abundance based on the previous year's young-of-the-year (YOY) abundance and the estimated rate at which young bass are lost at the export

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pumping plants. YOY abundance is estimated by measuring spring and early summer outflows, exports, and egg production. The export loss rate, after the YOY index is set, is a function of late summer-winter outflows and exports.

Some believe this DFG model may not be an effective tool in determining the potential effects of angling regulations on the Estuary's striped bass population because harvest is not used as an adjustable variable. However, DFG believes such concern is unwarranted. The procedure itself is used to estimate the effect of a reduction in harvest (and thus a predicted increase in egg production) produced by a particular change in angling regulations. The new egg production data was input to the model in place of the initial adult abundance data and the model then estimated the sustained adult abundance.

The DFG model suggested that the proposed changes in angling regulations would provide minimal benefit to the striped bass population. Starting with an abundance of 500,000 legal-sized bass, the model predicted increasing egg production by 27 percent (equivalent to increasing the minimum legal size to 24 inches) would result in a stable population of 515,000 legal-sized fish. A 68 percent increase in egg production (resulting from a change to a minimum legal size of 28 inches and maximum legal size of 38 inches) would result in a stable population of 539,000 adult bass. Since none of the proposed angling restrictions provided a sufficient expectation of increasing the striped bass population, no recommendation was made to further restrict anglers.

The evaluation, however, suggested that conditions in the Estuary, such as levels of outflow and exports, are more important than adult mortality rates associated with harvest in affecting striped bass abundance. The conclusion of the investigation was that managers cannot affect large enough changes in angling mortality rates to have a significant impact on adult abundance at the level of exports and outflow observed in the 1980s and early 1990s (D. Kohlhorst, DFG, pers. comm.).

SUMMARY

Measures of mortality rates indicate that approximately 25 percent of the decline in bass abundance since 1969 is attributed to increased adult mortality. Some of this 25 percent may result from poaching, but mortality caused by legal sport fishing has not increased as measured by harvest percentage.

DFG analyses have shown additional restrictions on legal sport fishing would result in only small increases in adult abundance. These analyses also show that efforts to reduce the mortality of sub-legal bass would more effectively increase the population.

While poaching has historically been a significant contributor to increased mortality of sub-legal striped bass, the DBEEP appears to be reducing such activity significantly.

Other Perspectives

While many of the techniques described above have shown some success in managing striped bass populations, some believe that it may also be worth investigating taking further action in the Delta, perhaps similar to that taken to restore the striped bass fishery in the Chesapeake Bay (essentially closing the fishery for some limited period, resulting in a rebound of populations). (R. Potter, pers. comm.).

Striped bass resource managers, point out, however, that Chesapeake Bay striped bass harvest rates are far higher than those for striped bass in the Estuary and therefore it is not an appropriate model to apply to the Delta (P. Chadwick, pers. comm.).

WHITE STURGEON

From the 1860s until 1917 there was a white sturgeon commercial fishery in the Estuary. The harvest began decreasing after an 1887 peak catch of 1.66 million pounds.

In 1901, commercial fishing was halted after less than 200,000 pounds were harvested. Commercial harvest was allowed in 1909, 1916, and 1917, but populations were still low and commercial fishing of white sturgeon was prohibited entirely in 1917 (Brown, 1978).

From 1918 through 1953, it was illegal to take white sturgeon by any means in the Estuary. Sport catch of white sturgeon resumed in the Estuary in 1954. This heavily regulated sport fishery has allowed 1 fish per day with a minimum legal length (which has changed several times over the years) ranging between 40 and 50 inches. Initially, large numbers of fish were taken by party boat trolling. Trolling for white sturgeon was outlawed in 1956, and harvest immediately dropped to a small number of fish caught by anglers fishing for other species. It wasn't until 1964, when it was discovered that shrimp was an effective bait, that the sport fishery increased (Brown, 1978). Current sport fishing regulations provide for a 46" minimum legal length, a 72" maximum, and a one fish per day limit (California Sport Fishing Regulations, 1994).

