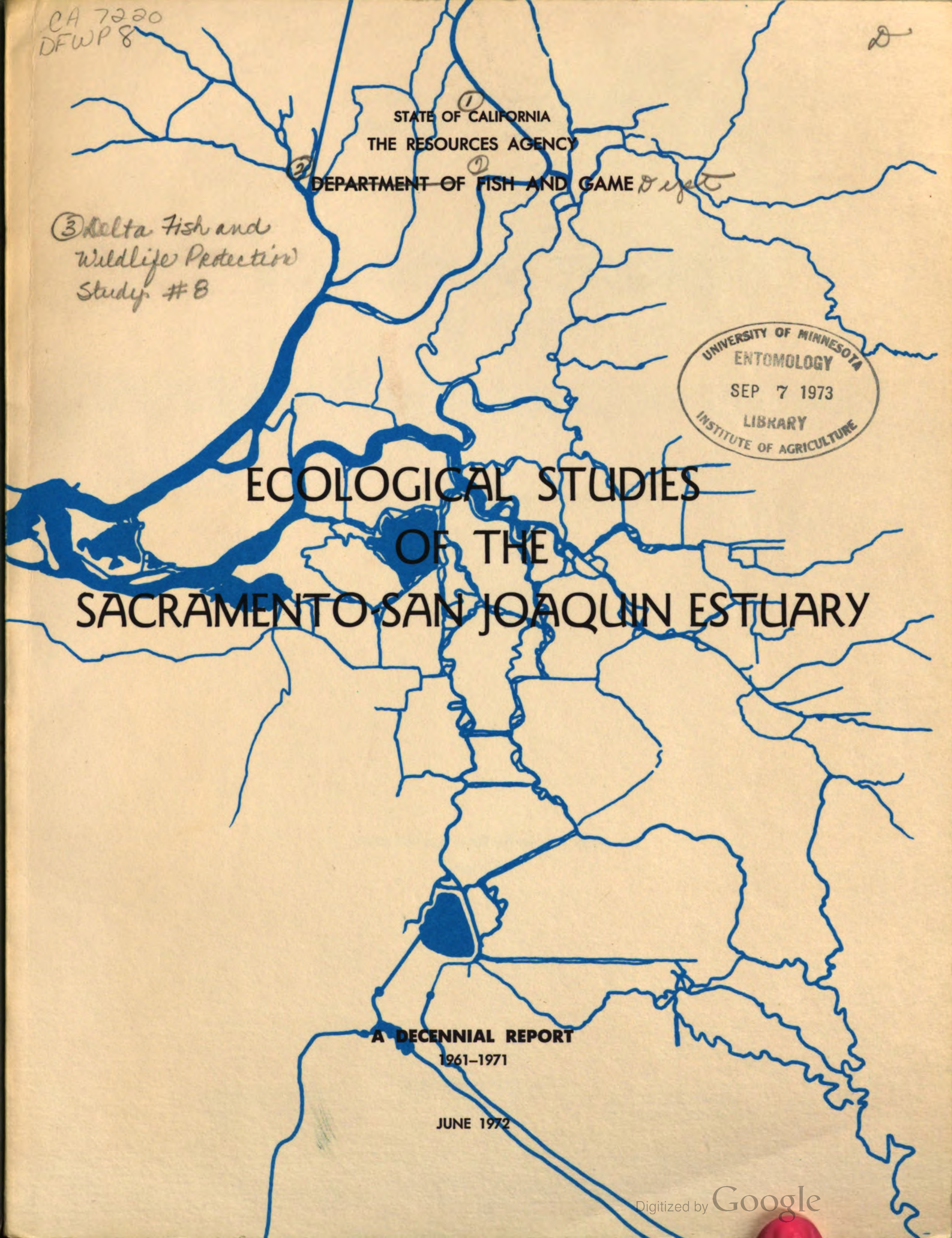

STATE OF CALIFORNIA

THE RESOURCES AGENCY

DEPARTMENT OF FISH AND GAME Dept

(3) Delta Fish and Wildlife Protection Study #8

ECOLOGICAL STUDIES OF THE SACRAMENTO-SAN JOAQUIN ESTUARY

A DECENNIAL REPORT

1961–1971

JUNE 1972

THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF FISH AND GAME

ECOLOGICAL STUDIES OF THE SACRAMENTO-SAN JOAQUIN ESTUARY

Compiled by
JOHN E. SKINNER

Delta Fish and Wildlife Protection Study
Report No. 8

June 1972

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Secretary for Resources

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CALIFORNIA DEPARTMENT OF FISH AND GAME

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This report was prepared by the Department of Fish and Game under the direction of George H. Warner, Chief, Anadromous Fisheries Branch, and Harold K. Chadwick, Program Manager, Bay-Delta Fishery Project. The Department of Water Resources, through the Water Development Bond Act, has been the primary source of funding for these studies. Water Resources has also provided essential engineering support for the biological study program and prepared the chapter on concept and operation of the Peripheral Canal.

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FOREWORD

This document is intended to summarize existing knowledge about the principal fish and wildlife resources of the Sacramento-San Joaquin estuary, their ecological relationships and their environmental requirements, with emphasis on requirements bearing some relationship to water development. It represents an accumulation of knowledge spanning many years, but particularly the results of the 10 years of intensive study by the Delta Fish and Wildlife Protection Study between 1961 and 1971. The topic is complex and the amount of information available is voluminous. Hence, this report is intended only to provide a summary of the knowldege regarding the resources and their environmental requirements as we know and understand them at this point in time.

The Department of Fish and Game is well aware of the widespread interest in the Delta, its fish and wildlife, and of the tremendous concern exhibited by the public to see that the resources and environment of the Delta are protected under any plan of delta water development that may be implemented. The essential aim and purpose of this report, therefore, is to provide the public and specialist alike with a common reference of the most up-to-date information available concerning the resources, their requirements, and their relationship to delta water plans.

In this approach we have deemphasized the statistical documentation and technical discussion common to most research reports. Since this may be a disadvantage to those who wish more technical detail, we have stressed the inclusion of literature citations to show the sources of our information.

In the past, progress of the Delta Fish and Wildlife Protection Study has been reported by means of formal or informal annual reports. For the years 1961 through 1967, the annual reports were published by the Departments of Fish and Game and Water Resources. From 1968 through 1970, letter reports were used to transmit the progress of the studies from the Department of Fish and Game to the Department of Water Resources. This report, for 1971, summarizes the activities and findings of the past 10 years.

The ecological studies undertaken by the Delta Fish and Wildlife Protection Study from 1961 through 1969 were funded almost exclusively by the Department of Water Resources through funds from the State Water Resources Development Bond Act. In 1968, in an effort to promote efficiency, the Department of Fish and Game's independent striped bass and sturgeon project, which is supported by federal aid to fish restoration funds, was combined with the delta study to form a unit studying fishery resources in the Sacramento-San Joaquin estuary.

George H. Warner
Chief, Anadromous Fisheries Branch
June 1972

ACKNOWLEDGMENTS

These 10 years of study have involved the efforts of many people, clerks, boat operators, engineers and seasonal aids as well as scientists and administrators. Over the years people and positions have changed; hence, it is impossible to credit properly all those who have contributed so much to this important program. To all who have participated and who are not specifically singled out here, we wish to convey our sincere thanks and appreciation.

Robert L. Jones and Don Kelley, who did a most commendable job of planning, staffing, and implementing the biological program initially, deserve particular mention. Their counterparts, Langdon Owen and Robert Whiting of the Department of Water Resources, were highly instrumental in the success of the program through their cooperation in program implementation and in providing engineering support. Gerald Cox deserves special recognition for his effort in the latter capacities over the past few years.

Janet Boranian and Marlene Oehler capably assisted all program personnel while doing a most creditable job of handling the office chores. Janet Boranian, Mabel Lichtenburger, Lynette Rau, Betty Jo Saunders and Mary Mulligan typed the manuscript for this report and Harry Inouye did a substantial part of the art work.

John E. Skinner

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JOHN E. SKINNER

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CHAPTER I

INTRODUCTION

By JOHN E. SKINNER

FISH, WILDLIFE AND THE ESTUARY

In 1776, Juan Batiste de Anza, leading an overland expedition from Monterey, crested the hills overlooking Carquinez Strait to become the first white man to gaze upon the immense expanse of tules, islands, and waterways that now constitute the Sacramento-San Joaquin Delta.

Anza and Pedro Fages were the first to comment on the abundance of game in the Bay area, although Jedediah Smith provided a much more detailed account following his visit in 1827. The significant contribution of fish and wildlife to the settlement of the West Coast and the Bay area in particular is well recorded in the history of the area. For fully 125 years following de Anza's visit, the rich and varied wildlife resources of San Francisco Bay and the Delta were important constituents of the area's growth and economy.

The local Indians depended heavily on the annual runs of salmon and the fall influx of waterfowl. Later came the Hudson Bay trappers who made overland treks from Astoria and Vancouver between 1826 and 1845. Until the late 1800s, trapping primarily for beaver pelts and waterfowl market hunting were prevalent. By 1850, the Italian immigrants had established the bay fisheries and the salmon fishery from Carquinez Strait upstream. By this time the Chinese had developed the shrimp fisheries in San Francisco and San Pablo Bays.

The estuary today is vastly different from the primordial conditions that greeted de Anza almost 200 years ago. (See Skinner, 1962 for an extensive review of the fish and wildlife resources of the San Francisco Bay area.) By the latter part of the 19th century there was a decline in many of the native fish and wildlife resources. 1870 saw the creation of the first California Fish Commission and the importation of fishes from the East. Of those introduced, striped bass, American shad and white catfish were spectacularly successful. Today these species support the bulk of all recreational fishing in the Delta.

Until 1957, the Delta supported a substantial commercial fishery. One by one, due to an apparent decline in the resources and a long-standing conflict between sport and commercial interests, the commercial fisheries were legislated out of existence. Commercial fishing in the delta was closed to sturgeon for the last time in 1917, to striped bass in 1936, to catfish in 1955, and to salmon and shad in 1957.

Around the turn of the century most of the Delta was reclaimed and converted to one of the world's richest agricultural regions. By leveeing and draining, some 700,000 acres of land, mostly below sea level and spread over 30 large islands, were converted to agricultural purposes.

The principal large remnant not now under agricultural production is the 55,000 acre Suisun Marsh. Attempts to reclaim this marsh have been fraught with trouble due to high wind and wave action and flooding, but primarily the unreliable quality of the water. Suisun Marsh consequently is a winter haven for migratory waterfowl of the Pacific Flyway. It winters upwards of a million birds and supports about 200 private duck clubs in addition to the 10,000 acre state-owned Grizzly Island Wildlife Area.

The natural wetlands of the Bay and Delta represent more than 25 percent of the statewide total of such habitat and regularly harbors about 20 percent of the waterfowl of the Pacific Flyway which winter in California.

Although the fish and wildlife of the estuary have diminished over the years, the area is still the State's focal point for many of these resources. About half the State's anadromous fish resources pass through or depend upon the delta. These include all of the salmon and steelhead of the Sacramento and San Joaquin River systems, and virtually the entire striped bass, American shad and white sturgeon resources of the State. Each of these species is of particular significance to the angling population of the State and in the case of salmon contribute about 80 percent of the State's commercial salmon catch. The estuary (Figure 1) possesses an immense capacity for water oriented recreational pursuits.

There are between 40,000 and 50,000 surface acres of water, 700 miles of navigable channels and in excess of 1,000 miles of shoreline within the Delta. The San Francisco Bay system from Chipps Island downstream included 474 square miles of water area and 313 square miles of marshland in 1968. This is a reduction of 53 square miles of water area and 186 square miles of marshland since 1850 (Bay Conservation and Development Commission, 1971).

ECOLOGICAL STUDIES OF THE ESTUARY

Fish and wildlife research and management programs were initiated before 1920, but programs of increasing scope have been carried out since then. The initial efforts were directed toward regulating harvest of the resources. A major effort toward protection of the resources was stimulated by authorization of the federal Central Valley Project including Shasta and Friant Dams and the Contra Costa and Delta-Mendota Canals. Substantial work directed toward evaluating the impact of those projects was conducted during the late 1930s and 1940s. In the

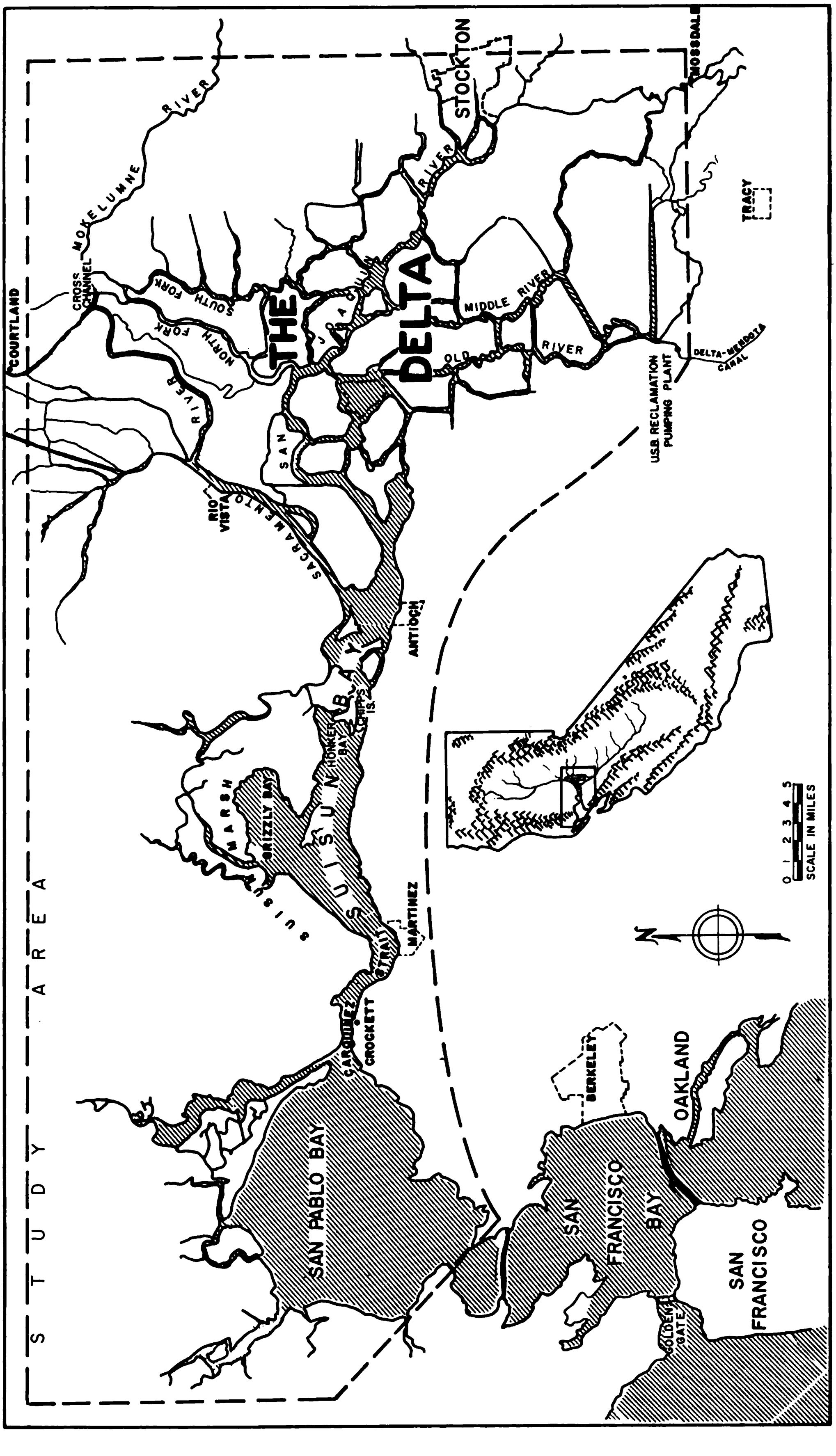

FIGURE I SAN FRANCISCO BAY AND DELTA ESTUARY

FIGURE 1—San Francisco Bay and Delta Estuary

1950s, efforts stemmed largely from the need for knowledge to manage effectively the popular striped bass fishery and the newly opened sturgeon sport fishery.

For the last 10 years, the California Department of Fish and Game has been engaged in an extensive program to obtain fundamental, yet practical, knowledge concerning the fish and wildlife resources of the Sacramento-San Joaquin Estuary. The latter effort was begun in 1961 following approval of the State Water Resources Development Bond Act by public referendum in November 1960. At that time the State Departments of Fish and Game and Water Resources entered into an agreement calling for a cooperative study of the Delta. These studies complemented the continuing investigations of the Department of Fish and Game.