POPULATION SIZE

White sturgeon population dynamics have been monitored intermittently since the sport fishery re-opened in 1954. Tagging studies have been used to estimate abundance, mortality rates, and to determine movement (Mills and Fisher, 1994). White sturgeon are captured for tagging purposes in the fall in San Pablo Bay, as it provides ideal conditions for such activity.

White sturgeon abundance was estimated using the Petersen method in years when a recapture sample was available from tagging in a later year(s). When adequate samples were not available, the Schumacher and Eschmeyer method was used, which required multiple censusing and was based on re-captures during the same tagging season.

When calculating mean abundance, population estimates were determined by linear interpolation in years when no tagging occurred.

Catch/harvest data are estimated from tag returns. A total of 5,952 white sturgeon were tagged with $20 disc-dangler reward tags in 1984, 1985, and 1987. Tagging white sturgeon with reward tags first began in 1967 and 1968, when $5 rewards were offered. This study continued in 1974 and 1979, when $10 reward tags were used. The reward tags have since been boosted to $20 for added incentive (Mills and Fisher, 1994).

White sturgeon population estimates have varied greatly since the fishery re-opened in 1954. The 1954 estimated population of 11,200 legal sized fish increased to 114,700 in 1967 and dropped to 20,700 in 1974. By 1979, the estimated population again had risen to 74,500 fish. It reached its peak in 1984, at 120,000 fish. Subsequent population estimates have declined to 86,000 in 1987 and 29,000 in 1990 (Table 6) (D. Kohlhorst, DFG, pers. comm.). The large swings in population estimates reflect infrequent, high flow conditions and the occurrence of other favorable environmental conditions that boost populations. Population estimates are not yet available for 1991-1993.

HARVEST

The white sturgeon is a native anadromous fish that is growing in popularity as a sport fish. Many white sturgeon are found in Suisun and San Pablo bays throughout the year, although peak fishing activity occurs from November through January. In San Francisco Bay, most fish are caught from January through March. In the fall, some of these fish migrate up the Sacramento River to spawn and concentrate in the upper river, near Colusa. White sturgeon may also migrate up the San Joaquin River in the spring, although spawning activity has not been verified.

Tag return surveys have resulted in ten times the number of tags being returned from white sturgeon caught in the Sacramento River as in the San Joaquin River (Kohlhorst, et. al., 1991). The methods of take for anglers fishing in the Estuary include rod and reel fishing from shore, private boats and party boats. Anglers principally use various types of shrimp for bait, although, sometimes the same types of dead fish baits used for striped bass are also used (Kohlhorst, et. al., 1991).

Illegal Harvest

Anglers illegally harvest white sturgeon in the Estuary by keeping fish smaller than 46 inches or longer than 72 inches. White sturgeon are also illegally harvested by gillnetters and setliners. Anglers who use gaffs or firearms when they land white sturgeon are also guilty of illegal take.

Illegal harvest of white sturgeon in the Estuary has not been measured. However, in the last 30 years, the white sturgeon sport fishery has greatly increased in response to improved fishing methods and technology. With more people utilizing the resource, and improved catch success, it is likely that illegal harvest is also increasing. Although white sturgeon caught seized by DFG wardens, records of the illegal harvest are not kept (J. Gonzalez, DFG, pers. comm.).

Table 6. Population Estimates and Estimated Catch of White Sturgeon.

YEAR	EST. POPULATION	CATCH
1954	11,200	200
1967	114,700	8,400
1968	40,000	2,600
1969		
1970		
1971		
1972		
1973		
1974	20,700	1,200
1975		
1976		
1977		
1978		
1979	74,500	16,200
1980		
1981		
1982		
1983		
1984	118,000	11,500
1985	108,000	12,400
1986		
1987	86,000	7,200
1988		
1989		
1990	29,000	900

Sport Harvest

In San Francisco Bay, more than half the yearly sport harvest of white sturgeon is landed from January through March. The DFG has monitored white sturgeon harvest rates periodically since 1954 (Table 6). Until 1984, harvest rates stayed below 8 percent. Then they rose to nearly 11 percent in 1985. During the mid-1980s, the Estuary's sport fishery for white sturgeon was believed to be reaching a level with the potential to over-exploit the population (Kohlhorst, 1993). Consequently, in the late 1980s, the DFG and sport anglers became concerned about increased exploitation rates, declining catch, and the known susceptibility of white sturgeon populations to over harvest.