It was known many years ago that the Delta would play a key role in any plans to transfer water from Northern California to the San Joaquin Valley, Southern California and the southern San Francisco Bay area. Recognizing the potential effect of control structures and the transfer of large quantities of water across the Delta, the present study was initiated to: (1) evaluate the potential impact of the various water plan alternatives on fish and wildlife; (2) determine the environmental requirements of fish and wildlife affected by water development programs; (3) undertake the necessary research and development programs to design fish and wildlife protective facilities; and (4) conduct research essential to development of project operating procedures and criteria for protection of the resources and the Delta environment.

An inherent aspect of the present study is the effort being made to develop a fuller understanding of the interrelationships between the fish and wildlife resources of the Delta and the physical and biological characteristics of the environment upon which they depend.

The early stages of the present effort were devoted primarily to: (1) an inventory of the resources to define their gross ecological and geographical relation-

The Sacramento River near Hood

TABLE 1. ECOLOGICAL STUDY PROGRAMS—DELTA FISH AND WILDLIFE PROTECTION STUDY, 1961–1971

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
I. Physical Environment[1]																					
II. Delta Environment and Water Plan Review		xxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxx															
III. Resources Inventory																					
Plankton		xxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxx															
Neomysis		xxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xx															
Benthos		xxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxx															
Fishes including food habits		xxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxx														
Wildlife including Suisun Marsh		xxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxx															
IV. Fish Facility Studies																					
General Assessment of Problems and Needs			xxxxx	xxxxxxxx	xxxxxxxx	xxxx															
Peripheral Canal Research and Development					xxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	////////	////////	////////	////////	////////				
Evaluation of Delta Fish Protective Facilities										xxxx	xxxxxxxx	xxxxxxxx	////	///							
V. Ecological—Environmental Studies																					
Fishes																					
Striped Bass																					
Spawning location				xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx													
Egg and Larval Survey							xxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx									
Fry Abundance Index		xxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	////////	////////	////////	////////	////////				
Fall and Winter Survival								xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx									
Adult Population Study										xxxxxxxx	xxxxxxxx	xxxxxxxx									
Salmon																					
Distribution and Occurrence					xxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx		x	xxxxxxxx	xxxxxxxx									
Sturgeon																					
Larval Studies										xxxxxxx	xxxxxxxx	xxxxxxxx	////////	////////	////////	////////					
Phytoplankton including dissolved oxygen dynamics						xxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxx—	——	→xxxxx	////////	////////	////////	////////	////				
Zooplankton											——	→xxxxx	////////	////////	////////	////////	///				
Neomysis						xxxxxx	xxxxxxxx	xxxx Mo	nitoring	& Index											
Waterfowl—Suisun Marsh			xxxxx	xxxxxxxx	xxxxxxxx	xxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx	xxxxxxxx			////////	////////							
Other Wildlife (Pheasants and Sandhill Cranes)			xxxxx	xxxxxxxx	xxxxxxxx	xxxx															
VI. Monitoring[2]																					
Physical Environment																					
Biological																					

←— Pre-Peripheral Canal Program —→←— Program following adoption of the Peripheral Canal —→

[1] The Department of Water Resources, U.S. Bureau of Reclamation and other agencies have had ongoing studies regarding Delta hydrology, water quality, and salinity for many years. Water Resources has undertaken specific studies on the physical environment upon request by the Delta Fish and Wildlife Protection Study.
[2] Monitoring of Delta physical and biological factors is presently being planned under a cooperative program in concert with the State Water Resources Control Board.

ships; and (2) an evaluation of the various Delta water transfer alternatives to assess their relative impact on the resources. The annual reports of the Delta Fish and Wildlife Protection Study from 1962 through 1967 review the first 6 years of progress and evaluation.

The results of these efforts provided important input to the Interagency Delta Committee, which was established to evaluate alternative Delta water transfer plans. Based on its review of all uses and needs in the Delta, the Committee proposed the Peripheral Canal concept. Subsequently, the heads of the participating water development agencies formally adopted the Peripheral Canal concept as the recommended plan of development for the Sacramento-San Joaquin Delta.

The Peripheral Canal concept was later endorsed by the Department of Fish and Game, the U.S. Bureau of Sport Fisheries and Wildlife and numerous conservation organizations. Endorsement by these groups was based largely on a determination by the Department of Fish and Game that the Peripheral Canal concept was the only method for transferring water across the Delta that could protect the fish and wildlife resources adequately. In addition the Peripheral Canal also possessed the inherent capability to enhance the resources.

It was understood at the time the Peripheral Canal concept was adopted that achievement of the fish and wildlife objectives would depend on two major considerations: (1) provision of adequate fish protective facilities; and (2) development and implementation of criteria to assure proper operation of the project for fish and wildlife purposes.

Since 1964, the effort of the cooperative Delta Fish and Wildlife Protection Study has been concentrated on research and development activities aimed at fulfilling these primary considerations.

A recapitulation of the first 10 years of the Delta Study program is presented in Table 1. The table shows in brief summary form the broad categories of studies undertaken, and the period of time over which they occurred. To date approximately 3.5 million dollars has been expended by the Department of Water Resources for these ecological studies and the engineering support associated with them. This amount does not include the Department of Fish and Game's continuing research and management program which would add approximately another 2.5 million dollars for a total of about 6 million dollars.

Very substantial progress has been made in determining the ecological relationships of the important species and their environmental requirements. The accumulation of practical knowledge must, on the whole, be considered outstanding for an ecosystem as complex as the Estuary. It is clear that final answers to many questions are still some years in the future; cannot be answered until the Delta water facilities are operating and tested.

Nevertheless, it is the conviction of the biological staff of the Department of Fish and Game that enough is known of the resources and their requirements to: (1) demonstrate that the Peripheral Canal should be built to correct existing adverse conditions; and (2) recommend the broad physical and environmental conditions that should prevail in the Delta irrespective of the form or plan of development ultimately implemented. In many cases detailed environmental requirements have been tentatively established. The knowledge leading to these conclusions is summarized in this report.

It will likely be noted that the bulk of the effort under this program has been directed toward the more prominent species in the Estuary, namely, those which are most widely recognized whether by virtue of their rarity, forage, game or commercial value. This is not to say the other species are being ignored. Early in the formulation of the Delta Study program, key species were selected under the assumption that environmental requirements evolving from the study of the key species would also suffice for others on which comparable effort has not been devoted.

Ecological studies are continuing under a quadripartite agreement among the State Departments of Water Resources and Fish and Game and the U.S. Bureaus of Reclamation and Sport Fisheries and Wildlife.

The general format for the subsequent chapters of this report is to set the stage—first by summarizing how water development has influenced the Estuary physically, and then by describing our current understanding of the principal fish and wildlife resources and their requirements. This is followed by an evaluation of water development plans in light of resource requirements. The final chapters include a summary of the fish facility program, a review of future environmental study needs, and a listing of publications concerning fish and wildlife in the Estuary.

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CHAPTER II

WATER DEVELOPMENT AND THE DELTA

By JOHN E. SKINNER

WATER STORAGE AND DIVERSION

About the time the Delta was being reclaimed, the storage and diversion of water for hydroelectric power, agriculture and municipal purposes was occurring in the foothills and mountain tributaries of the Great Central Valley. The construction of dams on Central Valley streams was begun before 1870, increased rapidly between 1910 and 1930 and occurred on an unprecedented scale between 1940 and 1970.

From the time of American settlement in 1850 until 1910, these developments did not greatly alter the natural runoff pattern into the Delta, because most were small and lacked long-term carryover capacity. The total storage capacity did not exceed 300,000 acre-feet until 1910, although the quantity diverted for irrigation at that time was on the order of 2.75 MAF (million acre-feet) (DWR, 1931b).

Between 1910 and 1930 reservoir storage capacity increased to more than 4 MAF, while the total amount diverted for irrigation reached almost 6 MAF (DWR, *op. cit.*). Since the mean annual runoff into the Delta was on the order of 30 MAF, storage had little effect on the overall seasonal runoff pattern. The primary effect was a reduction of summer inflow. The greatest absolute reductions in July and August were of greater consequence in the Delta because of the lower natural flow at that time. The lack of long-term carryover capacity for use in dry years in relation to total irrigation use during this period served to accentuate the summer reductions.

With the advent of the federal Central Valley Project (CVP) in the early 1940s and more recently the State Water Project (SWP) there has been a pronounced change on the hydrologic pattern in the Delta. The federal and state projects alone, now have a combined storage capacity on the tributaries of the Central Valley of more than 15 MAF (DWR Bulletin 17-69). The authorized New Melones and Auburn projects will increase the total to about 20 MAF. In addition, the Trinity Division of the Central Valley Project provides storage of 2.7 MAF of which about 0.5–1.5 MAF is exported annually to the Sacramento River.

The combined storage of irrigation districts, utilities and private owners on streams tributary to the Central Valley is probably in excess of 10 MAF. Hence, they also affect flows reaching the Delta. In recent years, two irrigation districts built two such projects on tributaries to the San Joaquin River with a combined storage capacity of over 3 MAF.

In concept, storage projects operate to remove and store peak flows for later release to meet planned purposes during periods of low flow. Hence, it is not difficult to envision the potential capacity of storage projects to regulate the flow of water into the Delta during much of the year. Most large water supply projects are now designed to insure a supply of water over a series of dry or critically dry years. They are therefore, rarely subjected to maximum drawdown levels. As a result, only part of their total capacity is available for new storage on an annual basis. DWR (personal communication) estimated that about 25 to 30 percent of the total storage capacity in the Central Valley is replaced on an annual basis.

The consumptive use or export of water from the basin is of more concern than storage in terms of actual impact on environmental conditions, since these uses affect its availability or use in the Delta. About 85 to 90 percent of the consumptive use of water is for irrigation of agricultural lands.

Figure 2 represents an estimate of the outflow that would have occurred during the period 1922–1969 without the Central Valley Project or the State Water Project, but including all other use both in the Delta and upstream. It also shows a projection of flows in a normal year about 50 years from now with the CVP and SWP for comparative purposes. The actual flows at that time will, of course, depend upon needs identified between now and then and future legislative, regulatory and administrative decisions.

Inflow as used here and elsewhere in this report refers to the volume of water reaching the Delta via natural tributaries. Outflow is defined as the volume of water flowing out of the Delta via the main river and into the Bay system as measured at Chipps Island (see Figure 1).

SALINITY CONTROL

The "salt" content or salinity of estuarine waters is commonly measured in terms of chlorinity or total dissolved solids (or total solids). In estuaries where sea water and fresh water meet, "salinity" is a mixture of both ocean and land derived salt components. Chlorinity is the common measure of ocean derived salts while total dissolved solids (TDS) is the most common measure of salinity in inland or fresh water.

Chlorinity is a measure of salts having the chloride ion (Cl^-) as the negative radical and is normally expressed as the number of parts of chloride per thousand parts of water (ppt or ‰) or, less commonly, in parts per million (ppm). The chloride content of undiluted sea water is usually on the order of 19 parts per thousand.

The term total dissolved solids is a more inclusive measure of salinity. It represents the amount of matter

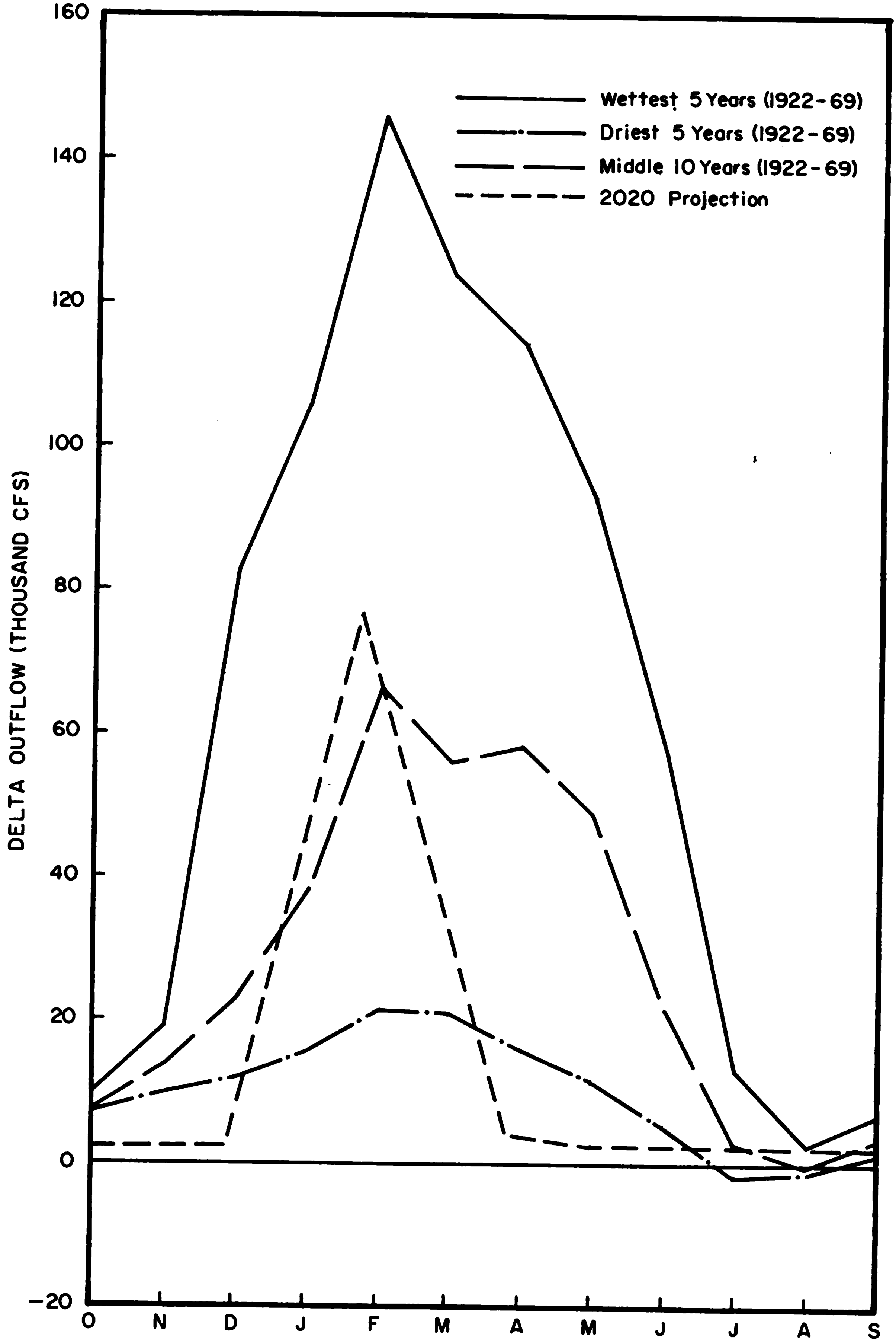

FIGURE 2—Comparison of synthesized outflows with projected outflows

held in solution and is defined as the number of parts of solid matter dissolved in one million parts of water (less commonly in parts per thousand). In addition to salts of chloride origin, it includes compounds having as their negative radicals, the nitrates, sulphates and bicarbonates. The principal freshwater components of salinity in the Delta are the bicarbonates of calcium and magnesium.

A TDS content of 35 parts per thousand is the approximate salinity equivalent of 18 parts per thousand of chlorides. Hence, a crude "rule of thumb" for equating the two, when discussing ocean salts, is to simply multiply chlorinity by two or divide TDS by two.

The estuary is the transition zone between the fresh water from inland sources and the salt water of the ocean. As one proceeds toward the ocean the water becomes more saline. The steepness or rapidity with which this transition occurs is referred to as the salinity gradient and can be measured in terms of the distance over which it takes place. Outflow affects it in two ways. Seasonally, the gradient shifts so that for any given salinity level the location is farther downstream with high outflow and farther upstream with low outflow. In addition, the gradient steepens directly with outflow. In other words, under low-flow conditions the transition occurs over many miles; while under high outflow conditions the transition may be very abrupt. For example, during the low flows of summer the gradient extends from San Francisco Bay into the Sacramento and San Joaquin Rivers as much as 70 miles upstream. Under the flood conditions that prevailed in 1955, the entire estuary as far downstream as San Pablo Bay was entirely fresh water creating a gradient on the order of 20 miles or less.

The primary reason outflow is of concern, is that it controls the intrusion of saline ocean water into the Delta (DWR Bulletin #28, 1931). As runoff from the Central Valley is diverted or used, less is available in the Delta to repel seawater. The consequences of this were quite alarming between 1919 and 1931 when the combination of dry years and upstream depletion resulted in the movement of saline water deep into the Delta. It was concluded (*loc. cit.*, p. 29) that, historically "saline water from the Bay has advanced as far upstream as the vicinity of Collinsville and Antioch causing a noticeable degree of salinity of ten parts or more of chlorine per 100,000 parts of water at some time every year during the period of low stream flow".

Since then, a great deal of additional upstream depletion and export has occurred to further reduce the total runoff reaching the Delta. As a result, salinity encroachment would have proceeded farther upstream and for longer periods each year, except for the operation of the CVP and more recently the SWP. In general terms, these projects have been operated to limit upstream intrusion to less than that which occurred historically. On the other hand they have allowed salinity encroachment for a longer period of time each year than occurred historically.

Since the completion of Shasta Dam in 1944, this has been accomplished by storing water during high-flow periods for release during summer low-flow periods. Maximum intrusion has been limited to about 1,000 ppm of chlorides at Jersey Point above Antioch on the San Joaquin River. Without project releases salinity would exceed that amount almost every summer. Figure 3 shows the maximum intrusion of 1,000 ppm of chlorides for the period 1920–1964. Mall (1969) and elsewhere in this report has projected seasonal salinity changes under 1990 conditions of development for the area between Benicia and Collinsville.

WATER TRANSFER

Aside from the diversion and storage of water, the system of transferring water across the Delta is a major factor affecting ecological conditions. Local residents have pumped or otherwise removed water from Delta waterways almost since the area was first settled. The environmental impact of any particular local diversion is limited, because these diversions are usually intermittent and most are too small to affect large areas of the Delta. However, since the total quantity of water diverted for use in the Delta amounts to about 1.3 MAF annually, (DWR, 1966) the cumulative effect could be substantial, particularly through the loss of small fish (Hallock and Van Woert, 1959).

The State Water Project and the Central Valley Project involve the transfer of immense volumes of water across the Delta. Large pumps near Tracy draw water through intake systems located on Old River. As water is pumped out of Old River it is replaced by natural flow or specific releases from storage. The net result is a steady movement of water towards the pumps (Figure 30). Ultimately, the state and federal pumping plants will have a combined capacity of over 15,000 cubic feet per second or 30 thousand acre-feet per day at peak operating capacity. At the present time the practical operating capacity is on the order of 11,000 cfs, but this is reached only during the peak of the summer irrigation demand or during mid-winter to fill San Luis Reservoir.

The hydrologic impact of this process is to create a general north to south movement of water across the Delta during much of the summer. In essence, the principal channels of the Delta, south of and including the San Joaquin River, often have a net flow during low runoff periods that is just the reverse of the natural direction, which is toward San Francisco Bay and the Pacific Ocean.

Although the Contra Costa Canal was the first delivery unit of the Central Valley Project, it was not until the Delta-Mendota Canal became operational in the early 1950s that the impact of cross-Delta water transfer became significant. The volume of water exported via the Delta-Mendota Canal ranged from

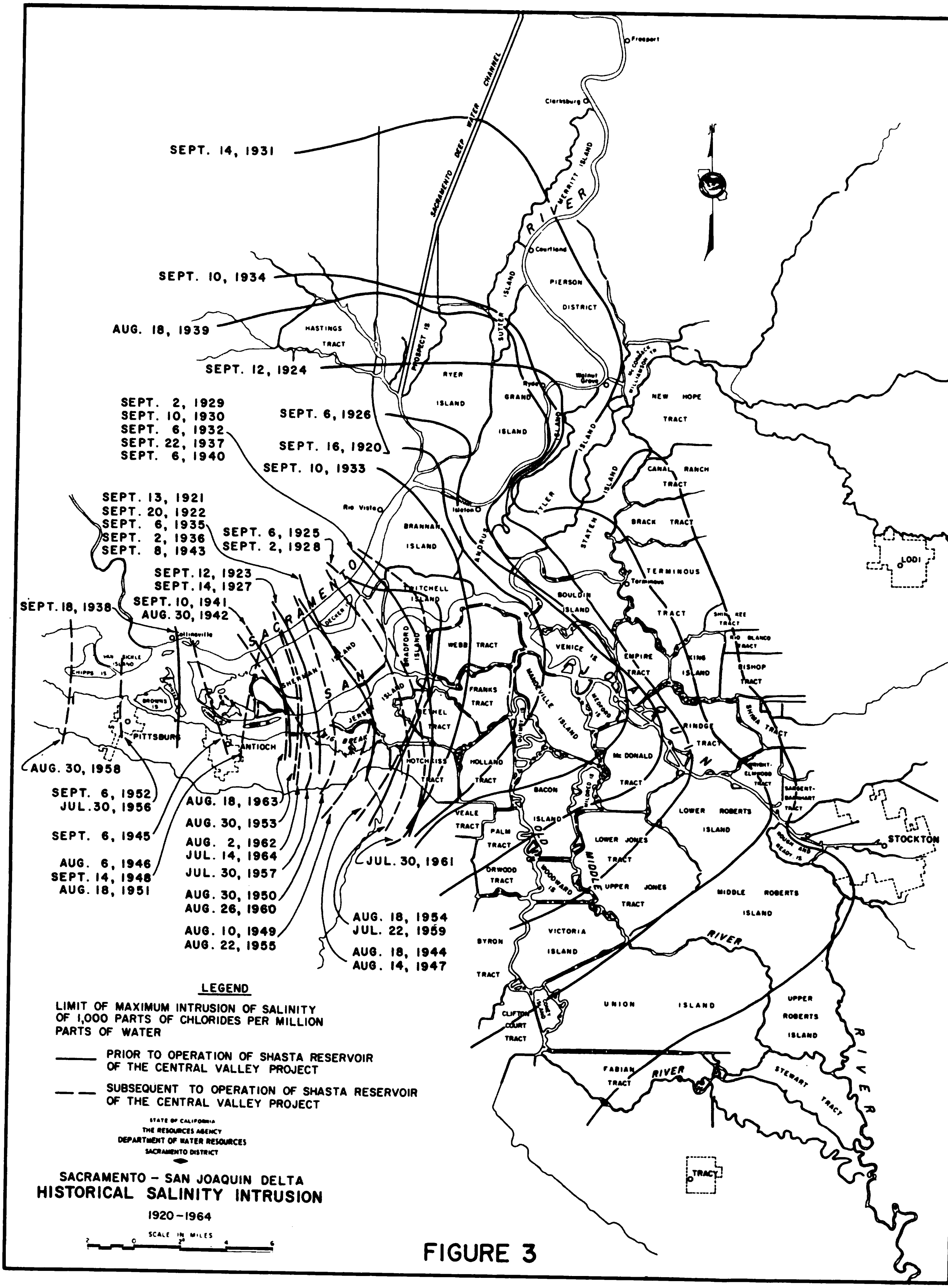

FIGURE 3—Historical salinity intrusion

about 0.5 to 1.5 MAF between 1957 and 1967 (USBR records). Usually, the highest quantities of water were pumped in the driest years. During this period of time also, water was pumped primarily during the agricultural season, usually from April into early fall.

In 1967 the San Luis Reservoir storage unit in the San Joaquin Valley and the state pumping plant near Byron went into operation. Since then it has been possible to pump more intensively and for more prolonged periods of time each year. As a matter of fact, much of the storage for San Luis Reservoir is pumped during the winter and spring in contrast to the pre-1967 operation.

Unless the system of transferring water across the Delta is changed, cross-Delta flows will increase in duration and magnitude as a result of increased exports. It has been predicted that exports will increase to 10.1 and 15.7 MAF by 1990 and 2020 respectively (Kaiser Engineers, 1969). Existing legislation, however, authorizes only 8.5 MAF for export (Table 2). The disposition of the water supply under 1970 and 1990 conditions is depicted by the Department of Water Resources in Figure 4.

IMPACT ON THE DELTA ENVIRONMENT

In terms of gross environmental impact, the present method of storing, regulating and pumping water across the Delta may be summarized as follows:

1. **Effect on Delta Flow.** Less water reaches the Delta each year due to upstream depletion (use) and long-term holdover storage capacity. Delta outflow is now only about half the natural level due to the combined effect of upstream depletion storage, and pumped exports.

2. **Effect on Seasonal Flow.** Although the hydrologic cycle is essentially similar to historic patterns in terms of seasonal variation, several very important differences are apparent. First and most obvious, the volume of water reaching the Delta is reduced during the heavy runoff season because of upstream storage.

Secondly, when the natural runoff does not exceed the regulatory capacity of storage and flood control works, the amount of water reaching the Delta is closely regulated to meet specified purposes. In brief, the tops are removed from peak winter flows, and the moderate spring flows are usually less than natural uncontrolled levels.

Finally, from mid-summer into the fall both Delta inflow and outflow usually exceed the amount that would have occurred without the CVP and SWP. This occurs as a result of specific releases by these projects to repel salinity and maintain water quality in the Delta and at the intake systems of the Delta-Mendota Canal and California Aqueduct. It is rare that outflow from the Delta would be negative or even less than 2,000 cfs under natural conditions. However, upstream depletion, exclusive of the CVP and SWP has, in fact, reduced summer inflow and outflow to the point where, more often than not, they are sustained primarily by releases from the CVP and SWP.

3. **Effect on Salinity.** Due to upstream storage and depletion, and consequently the reduced outflow, saline water intrusion occurs over a longer period each year. However, releases from storage are used to control the upstream limits of salt intrusion during the summer lowflow period. Otherwise, the Delta would be subject to more extensive incursions of saline water in most years with the degree of salinity being related to the amount of runoff.

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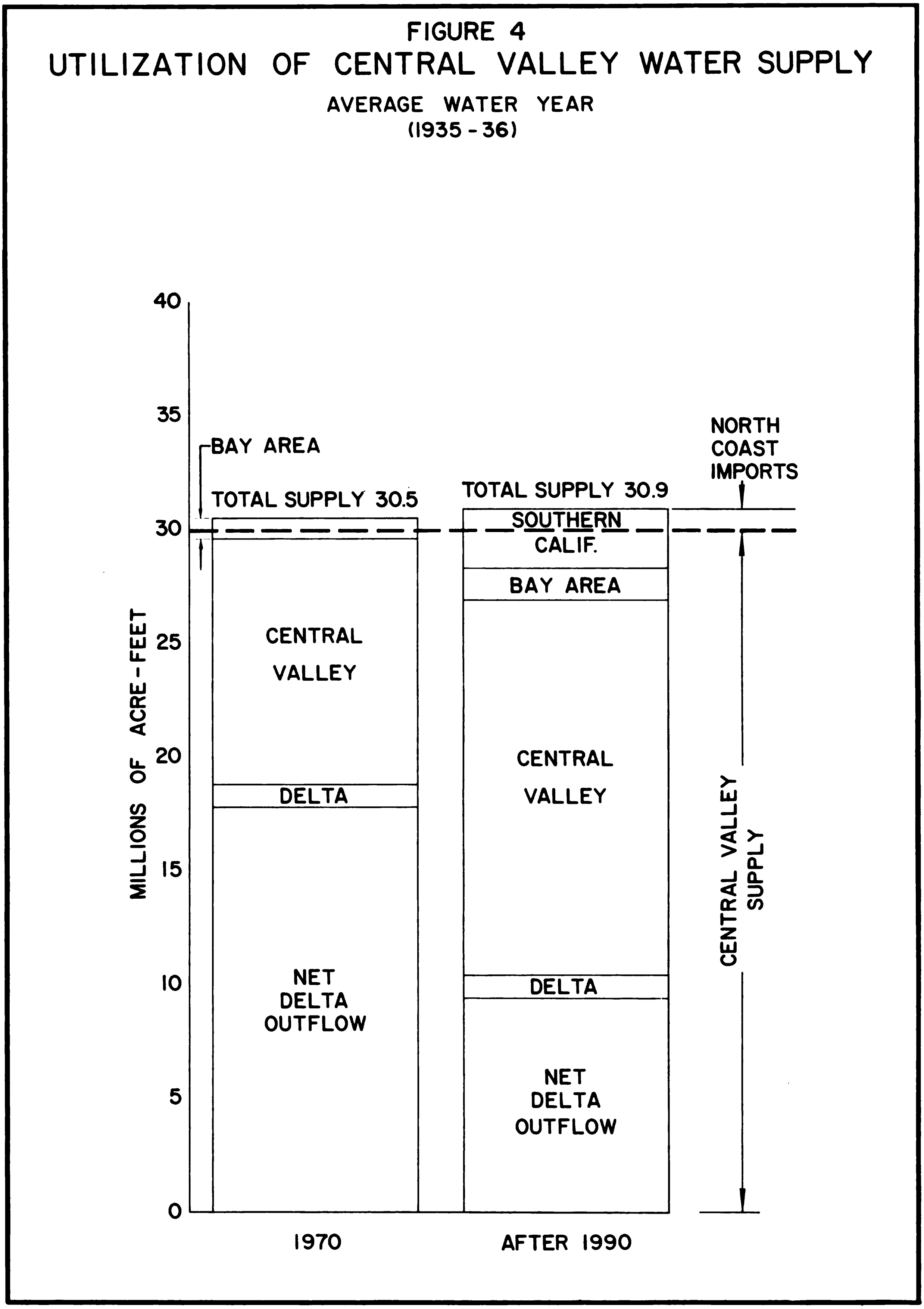

FIGURE 4—Utilization of Central Valley water supply

CHAPTER III

PHYTOPLANKTON AND THEIR ENVIRONMENTAL REQUIREMENTS

By HAROLD K. CHADWICK

INTRODUCTION

Phytoplankton are small plants which float in the water and drift with the currents. They are members of a group of plants called algae and are important in the estuary because they, along with other microscopic organisms and detritus, form the base of the food chain. For all practical purposes they are the only aquatic component of the food chain capable of converting inorganic chemicals into organic compounds which can be utilized as food by animal life from zooplankton to fish.

Phytoplankton are also important because of their role in the dissolved oxygen dynamics of the estuary. Like other green plants, they produce oxygen as a by-product of the food manufacturing process; but they also consume oxygen, just as animals do, during respiration. When phytoplankton populations are growing rapidly, they produce more oxygen than they consume. This happens in the spring over much of the estuary. A rather extreme example of this effect occurs in the San Joaquin River where it enters the Delta near Tracy. In 1966, dissolved oxygen concentrations there were always above saturation from April through September with peak daily mean concentrations approaching 200 percent of saturation.

Phytoplankton populations contribute to total oxygen demand in the water through both their endogenous respiration and their decay after death. Whenever these two processes exceed the photosynthetic production of oxygen, phytoplankton reduce dissolved oxygen concentrations. When large populations die rapidly, they can cause dissolved oxygen concentrations to fall to zero. No such drastic response due to phytoplankton, however, has been observed anywhere in this estuary. The death of phytoplankton though, undoubtedly, does contribute significantly to the dissolved oxygen deficit generally found throughout the estuary in the fall. This deficit is typically on the order of 10 to 30 percent below saturation.

In some situations, phytoplankton also cause significant esthetic problems. When dense populations die the decaying mass can be unsightly and produce unpleasant odors. This occasionally occurs in limited areas of the estuary.

ABUNDANCE AND DISTRIBUTION

Phytoplankton populations vary seasonally and geographically in a predictable pattern in the estuary (Storrs, et al, 1964; Bain and McCarty, 1965; Chadwick, et al, 1967). Populations are lowest during the winter and highest usually during the spring or early summer. In the eastern San Joaquin Delta there sometimes is a secondary peak in the fall.

Population abundance and the magnitude of seasonal changes vary greatly in different parts of the estuary. Phytoplankton are generally most abundant in the eastern San Joaquin Delta and least abundant in northern San Francisco Bay. Peak summer populations are often an order of magnitude higher in the eastern San Joaquin Delta than in the western Delta. Progressing farther downstream, summer peaks are somewhat greater in Suisun Bay than in the western Delta; then they are often an order of magnitude or more lower in San Pablo and San Francisco Bay.

Population trends cannot be compared precisely because of variations in the analytical procedures used in the various studies and because of appreciable annual variation in abundance. In 1966, peak phytoplankton populations (measured in terms of chlorophyl) at Mossdale on the San Joaquin River, in the western Delta, and in Suisun Bay were approximately 280, 40 and 60 milligrams per cubic meter, respectively.

The most abundant group of phytoplankton in the estuary is diatoms. These are distinguished from other forms by their shell-like cell walls which are composed largely of silica. They are always the predominant group during periods of peak abundance.

Green algae and flagellates are also important constituents of the phytoplankton in the estuary. During the winter and spring, these two groups often comprise 60 to 70 percent of the phytoplankton in the Delta and Suisun Bay (DF&G, unpublished data).

A fourth group, blue-green algae, generally contribute little to phytoplankton populations in the estuary. In 1966 and 1967 for example they usually constituted less than 5 percent at 10 stations scattered throughout the Delta and Suisun Bay. Blue-green algae may, however, comprise a higher percentage of the phytoplankton in backwater areas of the Delta which have seldom been sampled.