A mathematical model was developed to evaluate the effect of angling regulation changes on white sturgeon abundance, egg production, and harvest over a 30-year period. The goal was to use this data to develop and adopt regulations that were socially acceptable, while maintaining white sturgeon abundance and egg production at the high levels of the mid-1980s (Kohlhorst, 1993).

Based on that initial modelling, minimum size limits of 42-48 inches and a maximum size of 72 inches were recommended to protect white sturgeon spawning stock. These new limits went into effect March 1, 1990, with the minimum legal size to increase from 42 inches by two inches per year until it reached 48 inches. These regulations reduced legal harvest to less than 5 percent of the total estimated population (Table 6). Based on additional modelling by the DFG, undertaken after charter boat operators and bait shop owners complained about severe economic hardships, the Fish and Game Commission halted the minimum size limit increase at 46 inches in 1993. The maximum legal size allowed to be taken remained unmodified at 72 inches.

EFFECT OF HARVEST ON POPULATION

Over the past 35 years, white sturgeon abundance in the Estuary has varied greatly. This has occurred primarily as a result of variations in recruitment rates while the annual harvest rate, a major component of total annual mortality rate, has increased from a mean of 0.069 in the 1960s and 1970s to 0.097 in the 1980s. This 41 percent increase in harvest rate for white sturgeon resulted from the previous mentioned burgeoning popularity of the sport fishery. Also, angler sophistication has increased through the use of sonar to locate fish and use of more effective baits. An increase in annual mortality rate estimates from 0.16 in 1967 to 0.26 in 1984, reflects the impact of the expanded harvest on the white sturgeon population (Kohlhorst, et. al., 1991).

Some studies suggest that variation in recruitment may be a result of fluctuations of high outflows through the Estuary in spring and summer. During peak outflow years, more young white sturgeon are produced (Kohlhorst, et. al., 1991).

CURRENT REGULATIONS AND ENFORCEMENT EFFORTS

White sturgeon shorter than 46 inches or longer than 72 inches may not be harvested. These restrictions protect young white sturgeon that have not reached spawning age and allow for increased egg production by protecting larger fish. White sturgeon have a long life span and only reach sexual maturity at approximately 14 years (Kohlhorst, et. al., 1991).

Fishing regulations also prohibit the use of firearms or gaffs in landing white sturgeon and impose a one fish limit. (California Sport Fishing Regulations, 1994). Also, snagging and trolling is prohibited. White Sturgeon must take anglers' bait willingly.

AMERICAN SHAD

American shad were introduced to the Pacific coast from the east coast of the United States to enhance sport fishing opportunities. From 1871 to 1880, American shad were planted in the Sacramento River near Tehama. Except for 1976 and 1977, there are no annual population estimates for American shad in Central Valley rivers and streams (Mills and Fisher, 1994). American shad population estimates were 3.04 million in 1976 and 2.79 million in 1977.

HARVEST

American shad are harvested by anglers in the Sacramento and San Joaquin river systems. Artificial flies, shad darts, and other lures fished with rod and reel are popular methods of take. Bump nets (trolling a chicken wire mesh net in the wake of a slow moving boat) provide another form of harvest. Male shad are caught when they are attracted to motor turbulence and "bump" into the net cone. The angler then flips the shad into the boat (Meinz, 1981; Radovich, 1970). For some reason, female shad are not attracted to the turbulence.

American shad were harvested commercially by gillnetters in the Sacramento and San Joaquin rivers and in the Estuary from 1879 to 1957 (Meinz, 1981). Annual harvest was about 1 million pounds. The commercial fishery was closed in 1957 to reduce the incidental take of striped bass and salmon.

Means of illegally harvesting American shad include exceeding possession limits (25), and gillnetting. Records are not kept of shad fishing violations (J. Gonzalez, DFG, pers. comm.).

Illegal Harvest

Illegal take is not monitored to an extent that an estimate of its magnitude can be made.