The relative scarcity of blue-green algae is important because blue-green algae are commonly responsible for most of the severe adverse conditions caused by high phytoplankton concentrations. Blue-green algae apparently are scarce in marine waters outside of the tropics (Raymont, 1963); Lackey, a leading phytoplankton specialist, reports never having observed nuisance blooms of blue-green algae in waters with chloride concentrations exceeding 500 mg/l (FWPCA, 1968). Hence, it is improbable that blue-green algae will ever become a problem in the western part of this estuary. Furthermore, it is improbable that they will become a problem in major channels of the freshwater portion of the estuary, because blue-green algae are usually most abundant in quiet water environments. The major channels have relatively high water velocities and turbulence due primarily to tidal action, which will remain unchanged in the future, unless barriers are constructed across the channels.

LIMITING FACTORS

The seasonal and geographical differences in abundance reflect variations in the several mechanisms which control phytoplankton growth. In a recent review, Raymont (1966) considered requirements for light, temperature salinity and nutrients as the factors controlling growth, with zooplankton grazing often affecting the standing crop. In addition, hydraulic conditions are probably an important mechanism influencing phytoplankton in this estuary. Generally speaking, if any one of these conditions is not favorable, it will limit growth, even though all other conditions are favorable.

The role of any particular limiting factor though cannot be looked upon as an all or nothing effect. For example, there is an optimum intensity of light which varies for different phytoplankton; as intensity increases or decreases from this optimum, growth rates decrease. Growth in a particular situation is often controlled by an interaction of factors, each being limiting to some degree, with the principal limitation varying from time to time.

Light

The general increase in phytoplankton abundance in the spring parallels the seasonal increase in light and temperature. Light, however, appears to be the primary limiting factor, as indicated by studies elsewhere (Raymont, 1963).

In addition to seasonal limitations arising from the variation of light intensity, light penetration is an important limiting factor, particularly in this estuary where turbidity is great. As a rule of thumb, phytoplankton will only grow at depths where light intensity exceeds about 1 percent of the surface light intensity (Talling, 1962). This is often defined as the euphotic zone.

In waters which are mixed to depths greater than the euphotic zone, phytoplankton are carried back and forth between the inadequately and adequately lighted zones. This limits growth when respiration (or use of food, which occurs in both zones, exceeds photosynthesis, which can occur only in the euphotic zone. In such situations, net increases in phytoplankton sometimes occur though as a result of recruitment from other areas. Population growth in the ocean sometimes occurs when the depth of the mixed layer is 5 to 8 times the euphotic zone depth (Sverdrup, 1953; Cushing, 1962). However, in the turbulent productive waters of Lake Erie, growth is sometimes limited when the mixed layer is only 2 to 3 times the euphotic zone (Verduin, 1954; McQuate, 1956).

The Sacramento-San Joaquin Estuary is generally well mixed vertically, and ratios of total depth to euphotic depth range from about 2 to 10 in Suisun Bay and the Delta. During 1966 maximum populations were generally small where the total depth was more than 5 times the euphotic depth but increased as the ratio approached 2 (Chadwick, et al, 1967). These observations indicate that light penetration is a major factor limiting phytoplankton in Suisun Bay and the Delta where depths are greater than 9 to 15 feet. The only locations in Suisun Bay and the Delta which have substantial amounts of water less than 9 feet deep are the San Joaquin River as it enters the Delta near Mossdale, some flooded islands, and Suisun and Honker Bays on the north side of the main channel.

Transparency measurements in San Pablo and San Francisco Bays (Storrs, et al, 1963; Storrs, et al, 1964) indicate that the euphotic zone in these bays is more variable; in San Francisco Bay particularly, it is deeper than in upstream areas. Annual mean euphotic depths at different places in San Pablo, south San Francisco, and north San Francisco Bays were about 3 to 7, 2 to 7, and 6 to 10 feet respectively. Considering the deeper light penetration and the extensive shallow areas in these lower Bay areas, light limitation is probably less important there than in the Delta and Suisun Bay.

Temperature

Raymont (1966) points out that temperature is unlikely to have an important net effect on primary productivity in the natural environment, because respiration rates increase with temperature thus, offsetting increases in photosynthesis. This logic seems reasonable for this estuary. The primary effect of temperature may be its influence on seasonal changes in species composition.

Salinity

Although salinity can influence the photosynthetic rate of individual photoplankton species, its influence on species composition is probably its primary effect (Raymont, 1966).

Nutrients

Nitrogen and phosphorus are usually considered to be the major plant nutrients. These two and in the case of diatoms, silica are among the elements most likely to be depleted by phytoplankton (Talling, 1962). In addition, at least 14 other elements are necessary for the growth of some plants (Goldman, 1966).

Nutrient limitations are difficult to identify for several reasons including variations in nutrient requirements among species and differences in the many chemical forms which individual nutrients may take. Perhaps the greatest difficulty, however, is the dynamic nature of nutrient relationships. Water movements and chemical exchange with the bottom continually augment and deplete nutrient supplies in the water. Phytoplankton may also store surplus nutrients for future use. As a result of these dynamic conditions, phytoplankton abundance typically has no relationships to the concentration of nutrients present at any given moment; hence, limitations can be identified only through adequate consideration of these dynamic relationships.

There is considerable evidence that the form of the relationship between growth rate and nutrient concentration is similar for all nutrients. In essence, growth rate increases as the concentration of a nutrient increases up to a point at which that specific nutrient is no longer limiting. Any further increase in nutrient concentration has no significant effect on growth rate. Results of experiments to measure nutrient limitation typically are expressed in terms of the nutrient concentration at which the growth rate is half of the saturation growth rate. This resultant concentration is referred to as the half-saturation constant.

Dissolved phosphorous concentrations of 0.01 milligrams per liter (mg/l) have led to phytoplankton blooms (Sawyer, 1947); this appears to be about the half-saturation constant for phosphorous, (DiToro, et al, 1970). Recent measurements throughout this estuary (Storrs, et al, 1964; Bain and McCarty, 1965; Chadwick, et al, 1967) have shown that phosphorous concentrations rarely get as low as 0.01 mg/l and are usually at least an order of magnitude higher than this, even when phytoplankton populations are highest. This has led to the conclusion that phosphorous has not limited phytoplankton growth in this estuary (Chadwick, et al, 1967; FWPCA, 1968).

Silica concentrations in the western part of the estuary typically fall to low levels (0.5 to 2.0 mg/l) coincident with peak phytoplankton growth in the summer (FWPCA, 1968; U. S. Bureau of Reclamation, unpublished data). These levels probably approach the limiting concentration of silica which Fogg (1965) considered to be 0.5 mg/l. The seasonal cycle in diatom abundance now, however, gives no indication that the observed changes in silica concentrations are causing populations to shift to other groups of phytoplankton. The decrease in concentrations is due to the combined effects of phytoplankton uptake of silica and the intrusion of silica-deficient marine water from the Pacific Ocean. The relative contribution of these two causes has not been assessed.

Since silica is essential only to diatoms, a deficit would probably result in a change in the species composition of the phytoplankton population rather than in a limitation of the total population size.

Nitrogen, the other major nutrient, is probably the most important limiting nutrient in the estuary. While the precise nitrogen requirements of phytoplankton are not known (Raymont, 1966), DiToro, et al, (1970) concluded from the literature that the half-saturation constant was about 0.025 mg/l for inorganic nitrogen. The determination of nitrogen limitations are complicated by the ability of phytoplankton to use various types of inorganic nitrogen and dissolved organic compounds (Yentsch, 1962).

Nitrate nitrogen concentrations declined to unmeasureable levels (less than 0.05 mg/l) during much of the summer of 1966 in the San Joaquin River at Mossdale and in the western Delta-Suisun Bay area (Chadwick, et al, 1967). At the same time, ammonia nitrogen was usually about 0.1 mg/l in the San Joaquin River and usually less than this (sometimes less than 0.05 mg/l) in the western Delta-Suisun Bay area. Nitrogen depletions were also noted in the western Delta-Suisun Bay area during the summers of 1961 through 1964 (Storrs, et al., 1964; Bain and McCarty, 1965).

Laboratory experiments with cultures of phytoplankton from the western Delta-Suisun Bay area have demonstrated consistently that nitrogen is a limiting nutrient (FWPCA, 1968; Brown, et al, 1969; Calif. Dept. of Fish and Game, unpublished data; U. S. Bureau of Reclamation, unpublished data). Thus, both field and laboratory data indicate that nitrogen is a limiting nutrient for phytoplankton in the San Joaquin River at Mossdale and in the western Delta-Suisun Bay area for at least part of the year.

A different situation prevails in the rest of the estuary. In the central Delta, brief nitrate nitrogen depletion occurred during the spring and fall of 1966 coincident with maximum phytoplankton populations. However, phytoplankton populations were low throughout the summer despite nitrate nitrogen concentrations of 0.2 to 0.4 mg/l or higher.

In San Pablo and San Francisco Bays low nitrate nitrogen concentrations have occurred irregularly (Harris, et al, 1961; Storrs, et al, 1964; Bain and McCarty, 1965). Nevertheless, they usually were above 0.2 mg/l, and there was no indication that trends in phytoplankton populations were related to the fluctuations in nitrogen concentrations.

It is interesting to note that Riley (1967) concluded that nitrogen depletion is the primary mechanism terminating the spring phytoplankton bloom in Atlantic Coast estuaries. He believes the low N to P (nitrogen to phosphorous) ratios commonly found in those estuaries are symptomatic of a high probability of nitrogen depletion. N to P ratios in the San Francisco Bay estuary also are low. The low N to P ratios are commonly believed to reflect the relatively slow regeneration of nitrogen during bacterial decomposition of phytoplankton.

There is little evidence regarding the concentrations of minor inorganic nutrients either in the estuary or required by phytoplankton (Talling, 1962; Goldman, 1966). The requirements for phytoplankton are almost certainly very small. Considering the variety of sources of natural runoff and municipal and industrial waste, it seems improbable that minor nutrients limit phytoplankton growth in the estuary.

On the contrary, the toxic effects of some minor nutrients may be more important than an absence of those nutrients in limiting phytoplankton growth. This is suggested by recent experiments indicating that copper and mercury concentrations on the order of 0.01 mg/l reduced growth rates of phytoplankton cultures from San Francisco Bay (Krock and Mason, 1971).

Hydraulic Conditions

The hydraulic characteristics of an estuary affect phytoplankton populations indirectly by determining salinity, affecting nutrient input, and influencing turbidity (Riley, 1967). Thus, hydraulic conditions play a role in the limitations discussed above. In addition, hydraulic conditions have a direct effect by controlling residence time which determines the rate at which phytoplankton are dispersed. A dramatic illustration of this effect probably occurred in 1966 and 1967 in the eastern part of the estuary. In 1967, a high runoff year, phytoplankton populations reached their peak about 4 months later and were only about half as large as in 1966 when flows were relatively low (Dept. of Fish and Game, unpublished data). Phytoplankton populations in the western estuary on the other hand varied little between 1966 and 1967. This reflects the fact that the impact of freshwater flow is much more significant in the eastern estuary than in the western estuary where tidal flow predominates.

Zooplankton Grazing

In the Delta and Suisun Bay, zooplankton populations sometimes parallel phytoplankton populations, indicating that zooplankton probably influence phytoplankton standing crops (Figure 5). However, in many cases fluctuations in zooplankton and phytoplankton populations are not closely related, so zooplankton is probably not the primary factor limiting phytoplankton in the Delta and Suisun Bay.

In the bays downstream there appears to be an even poorer relationship between phytoplankton and zooplankton, because population changes often do not parallel each other. Actually, zooplankton peaks often precede phytoplankton peaks (Storrs, et al, 1963 and 1964). However, this may not be a true indication of the importance of zooplankton grazing in the Bay area. Storrs' data indicate that the ratio of the zooplankton population size to the phytoplankton population size is considerably greater in San Pablo and San Francisco Bays than in Suisun Bay. This suggests that zooplankton grazing plays a more important role in influencing phytoplankton crops in the Bay area particularly since phytoplankton standing crops there are considerably lower than in upstream areas despite apparently more favorable light and nutrient conditions.

FUTURE CHANGES IN PHYTOPLANKTON POPULATIONS

The above discussion of factors limiting phytoplankton growth may be summarized by saying that the primary limiting factors in the Delta and Suisun Bay are the availability of nitrogen and light. At times hydraulic conditions are important and zooplankton grazing undoubtedly has an important influence on phytoplankton standing crops. In San Francisco and San Pablo Bays it is not at all clear what the primary limiting factors are.

Qualitatively, increased nitrogen input from municipal, industrial, and agricultural wasteloads and perhaps increased light penetration as a result of decreased sediment transport into the estuary (Krone, 1966; David Kennedy, Delta Water Rights Hearing Testimony) will cause phytoplankton populations to increase. In some portions of the estuary, reduced flows may promote greater phytoplankton growth by reducing the downstream transport rates. Throughout

Laboratory Technician Identifying and Counting a Sample

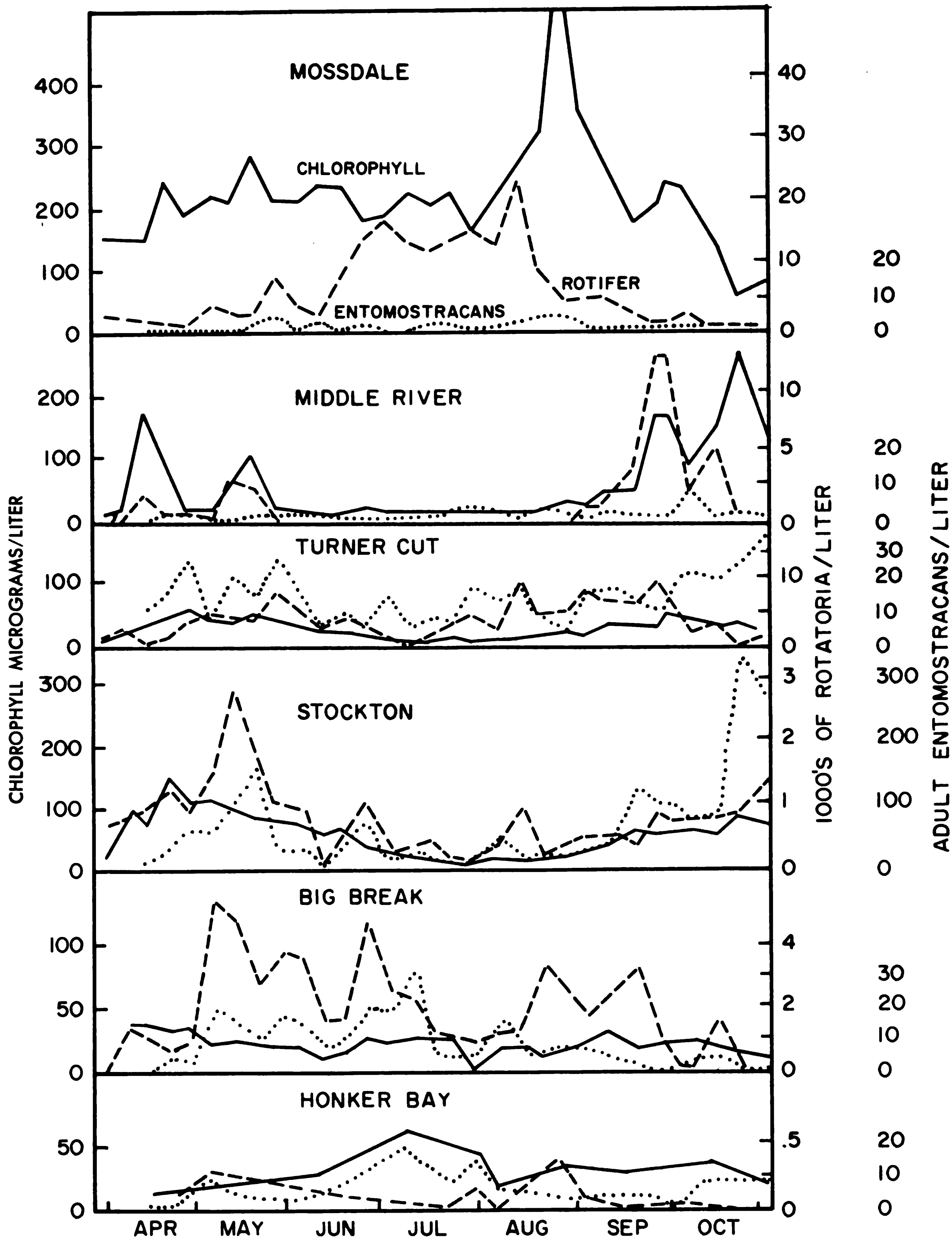

FIGURE 5—Relationship of populations of two major groups of zooplankton to the phytoplankton population at selected points in the Delta between April and October 1966

most of the estuary though, tidal currents are more important than the net flows resulting from freshwater inflow. Since tidal currents will not change significantly in the future, little change can be expected from changes in flow alone. However, since the supply of silica, which approaches limiting levels now, depends on freshwater inflow, this substance may become a significant limiting factor to diatoms.

While it is possible to make these qualitative judgments, the primary need is for a quantitative assessment of such changes. Quantitative assessment, however, is very difficult because of the number of interacting parameters and the fact that many of the relationships are nonlinear. It appears that the best hope of success in assessing change lies in a dynamic mechanistic model. Such a model has been developed for the eastern Delta and Suisun Bay (DiToro, et al, 1970) and has been used to make a preliminary assessment of future changes in that region (O'Connor, Delta Water Rights Hearing Testimony).

A major question regarding future management policies concerns the desirable concentration of phytoplankton. There is no good answer to this question. The large phytoplankton populations (chlorophyll concentrations of 200 to 280 mg/m³) in the San Joaquin River at the edge of the Delta in the summer of 1966 caused daily oxygen fluctuations on the order of 7 to 9 mg/l. Such fluctuations may be detrimental to the growth and survival of fish (Doudoroff and Shumway, 1970). In addition, these large phytoplankton concentrations undoubtedly contributed to dissolved oxygen deficits as they drifted downstream into the deeper channels of the Delta. On the other hand, chlorophyll concentrations on the order of 50 to 60 mg/m³ in Suisun Bay during the summer of 1966 were associated with daily dissolved oxygen fluctuations of less than 2 mg/l, and dissolved oxygen contrations remained close to saturation throughout the area. This suggests that acceptable limits of phytoplankton populations fall between 50 and 200 mg/m³. This needs to be examined through model studies of the relationship between phytoplankton populations and other factors controling dissolved oxygen. Appropriate models are currently being developed to do this.

One factor commonly overlooked in management decisions is that photoplankton are of vital importance to fish, as they are a major part of the base for the aquatic food chain. Thus, management decisions should be directed toward maintaining optimum growth levels for phytoplankton rather than simply toward arbitrarily limiting growth.

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CHAPTER IV

INVERTEBRATE ANIMALS AND THEIR ENVIRONMENTAL REQUIREMENTS

ZOOPLANKTON

By HAROLD K. CHADWICK

Zooplankton are small animals which live in the water. They essentially drift with the currents, although they have some capability to influence their distribution through their own powers of locomotion.

They are a highly diverse group. Two groups of crustacean zooplankters, the copepods and cladocerans, are of most direct importance to fish and often the term zooplankton just refers to them. Two groups of smaller animals, the protozoans and the rotifers, are also important in the San Francisco Bay-Delta estuary. These four groups are considered in the following discussion.

A larger crustacean, *Neomysis awatschensis*, is an extremely important zooplankter, but because of its unique role, it will be considered separately in the next section of this chapter. Other invertebrates are important zooplankters at times, particularly in the more saline portions of the estuary (see Painter, 1966 and Storrs, Pearson, and Selleck, 1966 for examples), but they will not be considered here. Many of the latter are the young forms of species which are not planktonic as adults.

In recent years several zooplankton surveys have been made in the estuary. A University of California study concentrated on San Francisco, San Pablo and Suisun Bays between 1960 and 1964 (Storrs, Pearson and Selleck, 1966). Department of Fish and Game surveys included San Pablo and Suisun Bays in 1963 (Painter, 1966); the Delta in 1963 (Turner, 1966a); the Delta and Suisun Bay in 1966 and 1967 (unpublished manuscript); and the Delta and Suisun Bay intermittently since then.

Although each of these surveys enumerated crustacean plankters, comparisons are difficult because of differences in sampling, analysis and degree of identification.

Protozoans

Protozoans are single celled animals, of which there are many diverse groups. The ciliates have been the principal group enumerated in this estuary and, of these, only the larger ones having shells have been considered. They generally are smaller than the other zooplankters discussed here, but they are also more numerous.

In the Delta and Suisun Bay in 1966, ciliate protozoans were most abundant in the San Joaquin Delta, least abundant in the Sacramento River and intermediate in Suisun Bay. At various locations in the San Joaquin Delta the maximum monthly population means ranged from about 14,000 to 40,000 animals per liter. In Suisun Bay, peak populations were on the order of 10,000 while in the Sacramento River at Rio Vista they never exceeded 6,000 and usually were on the order of 2,000 per liter or less.

At all locations, abundance varied widely and no general seasonal trend was evident.

The University of California study found ciliate abundance to be erratic in the Bay area also. Populations generally were higher in Suisun Bay than farther downstream with maximum densities of over 100,000 per liter. This is about 10 times the peak numbers counted there in 1966–67, which suggests that procedures were different in those two surveys.

The general abundance of ciliates in different parts of the system generally parallels primary productivity as evidenced by maximum standing crops of phytoplankton, suggesting a general relationship. Within each geographic area though, seasonal trends of phytoplankton and ciliates were not related.

Ciliates probably eat smaller protozoa, phytoplankton and bacteria and are in turn eaten by larger zooplankters.

Rotifers

Rotifers are usually somewhat larger than ciliates. Only the females are normally counted, since males are degenerate, small and short lived.

In the Delta and Suisun Bay in 1966, rotifers were much more numerous in the San Joaquin River near Mossdale than at any other location. Mean populations there peaked at about 14,000 per liter. Populations in the rest of the San Joaquin Delta and in the Sacramento River at Rio Vista were less than 10,000 per liter. Populations in Suisun Bay were low, with monthly means not exceeding 300 per liter.

The University of California study found that rotifers occurred erratically, and when present, were few in number throughout the Bay area. Few rotifer species occur in salt water (Pennak, 1953), so salinity evidently is a major factor in limiting their presence in downstream areas of the estuary. In freshwater portions of the estuary rotifer populations tended to parallel phytoplankton abundance, suggesting a dependence on phytoplankton for food.

At the freshwater stations, rotifer populations were highest at the shallowest stations. About half or more of those identified were forms generally expected to live on the bottom or in shoreline areas, suggesting that water depth has an important bearing on population size.

Most rotifers are omniverous, eating organic detritus, bacteria, protozoans and small algae. Some predaceous forms feed on smaller rotifers and crustaceans.

Crustacean Plankters

Crustacean plankters include copepods and cladocerans and vary greatly in size. The mean size of adult forms found in this estuary range from about 0.8 to 1.5 millimeters. Individual species of cladocerans and copepods may be either omnivores, strict herbivores, or carnivores. As a group their diet consists of phytoplankton, smaller zooplankton and organic detritus. Some are filter feeders, while others seize their prey or particles with specialized mouth parts.

Distribution and Abundance. Cladocerans and copepods are roughly equal in abundance throughout the freshwater part of the Delta. In saline water, cladocerans become much scarcer than copepods. Surveys have not shown the salinity tolerance of cladocerans precisely, but Painter (1966), sampling water more saline than 1,000 mg/l of chlorides, failed to find cladocerans in significant numbers.

Copepods occur in two well defined peaks of abundance along the longitudinal axis of the estuary from Suisun Bay through the Delta (California Department of Fish and Game, unpublished data). One peak occurs in Suisun Bay where fresh and salt water initially mix. The major concentrations there were located near Chipps Island in 1970 and near Port Chicago in 1971. The second peak of abundance occurred in the San Joaquin River below Stockton during both years.

The University of California study found that adult copepod populations were substantially higher in San Francisco and San Pablo Bays than in Suisun Bay (Storrs, Pearson and Selleck, 1966). Median annual concentrations ranged from 20 to 25 animals per liter in these bays, while the median was only 3.4 per liter in Suisun Bay. On the other hand, Painter (1966) found the peak concentration to vary between Suisun and San Pablo Bays but, most often the peak was located in Suisun Bay. The maximum concentrations he found in the surface waters of San Pablo Bay were only about half the median concentrations found there during the study by the University of California.

The distribution of individual species of copepods is correlated closely with salinity. In general there are groups of fresh, brackish and marine copepods (Painter, 1966).

There is a general seasonal trend in abundance (Figure 6) with individual species having distinct trends (Figure 7). Typical trends of total abundance are either a summer peak or a bimodal distribution with peaks in the spring and fall.

Factors Controlling Abundance. As was pointed out in the last chapter, zooplankton populations are probably not a primary factor limiting phytoplankton, although populations of the two tend to peak about the same time in some areas. Hence, zooplankton population size apparently is not generally related directly to phytoplankton abundance. One possible reason for this is that organic detritus is often an important food of zooplankton.

Within the freshwater portion of the estuary, the abundance of crustacean zooplankton is correlated with the rate of residence time which is a function of net water velocity (Figure 8) and the electrical conductivity of the water (Turner, 1966a). The electrical conductivity probably reflects basic productivity. In the more saline waters of the San Joaquin River, populations were generally about twice those under the same hydraulic conditions in the Sacramento and Mokelumne Rivers. Net velocities less than 0.1 fps were most conducive to the growth of zooplankton populations. However, significant increases sometimes occurred at net velocities between 0.1 and 0.3 fps.

NEOMYSIS

By WILLIAM HEUBACH

Introduction

The opossum shrimp, *Neomysis awatschensis*, is an abundant and relatively large zooplankter in the estuary, occasionally attaining concentrations in excess of 10,000 per cubic meter. Individual mysids reach a size of 18 millimeters (¾-inches). Their size, large concentration, and simultaneous occurence with young fish, particularly striped bass, make them an important food item in our estuary. Any substantial change in the *Neomysis* population due to an altered environment would probably affect several species of fishes. For this reason *Neomysis* have been an important element in our studies of the estuary.

From March 1963 to February 1964, mysids were collected monthly as part of the zooplankton study. This study was initiated to determine distribution and abundance. A more intensive survey followed from March 1965 to September 1966 to define more critically the factors affecting *Neomysis*. Since June 1968, mysids have been collected monthly to assess their distribution and abundance each year as food for young-of-the-year striped bass and to determine the environmental factors affecting their abundance and distribution.

Geographical and Seasonal Abundance

Mysids are most abundant from June through August with highest concentrations occurring from Suisun Bay to Rio Vista on the Sacramento River and Antioch on the San Joaquin River (Figure 9). Generally, peak densities occur in July or August, but in 1966 densities were highest in June (Heubach). The population peak is followed by a sharp decline in late summer and fall. The density of mysids is lowest between December and February, at which time it is less than one-tenth of the summer density. Concentrations are more uniform among areas during winter than the rest of the year.

Factors Influencing Abundance

Water Temperature. The spring increase in mysids coincides with increasing water temparture. The greatest increase in the population occurs in the spring and

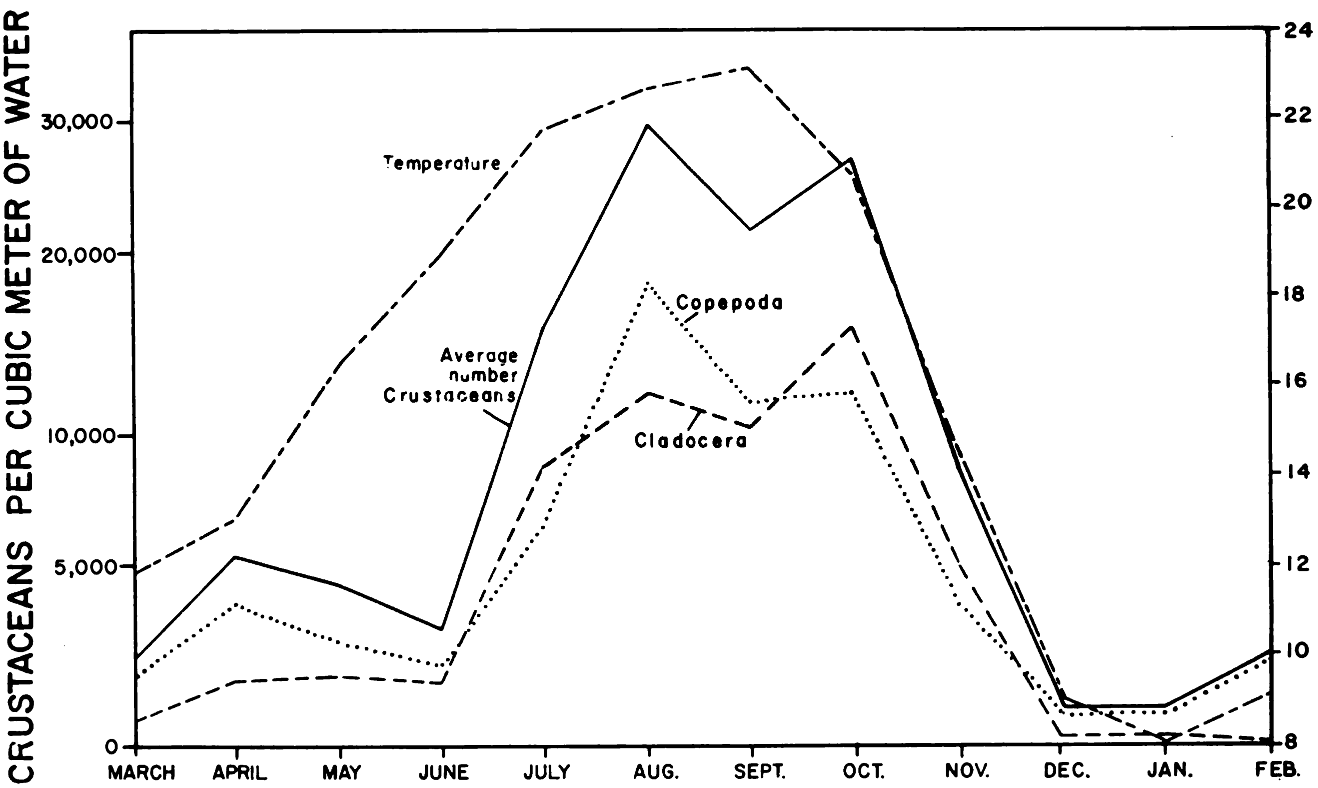

FIGURE 6—Comparison of the average concentration of crustacean plankters with the average temperature for all sampling stations in the Sacramento-San Joaquin Estuary from March 1963 to February 1964.

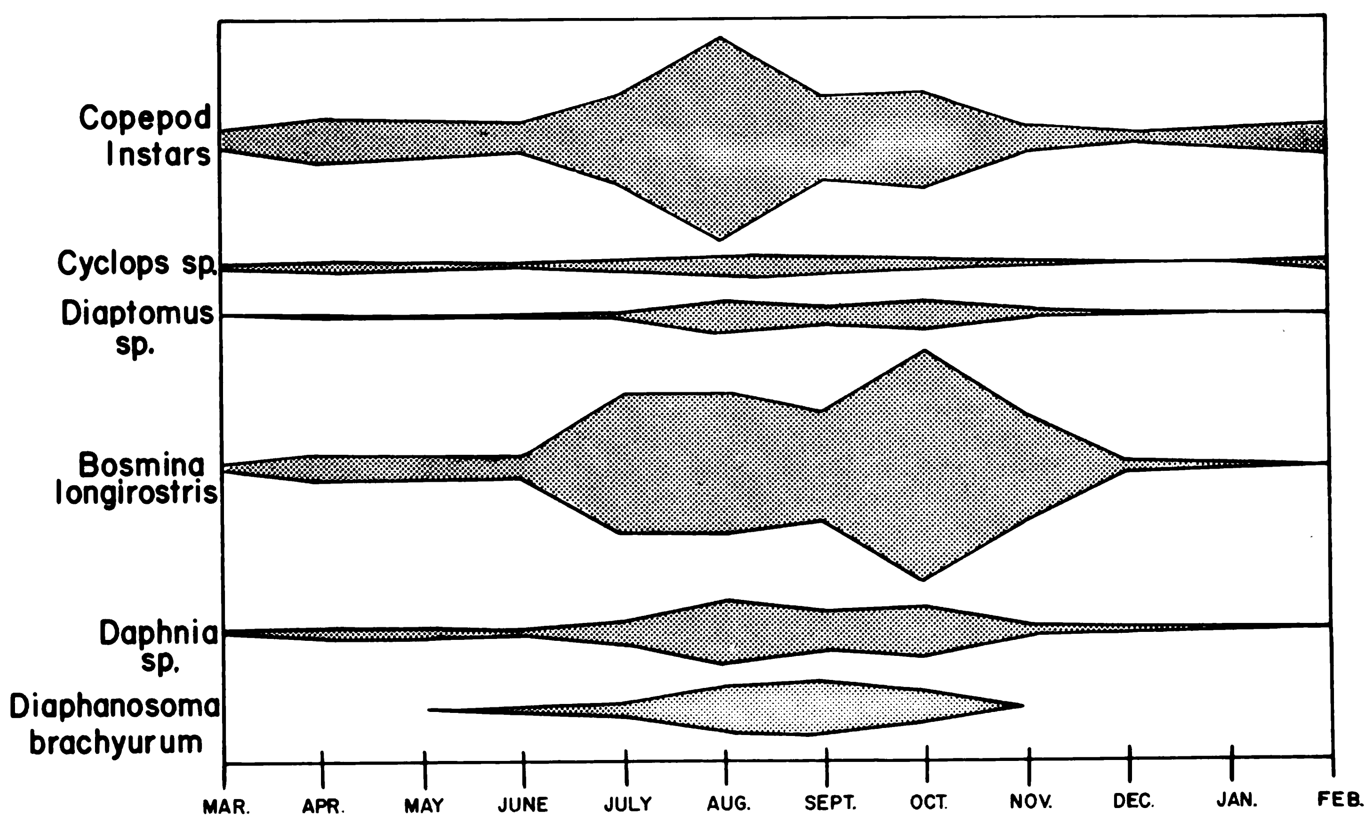

FIGURE 7—The numbers of major crustacean plankters caught each month from March 1963 to February 1964 in the Sacramento-San Joaquin Delta. The width of each line at each sampling period is proportional to the numbers of that species caught.