Sport Harvest

Shad angling became popular in the 1950s. Once the sport fishery became established, it grew to a mid-1960s level of 100,000 angler days fished annually. The Sacramento, American, Feather and Yuba rivers have traditionally been popular with shad anglers (Meinz, 1981).

Harvest records for the Sacramento-San Joaquin sport fishery are limited to the years 1976-1978 (Meinz, 1981) and 1990-1993 (L. Wixom, DFG, pers. comm.).

A creel census of the American shad sport fishery in the Sacramento River was conducted from 1976 through 1978 to measure harvest. The survey found that approximately 70 percent of the shad harvested in the Sacramento-San Joaquin Delta bump net fishery came from the lower Sacramento River or the North Fork of the Mokelumne River (Meinz, 1981). Annual catch from this region's fishery ranged from 7,200 to 11,600 shad (Meinz, 1981). Anglers' annual shad catch on the Sacramento, American, Feather and Yuba rivers in the years 1976-1978 ranged from 174,000 to 208,500. More than 60 percent of this total catch was from the Sacramento River (Table 7) (Meinz, 1981)..

The most recent harvest data covers a three year period from July 1, 1990 to June 30, 1993. The data were collected as part of the DFG Inland and Anadromous Sportfish Management and Research Project. Data were collected on salmon, steelhead, trout, sturgeon, striped bass, catfish and American shad along a 400 mile study area of the Sacramento River system.

Information collected included species sought, hours fished, fish kept, and fish released (L. Wixom, DFG, pers. comm.). Analysis of the data involved combining, sorting and summarizing individual records and then expanding this data to arrive at estimates of total angler use and harvest. Data collected prior to 1991 was insufficient to support any statistical correlation with assured influence factors (L. Wixom, DFG, pers. comm.).

From July 1, 1990 through June 30, 1991, an estimated 45,900 American shad were caught in the mainstem Sacramento River from the Carquinez Bridge to Redding. Of this total, an estimated 34,000 fish were released. An estimated 54,700 shad were caught during the July 1, 1991 through June 30, 1992 reporting period. Of this total, an estimated 34,500 shad were released by anglers. During the July 1, 1992 through June 30, 1993 reporting period, an estimated 80,500 American shad were caught by anglers. Of this total, an estimated 50,300 fish were released (Table 8) (L. Wixom, DFG, pers. comm.).

Effect of Harvest on Population

Historically, shad spawned extensively in the Delta, as well as in its upstream tributaries. Today, spawning is limited to the upper reaches of the north Delta. Reduced spring outflows from upstream reservoirs may prevent some juvenile shad from reaching critical nursing areas downstream. Entrainment of fish formerly produced in areas within the influence of water project

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Table 7. American Shad Catch Estimates (number of fish) for the Sacramento River System (1976-1978).

	Catch		
River	1976	1977	1978
Yuba	800	20	8,900
Feather	20,900	10,100	19,800
American	6,800	2,800	23,100
Sacramento	145,200	157,000	156,600
Total	173,700	169,900	208,400

Table 8. Estimates of sport fishing catch and release of American shad (1990-1993).

YEAR	EST. FISH KEPT	EST. FISH RELEASED	TOTAL
1990-91	11,900	34,000	45,900
1991-92	20,200	34,500	54,700
1992-93	30,200	50,300	80,500

export pumping may have eliminated some spawning runs to those areas. Entrainment of shad in in-Delta agricultural diversions also may have an adverse affect, however, such entrainment also occurred when American shad runs were much larger than at present. Estimates of sport harvest of American shad are low compared to estimated abundance levels, and lower than the historic commercial harvest.

LEOPARD SHARK

The leopard shark, also known as "tiger shark" or "cat shark," is valued as a food and game fish, as well as for aquarium displays. The extent of the leopard shark fishery is difficult to measure for two reasons: 1) commercial landings of this species are grouped under the general heading of "sharks unspecified" or "sharks miscellaneous"; 2) until the beginning of the last decade, statistics on sport catch were very limited (Smith, 1992). It is worth noting that the leopard shark, compared to other fish discussed in this paper, has a low reproduction rate (4 to 29 pups per year).