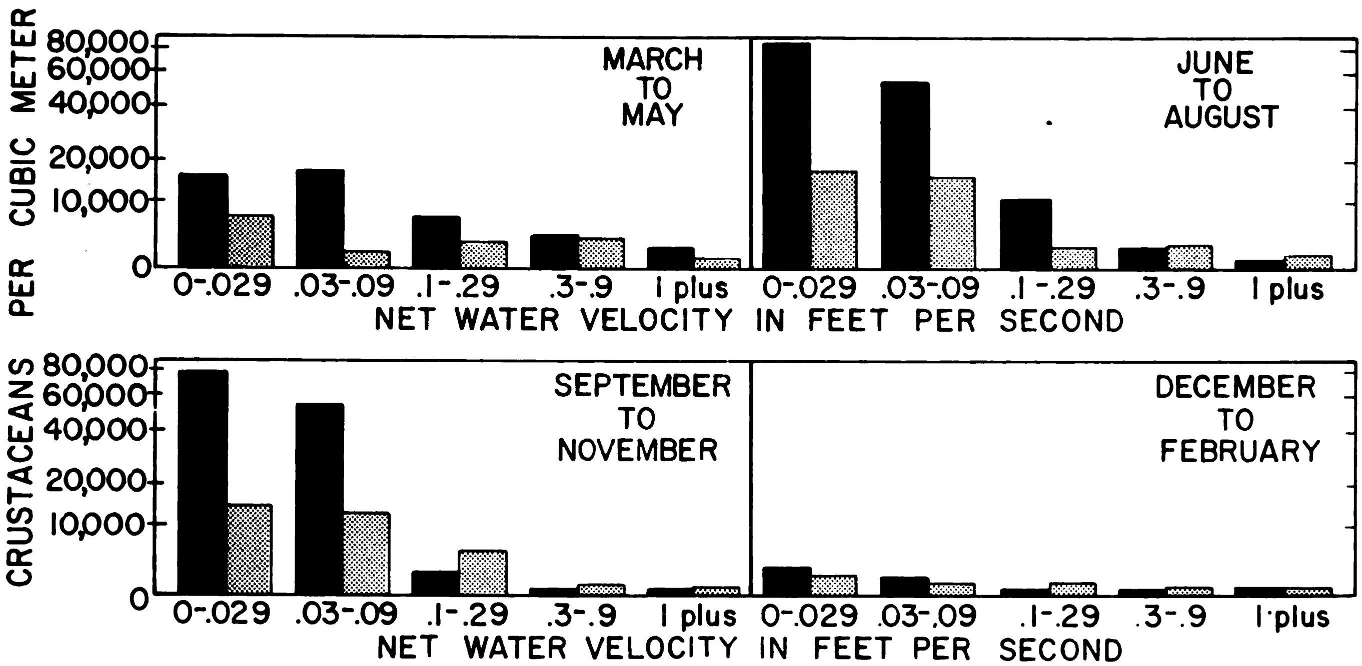

FIGURE 8—Average numbers of crustacean plankters each season in various rivers in the Sacramento-San Joaquin Estuary at different net water velocities. Solid columns indicate plankters collected in the San Joaquin River and the stippled columns the plankters collected in the Sacramento-Mokelumne Rivers. TDS content in the Sacramento River ranged from 50 to 150 ppm, while those in the San Joaquin River ranged from 150 to 700 ppm (Turner, 1966a).

early summer when water temperature ranges from 60°F to 70°F. Maximum densities generally occur when the water temperature is approximately 68°F to 72°F.

Field and laboratory observations suggest that water temperatures greater than 72°F to 74°F are inimical to *Neomysis*, which could explain the decline in the population in the summer and fall. Laboratory experiments with mysids collected locally suggest that the ultimate upper lethal temperature is between 75.6°F and 77.8°F (Hair, 1971). The ultimate upper lethal temperature is defined as the temperature at which 50 percent of the test animals die in a 48-hour exposure period. However, the survival of control animals held at 71.6°F was 85 percent compared to 55 per cent for those held at 72.5°F. It appears therefore, that water temperatures greater than 72°F may actually kill *Neomysis*. Temperature tolerance studies of *Neomysis* in other areas have shown similar results (Wilson, 1951; Mihursky and Kennedy, 1967). The Sacramento-San Joaquin Estuary is at the southern limit of the *Neomysis* range (Banner, 1954) probably making temperature a more critical environmental consideration.

Salinity. Salinities were measured and are reported here as parts per thousand chlorinity. Undiluted sea water is approximately 19 parts chloride per thousand parts of water.

In spring, mysid densities are similar over a wide chlorinity range, while in summer densities are greatest at salinities between 0.5 and 4.0 ppt (parts per thousand). Densities decrease rapidly at chlorinities greater than 4.0 ppt and mysids are scarce in chlorinities greater than 10 ppt. At equal distances on either side of the low chlorinity zone (0.5-4.0 ppt), mysids are generally more abundant in fresh water (Figure 10). During fall and winter, densities are highest near fresh water and decrease rapidly at higher chlorinities.

In the summer, mysid densities reflect salinity incursion. The population center occurs farther upstream during dry years when salinity incursion is greatest and farther downstream in wet years when salinity incursion is less (Figure 9). This indicates that the location of the mysid population is probably determined principally by salinity.

Dissolved Oxygen. High water temperatures in combination with low dissolved oxygen concentrations appear unfavorable to *Neomysis*. Mysid densities are relatively high in the San Joaquin River near Stockton from late fall to spring when water temperatures are less than 72°F and dissolved oxygen concentrations are greater than 5.0 mg/l. In late summer and fall, however, mysid densities decrease as temperatures exceed 72°F and dissolved oxygen levels fall below 8.0 mg/l. At dissolved oxygen levels of 3.0 mg/l mysids are essentially absent. In areas of the Estuary which were comparable except for having dissolved oxygen concentrations near saturation (approximately 8.0 mg/l), mysids were much more numerous.

Effects of Light and Tide. During the day, mysids generally are near the bottom with very few in the upper 10 feet of water. In areas where the channel depth is less than 10 feet, mysids usually are absent.

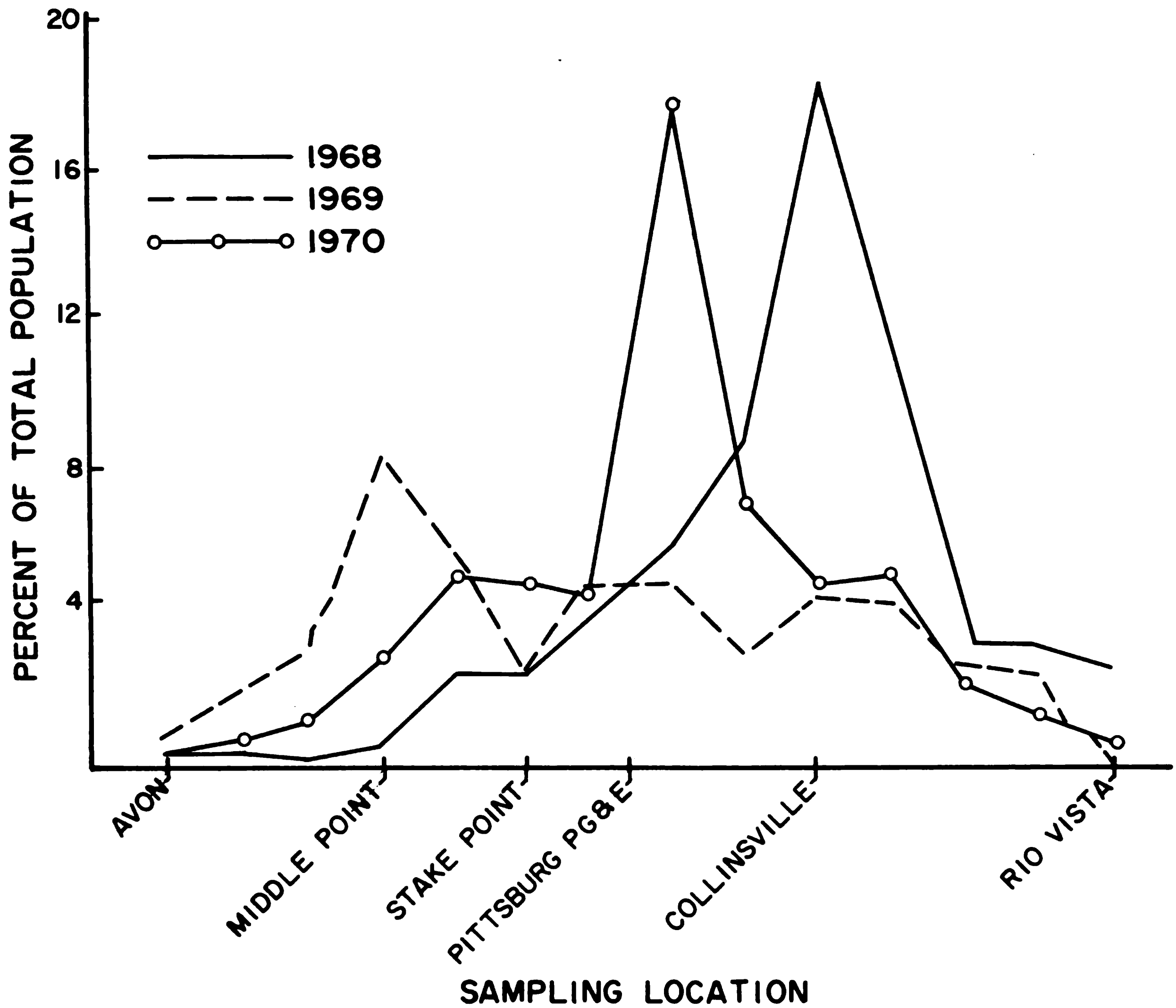

FIGURE 9—Abundance of *Neomysis* at high tide in the Sacramento River from Suisun Bay to Rio Vista during June to September of three years. Flows were greatest in 1969 and least in 1968.

At night they are more randomly distributed through the water column and also are found near shore and in the shallower channels. Mysids are nearer the bottom on ebb tide than flood tide and farther off the bottom during slack water. These findings suggest that their vertical distribution (depth) is influenced by light intensity, tide, and water velocity.

High net water velocities and high light penetration apparently are the principle factors limiting the upstream range of *Neomysis*. If the flood tide is inadequate to reverse the normal downstream current, mysids apparently are unable to move upstream. Mysids are most abundant where net velocities are less than 0.3 fps and absent where net velocities exceed 0.4 fps. *Neomysis* will not move upstream into areas where light penetrates to the bottom irrespective of upstream tidal flow.

Water velocities and tidal action also influence mysid distribution throughout their range. In summer, densities are generally higher in the Sacramento River than the San Joaquin River at comparable distances from their confluence. In winter, the opposite is true. This appears logical considering our knowledge of *Neomysis* and the hydraulics of the two rivers. Mysids have a limited capacity to swim and their upstream distribution therefore, depends largely on tidal action, especially flood tides which carry them upstream. In winter, downstream flows (and velocities) in the Sacramento River are much higher than at comparable locations on the San Joaquin River as measured upstream from the confluence of the two rivers. Hence, flood tides are less effective in carrying *Neomysis* upstream in the Sacramento River than in the San Joaquin River.

Flood flows sweep most mysids downstream into San Pablo Bay. Those found in the upper estuary during high flow periods are in the more protected areas such as Montezuma Slough.

Reproduction.. Both the percentage of females containing eggs and fecundity (mean number of eggs per

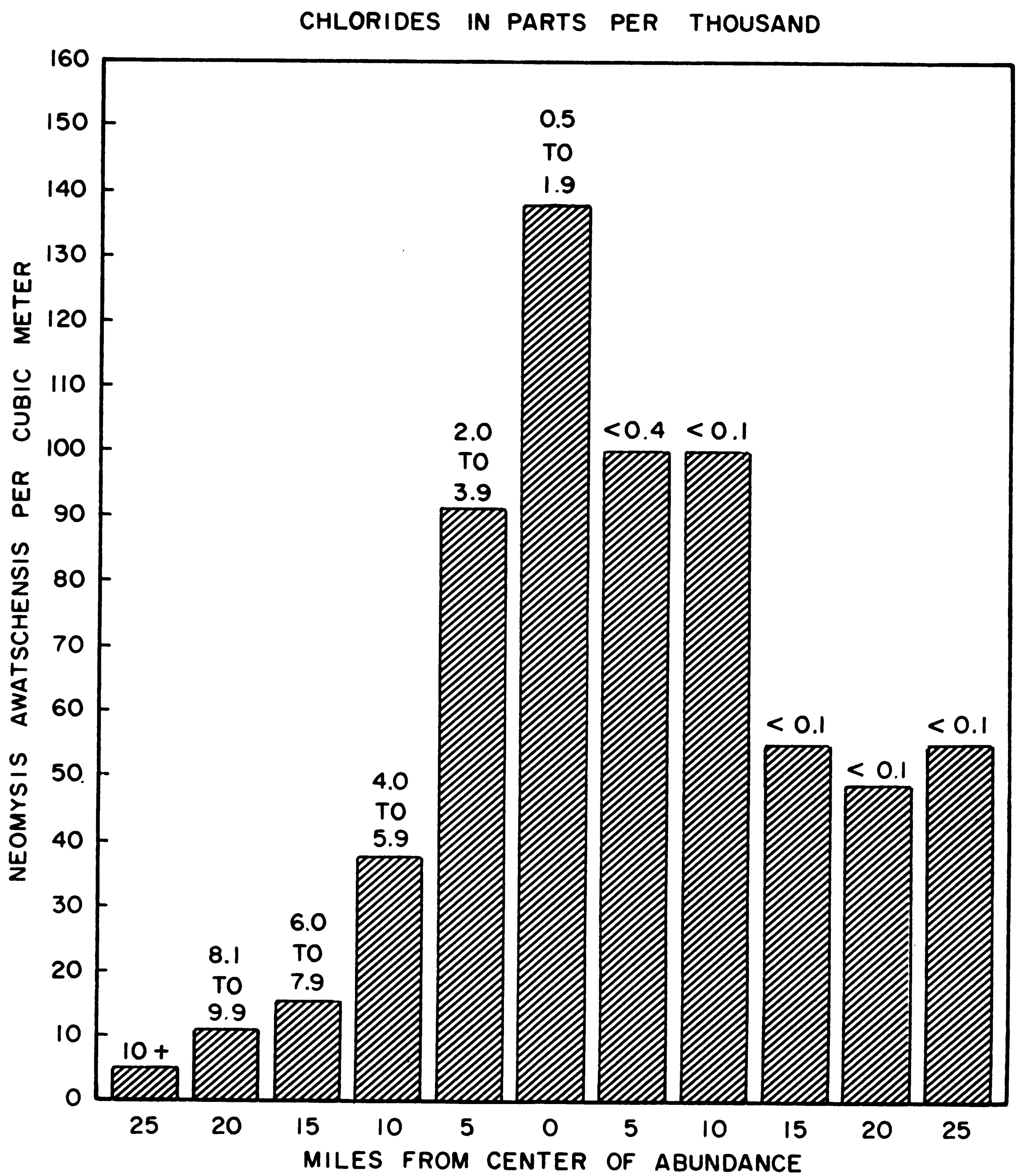

FIGURE 10—Mean density of *Neomysis awatschensis* in relation to salinity and distance from the 0.5 to 1.9 chloride range, Sacramento-San Joaquin Estuary, March 1965 to September 1965 (from Heubach, 1969).

female) in general, increase in the spring, are highest in summer, and then decrease to a winter low. Consequently, small mysids comprise a larger proportion of the population in the spring and summer. As the population declines in fall and winter, the proportion of small mysids decreases. Young mysids are scarce in the winter when reproduction is lowest. The spring and summer reproductive period is similar to that of other mysids occurring in temperate regions (Tattersall and Tattersall, 1951). Reproduction is also higher in fresh water than salt water at equal distances from the preferred low chlorinity range.

Reproduction accounts for the most significant changes in the seasonal and geographical abundance of *Neomysis*. Mysids are most abundant at the time and in the area in which reproduction is greatest; that is, in the summer from the lowermost, freshwater stations down to the area of 2.0 ppt chlorides.

Food Habits. Food habit studies of *Neomysis* are incomplete but investigations thus far have disclosed mysid stomachs to contain phytoplankton (principally diatoms), detritus, entomostracan parts and in some cases, entire rotifers (Dr. Allen Knight, University of California at Davis, personal communication). The genera of diatoms ingested by mysids differ between brackish and fresh water areas of the estuary. There is a higher preponderance of detrital material in the stomachs in winter.

Members of the genus *Neomysis* are considered omnivorous filter feeders, ingesting phytoplankton, detrital matter and zooplankton (Tattersall and Tattersall, 1951). The presence of smaller mysids and intact zooplankton in their stomachs suggests they may be particulate feeders as well.

Summary

A number of environmental factors interact to control the distribution and abundance of *Neomysis* in the Sacramento-San Joaquin Estuary. Mysids are most abundant in the summer in a chlorinity range of 0.1 to 2.0 ppt, where reproduction is greatest. Densities decrease rapidly at chlorinities greater than 4.0 ppt and were lowest at chlorinities over 10 ppt. Few mysids are found where flow reversal is negligible during flood tide or where light penetrates to or near the channel bottom. Water temperatures greater than 72°F in combination with dissolved oxygen levels less than 8 ppm appears unfavorable. Field and laboratory observations indicate that temperatures greater than 72°F are adverse to *Neomysis*.

Implications of Water Development

Salinity and tidal flow are significant factors affecting the geographical distribution and abundance of *Neomysis*. Since salinity in the Delta is a function of outflow, the amount of outflow is probably the most critical environmental factor affecting the location and, perhaps, the abundance of *Neomysis*. Water temperature, turbidity, and probably the amount of detritus coming into the Delta are also important. It has not been possible to isolate and evaluate each of these factors, but each is related to outflow. Therefore, it is imperative to continue monitoring the *Neomysis* population and the environment to determine more precisely the relationship of environmental factors to the abundance of mysids.

Flow direction and velocity also affect *Neomysis* distribution and population size in the Delta channels. The high net water velocities, which occur in some channels now as a result of water exports, reduce mysid densities and hence, reduce the range of the *Neomysis* population and its availability as a fish food. Flow reversal in the San Joaquin River from its confluence with the Sacramento River to the mouth of Old River may also be highly detrimental. A continual draft of mysids from the confluence of the two rivers, where they are most abundant, would tend to reduce their density in that critical area and probably affect the survival of striped bass which are most abundant near the center of the mysid population.

Recommended Environmental Conditions

Based upon existing knowledge, the environmental requirements of *Neomysis* include:

1. A large expanse of water in the salinity range of 0.1 to 4.0 ppt chlorides. Chlorinity should not exceed 4.0 ppt upstream from Chipps Island during the summer.
2. Positive downstream net flows.
3. Retention of tidal currents to provide mysids upstream transport mobility from centers of abundance.
4. Dissolved oxygen levels near saturation, but never less than 5 mg/l.
5. Maintenance of turbidity levels that will restrict light penetration sufficiently in most deeper channels of the Delta now utilized by *Neomysis* and which will permit limited extension of mysids into shallow channels.
6. Water temperatures not greater than 72°F.
7. Net water velocities less than 0.3 fps.

ZOOBENTHOS

By DICK DANIEL

Introduction

Benthic animals or zoobenthos are primarily invertebrates which live in or on the bottom substrate of aquatic habitats. They include such animals as clams, worms, aquatic insects and crustaceans. In our estuary they are important sources of food for some fish, as well as a number of waterfowl and shorebirds. They are important food for sturgeon and catfish. In recent years, they have gained importance as an indicator of water quality conditions in various environments because their populations generally reflect conditions in areas of industrial and municipal pollution.

A number of benthic surveys have been made in the estuary in recent years. Filice (1954a,b; 1958; 1959) described the general limits of many forms in San Pablo and Suisun Bays in the early 1950s. A University of California study concentrated on San Francisco, San Pablo and Suisun Bays between 1960 and 1964 (Storrs, Pearson and Selleck, 1966). Department of Fish and Game surveys included San Pablo and Suisun Bays in 1963 (Painter, 1966); the Delta in 1963 (Hazel and Kelley, 1966); and San Francisco and Delta waters in 1971 (Daniel and Chadwick, 1971). A Department of Water Resources survey included the Sacramento River in the Delta in 1962 (California Department of Water Resources, 1962).

Although each of these surveys enumerated the benthic animals, comparisons are extremely difficult due to differences in sampling, analysis and particularly degree of identification (Carlton, 1972).

Distribution and Abundance

There are many environmental and biological factors individually or in combination that determine the distribution of benthic organisms in an estuary. One of

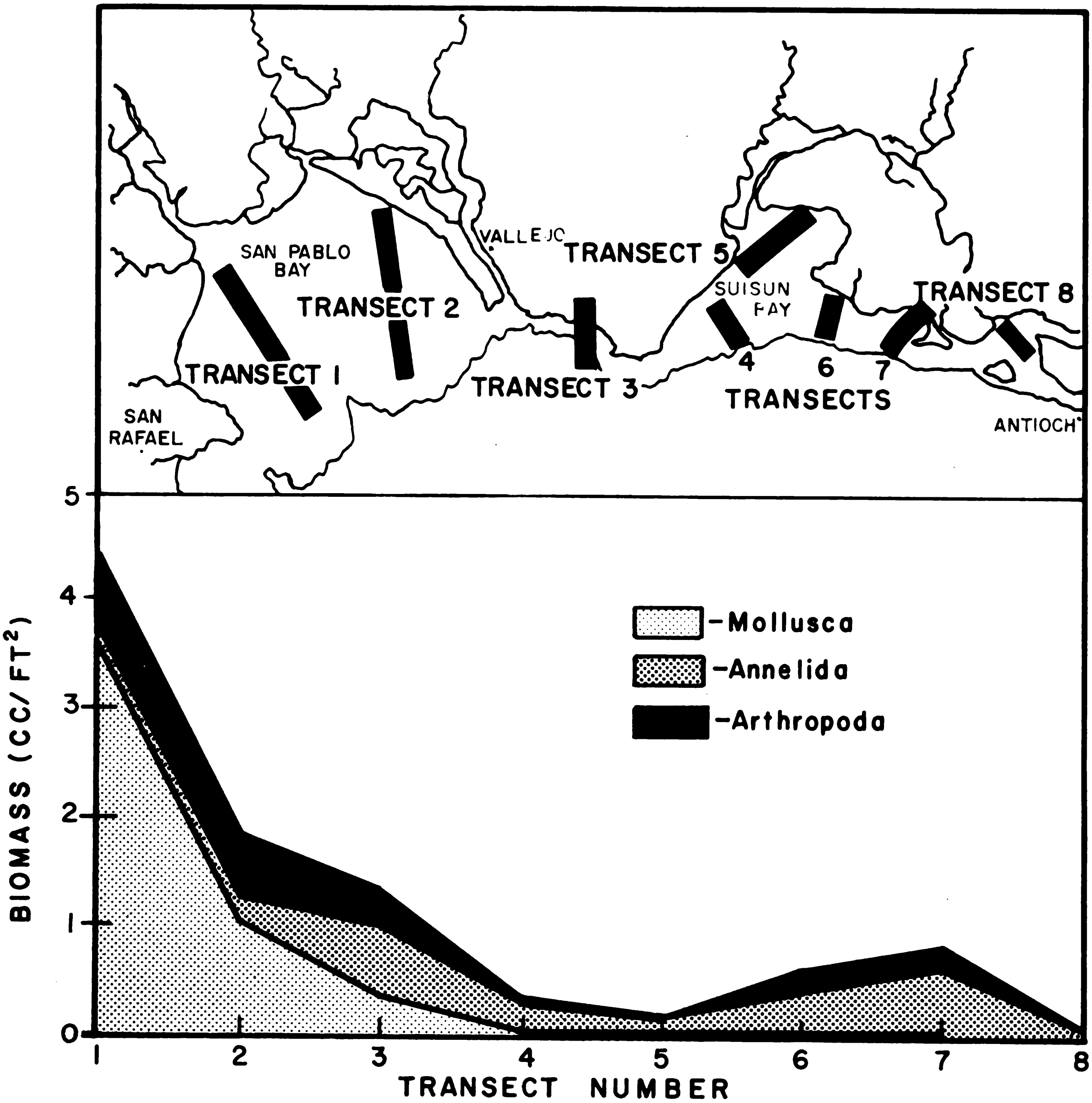

FIGURE 11—Average monthly biomass of selected fish and wildlife food organisms from eight transects in San Pablo and Suisun Bays. (From Fish Bulletin No. 133, Calif. Dept. Fish and Game.)

the most important factors and easiest to identify is that of salinity. Filice (1958) described a distinct change in species composition due to salinity in eastern Carquinez Strait. The seaward fauna consists of estuarine and marine forms, while the river fauna contains species that are of freshwater and estuarine origin. In addition to a change in species composition, there are many more species west of Carquinez Strait (Filice, 1958) and a greater total biomass of benthic forms (Figure 11; Painter, 1966).

Zoobenthos are an important source of food in San Pablo Bay for waterfowl, shorebirds and some species of fish. Thousands of diving ducks are found in the Bay area each winter. The redhead, bufflehead, scaups, American goldeneye, and canvasback all feed on benthic mollusks, crustaceans, and annelid worms. Small clams such as *Macoma, Gemma* and *Tapes* and the snail *Nassarius* are the more important species of food. Amphipods, isopods and annelid worms have also been found in gizzards of diving ducks (Browning, 1965). The small amphipod, *Ampelisca,* is important to juvenile striped bass, and several species of clams appear important to white sturgeon (Ganssle, 1966; McKechnie and Fenner, 1971).

The importance of zoobenthos in the food chain of fish diminishes moving upstream into the Suisun Bay-Delta area. This may be due to the presence of fewer species (Filice, 1958) and/or the lower benthic biomass (Painter, 1966).

The most important benthic animals that are eaten regularly by fishes in the Delta are small amphipods of the genus *Corophium.* They are frequent in occurrence and sometimes appear in large numbers in the stomachs of striped bass (Heubach, et al., 1963; Stevens, 1966; Thomas, 1967), catfish (Turner, 1966b), sturgeon (Radtke, 1966) and centrarchids (Turner, 1966c).

There are two major species of *Corophium* in the Delta, *C. spinicorne* and *C. stimpsoni.* Hazel and Kelley (1966) found that *C. stimpsoni* was most abundant in the fine-medium sand bottoms in the western Delta where the predominant currents are the ebb and flow of the tide. Its downstream abundance was believed to be limited by the salinity gradient and its upstream abundance by high net velocities of inflowing rivers, particularly near the mouth of the Mokelumne River. It does not flourish in quiet water.

Corophium spinicorne was almost entirely restricted to sediments with some solid substrate and usually was more abundant in shallow water near the shore.

Other benthic animals eaten by fishes in the Delta include the larvae of midge flies of the family Tendipedidae and the Asiatic clam, *Corbicula.* Small numbers of Tendipedidae larvae are found in the stomachs of young striped bass (Heubach, et al., 1963; Stevens, 1966), catfish (Turner, 1966b) and centrarchids (Turner, 1966c). Only a few *Corbicula* have been reported in fish stomachs.

Hazel and Kelley (1966) found that Tendipedidae were only significant in bottom samples taken from more river-like environments of the upstream Delta. *Corbicula* were abundant in many parts of the Delta but apparently are unavailable to fish.

Implications of Water Development

The effects of a reduction in freshwater flow into the estuary on the overall production of zoobenthos is not known. Freshwater inflow contributes nutrients and detritus which are necessary for high production. It also dilutes municipal and industrial wastes, thus helping to prevent pollution problems such as low dissolved oxygen levels and toxicity. Thus, excessive flow reductions tend to be detrimental to the present zoobenthic populations, although pollution effects should be controlled by treatment rather than dilution.

One of the significant factors affecting the distribution and abundance of *Corophium* in the river-like channels of the Delta and one that could change with future water development is the type of bottom sediment. High net velocities such as those which now occur in the Mokelumne River region result in shifting sand bottoms which support few benthic animals. Any reduction of water velocity in this type of habitat, such as would occur with operation of the Peripheral Canal, would be beneficial to the benthos populations.

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Typical Delta Channel

CHAPTER V

STRIPED BASS

By JERRY L. TURNER

INTRODUCTION

Striped bass (*Morone saxatilis*) are not native to the West Coast of the United States but were initially introduced from the East Coast in 1879 (Skinner, 1962). Their increase in California waters was quite phenomenal with hundreds of bass being caught 10 years after the first planting. Over 1,200,000 pounds were landed in California 20 years after the transplant and from 1916 to 1935 the commercial catch ranged between 500,000 and 1,000,000 pounds per year. In 1935, all commercial fishing for bass was halted to protect the sport fishery.

Striped bass have long been one of California's top ranking sport fish. The Stanford Research Institute estimated the net economic value of the sport fishery for 1970 at about 7.5 million dollars (Altouney, Crampon, and Willeke; 1966). The intangible benefits of angling, the enjoyment and relaxation afforded by the sport, which cannot be measured in dollars, are perhaps even more important considerations. Two million angler days are supported annually by this resource. Present estimates of the size of the adult striped bass population (fish 16 inches and over) are on the order of 1.4 million fish, but past records indicate a substantially larger population, perhaps of up to 3 million fish.

Since the early 1960s, there has been a general decline in angler success, presumably due to a decline in population size. Along with the decline in angler success, there has been a decline in annual harvest rate and a general increase in the average weight of striped bass caught. The annual harvest rates have varied from 14 to 37 percent (Chadwick, 1968; Miller, 1972). These low harvest rates and the increase in average weight of the fish caught both suggest an underutilized fish population and certainly demonstrate that the population decline in the early 1960s was not due to excessive angler harvest. In fact, reducing the minimum size limit, or relaxing restrictions which limit harvest rates or both, would probably result in greater catches of smaller fish with no harm to the population (Chadwick, 1969). The recent decline in angler success was probably due to a deterioration in the environment for young-of-the-year in the early 1960s. The results of a poor environment for young bass would not be noticed until 4 years or later in the adult fish catch. Reasons for the poor environment for young bass will be discussed later in this chapter.

LIFE HISTORY

Migration of Adults

Catch records and tagging studies in the early 1950s demonstrated a definite annual migration pattern for adult striped bass (Calhoun, 1952). There was a large upstream fall migration to the fresh waters of the Sacramento-San Joaquin Delta, where the fish remained during the winter. In the spring, they dispersed throughout the Delta and up the Sacramento River to spawn. After spawning they returned to spend the summer in San Pablo Bay and adjacent waters.

Tagging studies in the 1960s revealed a similar pattern except that bass were migrating farther downstream into San Francisco Bay and staying there longer (Chadwick, 1967). Part of the San Joaquin spawning population also shifted to the Sacramento side of the Delta during this later period.

Spawning Location

The two major spawning areas of striped bass are in the Sacramento River from Isleton to Butte City and in the main San Joaquin River and adjacent sloughs from Antioch upstream to Venice Island.

The location of spawning is largely determined by the amount of flow. In the Sacramento River, the amount of flow affects water temperature and hence the location of spawning (Calhoun, Woodhull, Johnson, 1950; Farley, 1966; Turner, MS). In years of high runoff when the Sacramento River warms more slowly, striped bass continue to migrate upstream waiting for the water to reach the spawning temperature. Under such circumstances, they spawn farther upstream when runoff is high and farther downstream when runoff is low.

The location of spawning in the main San Joaquin River is controlled to some extent by salinity which also is a function of outflow. Striped bass require fairly fresh water for spawning. Spawning occurs farther downstream in the Delta in years of high flow when salinities are pushed downstream. Early studies suggested that little spawning occurred in the San Joaquin River where ocean-derived salinities were greater than 200 mg/l of total dissolved solids (TDS). In 1968, substantial spawning occurred in salinities up to 600 mg/l TDS.