HARVEST

Commercial harvest of leopard shark in San Francisco Bay and other California waters involves the use of gillnets and commercial longlines. Gillnetting is allowed along the coast but catches are declining as a result of legislation that limits this practice. Bottom trawlers occasionally catch a few leopard sharks as well (Smith, 1992).

Sport anglers fish for leopard sharks in San Francisco Bay from party boats, private boats, and piers and jettys with hook and line. Anglers use bait such as clams, worms, ghost shrimp, herring, and anchovies, but the principal bait used is the midshipman (Smith, 1992). Also, divers spear leopard sharks.

Methods of illegal harvest of leopard sharks include gillnetting in San Francisco Bay, exceeding the 3 fish sport catch limit, or keeping sharks shorter than 36 inches.

Illegal Harvest

There currently are no data on illegal harvest of Leopard Sharks..

Sport Harvest

Sport harvest of leopard sharks is a significant factor affecting the total population. Analysis of recovery patterns of 948 tagged leopard sharks released in the San Francisco Bay area in 1979 by the National Marine Fisheries Service, has shown that roughly 82 percent of the 108 recoveries were returned by sport anglers, while only 18 percent were caught commercially (Smith, 1992). In the past ten years, the popularity of the leopard shark sport fishery has increased substantially.

Commercial Harvest

Total commercial harvest of leopard sharks in California has ranged from 9,278 pounds (representing less than 1,000 fish) in 1958, to 101,283 in 1983 (Table 9). In the last ten years, the leopard shark catch has been increasing off the southern California coast and decreasing from Monterey northward.

A legislative ban on inshore gillnetting of leopard sharks in the Monterey and San Francisco bay areas is a likely contributor to the observed decline in Northern California's catch after 1986 (Smith, 1992).

Table 9. Leopard Shark Commercial Harvest, California, 1977-1992.

Year	Number of Pounds Harvested
1977	22,267
1978	34,956
1979	38,939
1980	40,085
1981	51,506
1982	70,619
1983	101,283
1984	67,855
1985	75,838
1986	74,741
1987	55,025
1988	41,737
1989	50,167
1990	40,822
1991	47,677
1992	42,257
Average	57,052

EFFECT OF HARVEST ON POPULATION

Results of the San Francisco Bay tagging project (mentioned above) show that 10 percent of the resident population migrate into the ocean during the fall-winter period. California's total leopard shark population has not been estimated. Catch statistics are currently used to make inferences about stock abundance. However, this method of measuring stock abundance may not be completely reliable since some evidence suggests environmental conditions affect the population as well.

Increased commercial and sport harvest of leopard sharks have been recorded in the San Francisco Bay area in years when Delta outflow is high. Tagging results indicate this increase is not attributable to immigration of sharks from other areas (Smith, 1992). The implication of this observation is that if the local population is over harvested, recruitment from other populations is unlikely or will be slow.

Because of the leopard shark's increasing popularity as a game fish and its low reproduction rate, the DFG believes this species should be monitored closely to ensure against over-fishing adversely affecting its abundance.

CURRENT REGULATIONS AND ENFORCEMENT EFFORTS

The leopard shark has a very slow growth rate (less than 1 inch/year), a late sexual maturity, produces comparatively few young, and is a favorite species in the commercial aquarium trade. It is for these reasons that the California Fish and Game Commission instituted a 36 inch minimum legal length for the take of leopard shark (California Sport Fishing Regulations, 1994). California's 1994 sport fishing regulations also limit anglers to possession of no more than three (3) fish.

PACIFIC HERRING

Pacific herring is a marine fish that spawns in bays and estuaries. San Francisco Bay is the largest and most productive herring spawning area in California. The herring's spawning cycle appears to be related to high tides. Approximately 88 percent of herring spawning occurs when the tide cycle is highest and it occurs at night (Spratt, 1981).

California's Pacific herring fishery began in 1972 to serve Japan's growing market for herring roe. When the fishery began, there was little available information on California's herring stocks. The DFG began annual population assessment surveys in the mid 1970s to develop a management plan (Spratt, 1992). While this management plan was being completed, the California State Legislature set quotas for the fishery. The Fish and Game Commission undertook management responsibility for the fishery beginning with the 1973-74 season. In 1977, a limited permit program was adopted for Tomales and San Francisco bays, the largest herring fisheries, with San Francisco Bay users receiving the majority of the permits (Spratt, 1992).

HARVEST

There is no measurable sport fishery for Pacific herring.

Herring are fished commercially in San Francisco Bay using round haul gear such as lampara nets, purse seines, gillnets, and bait nets. In 1991, gillnetting was banned in a large section of San Francisco Bay, between the Bay Bridge and Hunter's Point. In those areas,

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premature spawning in deep water or on the nets was resulting when herring gathered in large numbers prior to spawning and gillnets were used (Spratt 1992).

Illegal harvest of Pacific herring includes fishing in closed areas, using prohibited gear, or fishing outside of open fishing seasons. Exceeding quota allocations for a particular type of gear or for a specific area are also components of illegal take.

Illegal Harvest

Presently, there are no data regarding the extent of the illegal harvest of Pacific herring.

Commercial Harvest

California's two most important herring spawning grounds, Tomales and San Francisco bays, support two separate and distinct spawning stocks that are managed to ensure that each is not over fished. DFG annual herring biomass estimates for both bays are determined by conducting hydro-acoustic and/or spawning ground surveys (Spratt, 1992; Wendell and Oda, 1990). Harvest quotas are usually set at approximately 15 percent of the total annual herring biomass estimates from each bay. Area quotas are set independently, and vary according to annual herring biomass measurements in each bay (Spratt, 1992).

The DFG has kept harvest records for the San Francisco Bay herring fishery since 1972. Seasonal harvest, recorded in tons landed, includes herring and herring roe attached to kelp. (Table 10) (Spratt, 1992).

EFFECT OF HARVEST ON POPULATION

Commercial harvest of Pacific herring does not appear to have a significant effect on the population's ability to maintain itself.

CURRENT REGULATIONS AND ENFORCEMENT EFFORTS

The majority of San Francisco Bay was off limits to encircling nets (purse seine, lampara, beach nets) for many years to protect Pacific herring, salmon, striped bass, sturgeon and shad. Bait
nets, made of purse rings and seine twine, had been allowed for the harvest of bait fish only (Spratt, 1992).

Beginning in 1979, the Fish and Game Commission ruled that lampara nets qualified as bait nets and this began a ten year period during which more of San Francisco Bay was opened to roundhaul gear; first, lampara, and in 1989-90, purse seines (Spratt, 1992). To prevent take of sport

Table 10. Commercial Herring Landings 1972-1994.

SEASON	QUOTA	CATCH HERRING & ROE (IN TONS)	AVERAGE % ROE	TONS LANDED HERRING ONLY
1972-73	1,500	436	12.2	383
1973-74	500	1,938	12.2	1,702
1974-75	600	514	12.2	451
1975-76	3,050	1,719	12.2	1,509
1976-77	4,000	4,201	12.2	3,688
1977-78	5,000	4,987	12.2	4,379
1978-79	5,000	4,121	12.2	3,618
1979-80	6,000	6,430	12.2	5,646
1980-81	7,250	5,826	12.2	5,115
1981-82	10,000	10,415	12.2	10,288
1982-83	10,399	9,695	12.2	9,577
1983-84	10,399	2,838	12.2	2,492
1984-85	6,500	7,740	12.2	6,796
1985-86	7,530	7,278	12.2	6,390
1986-87	7,530	8,098*	-	8,098
1987-88	8,500	8,741*	-	8,741
1988-89	9,500	9,736*	-	9,736
1989-90	9,057	8,962*	-	8,962
1990-91	8,858	7,741*	-	7,741
1991-92	7,134	7,417	12.2	6,512
1992-93	5,386	5,151	12.2	4,523
1993-94	2,009	2,300	12.2	2,019

* Herring only, roe on kelp is not included.

fish a rigid metal grate of parallel bars no more than 3 inches apart is placed over the hatch while dumping herring into the hold so that the sport fish will be deflected onto the deck and can be returned to the water.

Transfer of herring between vessels or permit holders is prohibited in order to keep groups of vessels from fishing together and to prevent commercial fishermen from circumventing gear quotas and vessel allocations (Spratt, 1992).

Starting with the 1991-92 season, the central part of San Francisco Bay, between Hunter's Point and the Bay Bridge, was closed to gillnet fishing to protect this important spawning area.

LARGEMOUTH BASS

The largemouth bass is a non-native warm water fish that can be found in nearly all suitable lakes, sloughs and slow moving rivers in California. In the late 1800s, 22 largemouth bass from the east coast were planted in Crystal Springs Reservoir in San Mateo County (Seymour, 1979).

HARVEST

Anglers fish for largemouth bass in the Estuary and the Sacramento and San Joaquin rivers with rod and reel. Typically, artificial lures are cast or trolled, although earthworms, grasshoppers, crickets, minnows, and artificial flies may also be used (Robbins and MacCrimmon, 1974).

The extent of the illegal take of largemouth bass has not been monitored in the Delta. Illegal harvest generally involves anglers exceeding take limits and fish taken by gillnetters, although largemouth bass are generally not very susceptible to gillnets (J. Gonzalez, DFG, pers. comm.).

Illegal Harvest

The level of illegal take of largemouth bass in the Delta has not been determined. Since there is a possession limit of five (5) fish, with no size restrictions, and largemouth bass are not very susceptible to gillnets, illegal take tends to be limited to over limits by anglers. The DBEEP has helped reduce the illegal take of largemouth bass.

Sport Harvest

There is very little information available concerning harvest rates and population size of largemouth bass in the Sacramento and San Joaquin rivers. The most recent harvest data are confined to that collected from largemouth bass tournaments, conducted in the Delta from 1985 through 1993. The information presented is limited to completed tournament harvest data reports as of March 21, 1994 (I. Paulsen, DFG, pers. comm.).

Largemouth bass tournament data lists the number of fish caught, including the number that died after being landed. Largemouth bass tournaments release live fish after weights and/or numbers of fish have been recorded. Tournament catch ranged from 78 fish caught during a single fishing day in 1985 to 15,546 recorded during 110 tournament days in 1992. Largemouth tournament data for 1993 are incomplete. The total 1993 catch recorded as of March 21, 1994 stands at 15,270 fish caught during 126 angling days (Table 11) (I. Paulsen, DFG, pers. comm.).

Largemouth tournament catch data includes the take of largemouth and smallmouth bass as well as redeye and spotted bass. The largemouth bass portion of the total tournament catch is not available so the most accurate measurement of largemouth bass harvest in the Sacramento-San Joaquin Delta would be the 30 percent harvest rate measurements recorded during 1980 through 1984. The DFG believes that the harvest rate has not changed appreciably during this period in relation to increased angler participation, improved angling efficiency, or increasing numbers of tournaments.

EFFECT OF HARVEST ON POPULATION

The estimated annual harvest of no more than 30 percent in the Delta, based on tagging studies done in the mid-1980s, is less than that of many other largemouth bass populations around the nation which are known to be stable. Consequently, the DFG believes that the sport take is well within acceptable levels.

CURRENT REGULATIONS AND ENFORCEMENT EFFORTS

Current California sport fishing regulations for the Sacramento-San Joaquin Delta allow anglers to take largemouth bass all year. There is a possession limit of five (5) fish, but no size restrictions (California Sport Fishing Regulations, 1994).

Table 11. Largemouth Bass Tournament Catch, Sacramento-San Joaquin Delta, 1985-1993.

Year	Catch
1985	78
1986	1,811
1987	2,657
1988	4,990
1989	5,592
1990	10,195
1991	10,924
1992	15,546
1993	15,270

APPENDIX

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GLOSSARY

Adjusted Peterson Population Estimate	Also called the single census method. Fish are marked once; a single sample is then taken and examined for marked fish. Marking should be restricted to a short period of time, but the sampling that follows may occur over a long period.
Anadromous	Migrating up rivers from the sea to spawn in fresh water.
Bump Net	A long handled, chicken-wire dip net is placed in the prop-wash of a slow moving boat. When a shad bumps the net, the "bumper" quickly attempts to flip the fish into the boat.
Creel Census	A survey of boat and/or shore sport anglers to record the number and species of fish caught, as well as other biological data.
Escapement	The number of fish that "escape" the fishery and return to spawn.
Exploitation Rate	The number of fish taken in the sport angler or commercial harvest, compared to the number of fish that escape to spawn.
Five-Year Running Average -- Method of Calculation	Running averages are often used to smooth time series data, removing some of the effect of extreme values. For the purposes of this paper, the five-year running averages of abundance were calculated for each year by adding the abundance for the year in question with the abundance of the four previous years, and calculating the average over the five-year period.
Harvest	Fish taken for sport or commercial purposes.
Harvest Rate	That part of the population taken by the legal or illegal fishery.
Lampara Net	An encircling shaped like a dustpan with wing-like attachments on each side.
Mortality Rate	The number of deaths from a certain cause, in a unit of population, over a certain period of time.
Party Boat	A fishing vessel that carries sport anglers for a fee.
PFMC	Pacific Fishery Management Council.
Purse Seine	A net that surrounds fish vertically and horizontally. The seine net opens to form a purse shaped mouth opening, which is then closed to capture fish.

Recruitment	The number of fish added to the adult population each year.
Redd	A hollowed out depression in the gravel of a river or stream that is excavated by a female salmon prior to depositing her eggs.
Round Haul Gear	Refers to purse seines and lampara nets.
Schumacher and Eschmeyer Population Estimate	$\frac{1}{N} = \frac{\Sigma(M_t R_t)}{\Sigma(C_t M_t^2)}$ N = population estimate M_t = total marked fish at large at the start of the tth day, i.e. the number previously marked less any accidentally killed during previous recaptures. M = ΣM_t, total number marked C_t = total sample taken on day t R_t = number of recaptures in the sample C_t R = ΣR_t, total recaptures during experiment
Smolt	A juvenile salmon that has undergone physiological changes that allow it to migrate into salt water.
Trammel Nets	A type of entangling net which has three net walls. The outer walls consist of wide mesh netting that is stretched tight around an interior loose net that surrounds a fish and entangles it.

PERSONAL COMMUNICATIONS

Date	Name	Title	Project
2-27-95	Bailey, R.	Private Biological Consultant	
3-17-94 5-18-94	Baracco, Alan	Senior Biologist	Ocean Salmon Project, DFG
3-17-94	Boydstun, L. B.	Program Manager	Ocean Salmon Project, DFG
2-27-95	Brown, R.	Chief, Environmental Services Office, Department of Water Resources	
3-21-94	Dixon, Richard	Associate Biologist	Ocean Salmon Project, DFG
4-27-94	Fisher, Frank	Associate Biologist	Central Valley Salmon and Steelhead Project, DFG
3-17-94	Flemming, Kevin	Marine Biologist	San Francisco Bay Study, DFG
3-17-94 5-25-94	Gonzalez, Joseph	Lieutenant	Wildlife Protection Division (DBEEP), DFG
3-18-94 5-23-94	Kohlhorst, David	Associate Biologist	Adult Striped Bass and Sturgeon Project, DFG
9-15-94	Kier, William	William Kier Associates	
3-17-94	Maxwell, Bill	Senior Biologist	Sport Fish Restoration Act Coordinator, DFG
3-18-94	Meyer, Fred	Associate Biologist	Fisheries Management, Region 2, DFG
3-24-94	Oda, Ken	Marine Biologist	Pacific Herring Project, DFG
3-18-94	Paulsen, Ivan	Associate Biologist	Reservoir Project, DFG
9/15/94	Potter, Robert	Chief Deputy Director, Department of Water Resources	
3-25-94	Ryan, Connie	Associate Biologist	Pacific Herring Project, DFG

3-25-94	Roper, Gail	Biologist	Pacific Marine Fisheries Council
3-25-94	Schultz, Donald	Senior Biologist	Marine Resources, DFG
3-25-94	Spratt, Jerome	Associate Biologist	Pacific Herring Project, DFG
2-27-95	Vogel, D.	Private Fisheries Consultant	
3-22-94	Wixom, Lynn	Associate Biologist	Sacramento River Angler Survey, DFG
3-25-94	Watters, Diana	Associate Biologist	Sea Otter Project, DFG

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