As mentioned previously, tagging studies have demonstrated a gradual shift in spawning from the San Joaquin River to the Sacramento River in the past 20 years (Chadwick, 1967).

Minor spawning has occurred in wet years in the San Joaquin River upstream from the Delta (Farley, 1966). In dry years, because of low quality agricultural return water, there is an increase in salinity in the San Joaquin River. This creates a reverse salinity gradient and, in such years, adult striped bass generally refuse to move upstream beyond the point where land (agriculture) derived salinities reach 350 mg/l TDS (Radtke and Turner, 1967).

The time at which striped bass spawn is related closely to water temperature. Spawning usually starts when the river temperature reaches 60°F and peaks when temperatures are between 63° and 68°F (Turner, MS). Spawning in the Delta occurs approximately 2 weeks earlier than in the Sacramento River because of temperature differences between the two areas. The principal spawning periods over the past several years have been between April 25 and May 25 in the Delta and from May 10 to June 12 in the Sacramento River.

Egg and Larva Development

Striped bass are prolific. An average 18-inch bass will lay approximately 200,000 eggs, a 24-inch fish 700,000 and a 30-inch fish over a million (Lewis and Bonner, 1966). The eggs are released directly into the water at which time they are fertilized by the male. The eggs develop as they drift downstream with the currents.

Live eggs are spherical and transparent. They are quite small after fertilization (1/16 inch) but they absorb water in the first 2 hours and double their original diameter. Laboratory studies show that survival is much greater for eggs that absorb water in which the salinity is less than 1,000 mg/l TDS than for eggs in higher salinities (Turner and Farley, 1971). The eggs are only slightly heavier than fresh water (mean specific gravity 1.0005) and suspension in the water was necessary for survival in laboratory experiments (Albrecht, 1964). The rate of egg development depends upon water temperature with higher temperatures increasing the incubation rate. Eggs will normally hatch in 48 hours at a water temperature of 67°F.

Immediately after hatching the striped bass larvae are capable of only very weak swimming movements. Their energy the first few days is derived from the larval yolk sacs. By the 7th or 8th day the larvae begin to feed actively on small zooplankton (Stevens, 1967). Feeding habits vary with the size of the bass and the area of feeding (Heubach, Toth and McCready, 1963; Stevens, 1966; Turner, MS). The copepod, *Eurytemora affinis*, is the major food item in the western Delta, where the bass are most common, until the larvae reach 0.6 inch in length at which time the mysid shrimp, *Neomysis awatschensis*, become the major food (Turner, unpublished data).

Egg and Larva Distribution

The eggs and newly hatched larvae are at the mercy of the currents. In the upper Sacramento River there is a one-way flow toward the ocean and the young bass are swept downstream rapidly into the Delta. In contrast, the net downstream flow in the channels of the San Joaquin Delta is negligible in comparison to the strong tidal flow. Thus, in the San Joaquin River the eggs and larvae develop in almost the same area they are spawned while they are being carried back and forth by the tides.

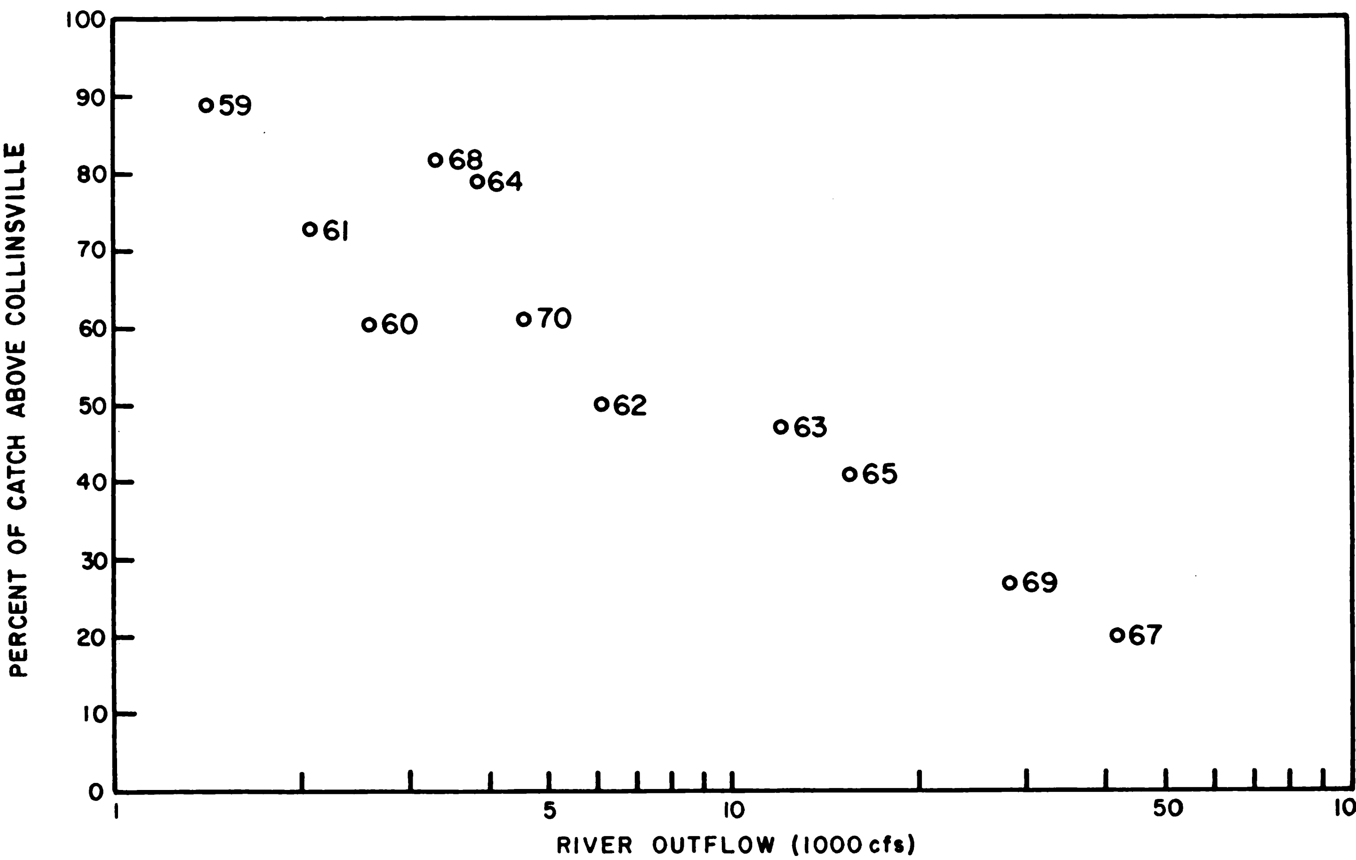

FIGURE 12—Relation between river outflow during June and July and the percent of the young striped bass population above Collinsville.

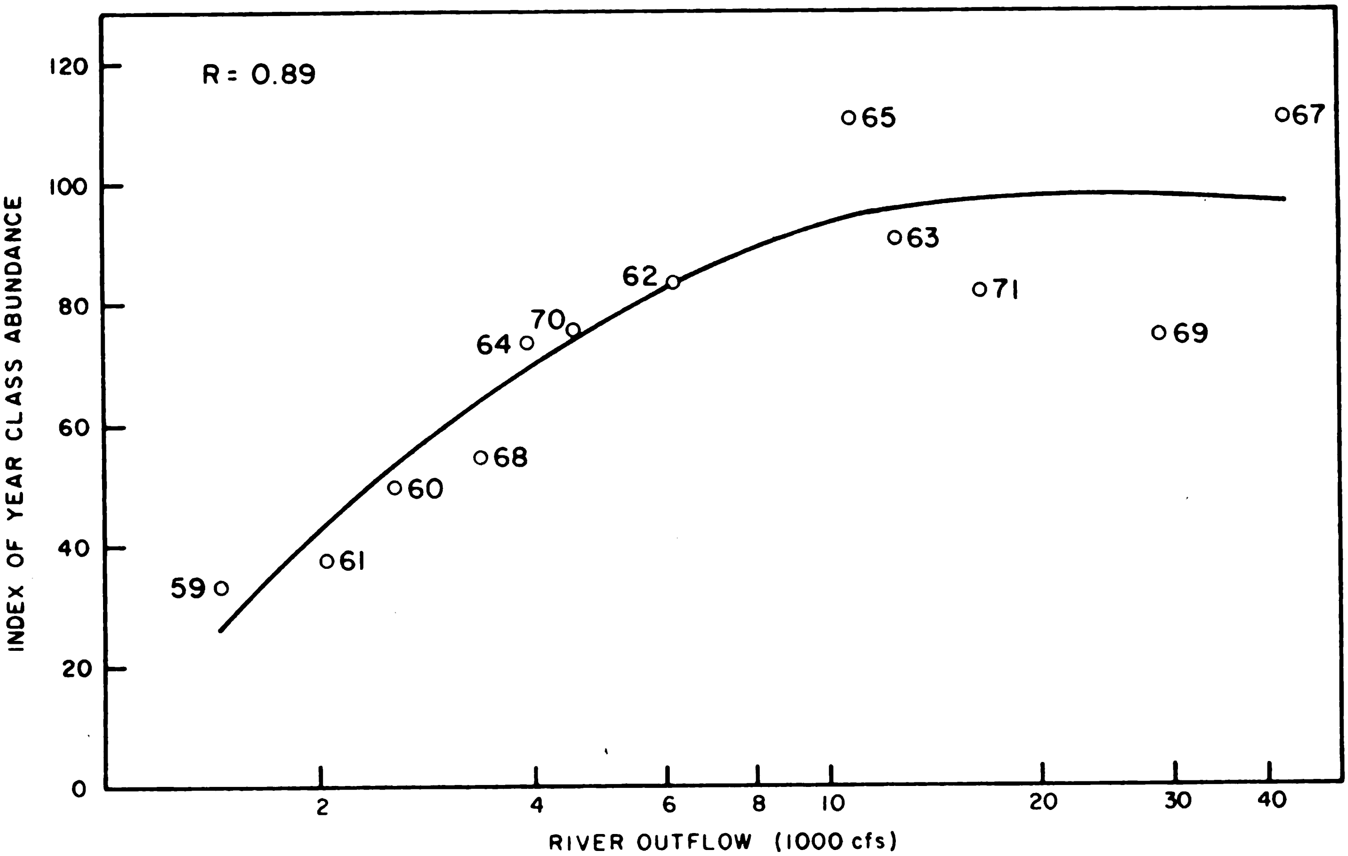

FIGURE 13—Relation between index of year class abundance of young striped bass and river outflow past Chipps Island during June and July. Numbers on figure designate years.

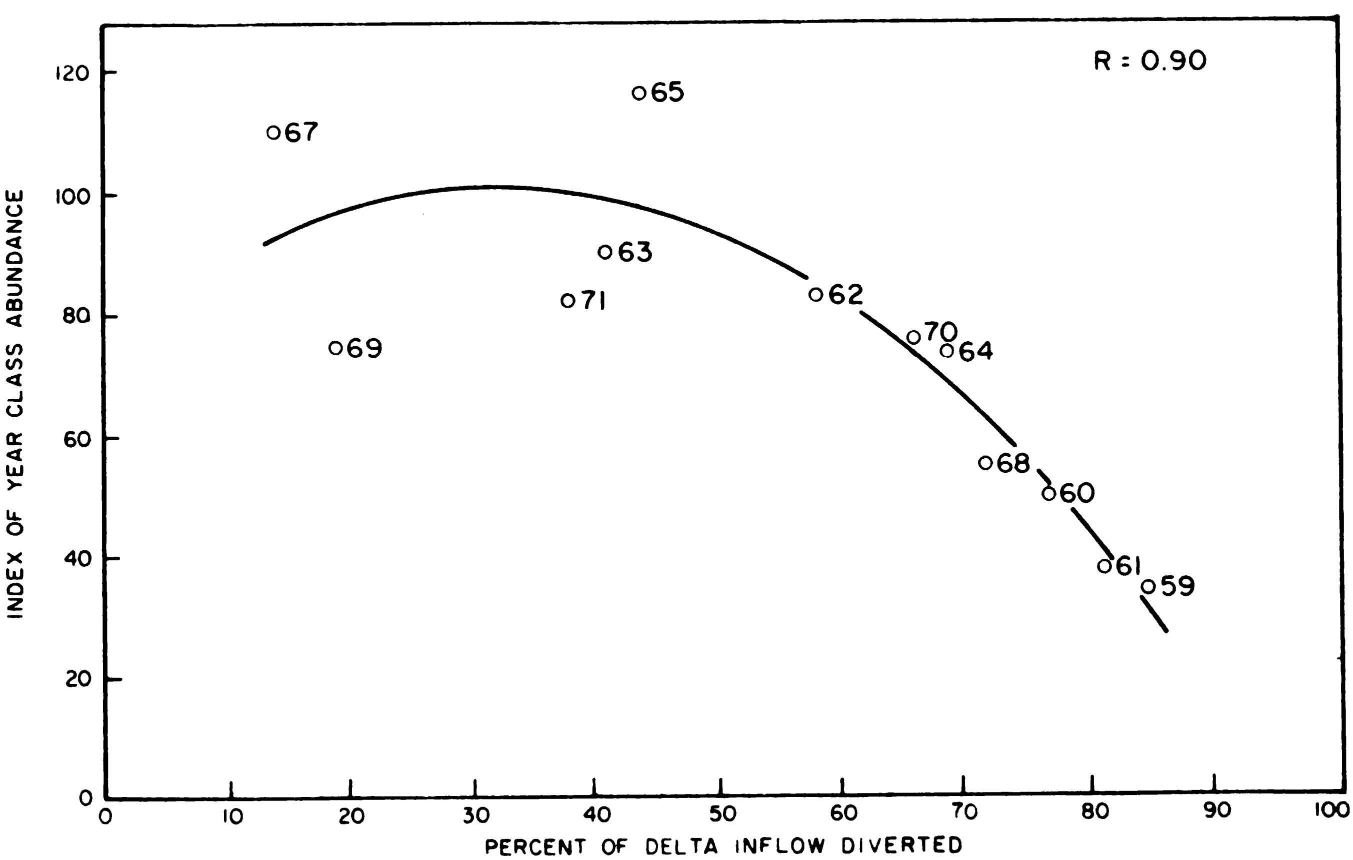

FIGURE 14—Relation between index of year class abundance of young striped bass and percent of delta inflow diverted for local consumption and export during June and July. Numbers on figure designate years.

Four to 6 weeks after spawning the young bass from both river systems are found in the Delta and Suisun Bay and are typically most numerous in the area where fresh and salt water initially meet (Chadwick, 1964; Turner and Chadwick, 1972). The location of this zone is a function of the amount of freshwater outflow but, generally, it is in the vicinity between Antioch and Pittsburg. In high outflow years, the young bass are located farther downstream and in low outflow years farther upstream (Figure 12).

Egg and Larva Abundance

The best estimates of individual year class size have been obtained by sampling when the population of small bass reaches an average length of 1.5 inches during the summer (Turner and Chadwick, 1972). Since 1959, there has been a significant correlation between the annual abundance of these small fish and the amount of Delta outflow in late spring (See Figure 13).

Since outflow, the level of salinity and the proportion of water diverted from the Delta all depend on the inflow to the Delta, these parameters likewise show a significant correlation with the abundance of small bass. In the case of diversion (Figure 14) and salinity, the relationship is negative, meaning that as salinity and the proportion of inflow diverted increases, the abundance of small bass decreases.

It is important to note the implications of the interrelated nature of each of the parameters discussed here. Under the conditions observed since 1959, it has not been possible to examine the parameters independently for their individual impact on the survival of small bass. Thus, although it is clear that the survival of small fish has been related to flows, the reason for this is not known.

The data indicate that annual summer abundance of young bass increases rapidly as summer outflows increase from 2,000 to 10,000 cubic feet per second (cfs), but changes little at flows above 10,000 cfs. The data also indicate that the greater the year class abundance, the later the time at which the various year classes reach a mean length of 1.5 inches (Figure 15). The principal reason for this is that spawning occurs later due to the lag in water temperature due to high outflow. The implications of the relationship between abundance and flow are discussed in more detail later in this chapter.

Young Bass from Late Summer to Spring

The opossum shrimp, *Neomysis*, are the most important food item of young striped bass through the remainder of their first year of life (Heubach, Toth and McCready, 1963; Stevens, 1966; unpublished data). The amphipod, *Corophium*, is also important. Small fish, however, become a major food item during the winter months.

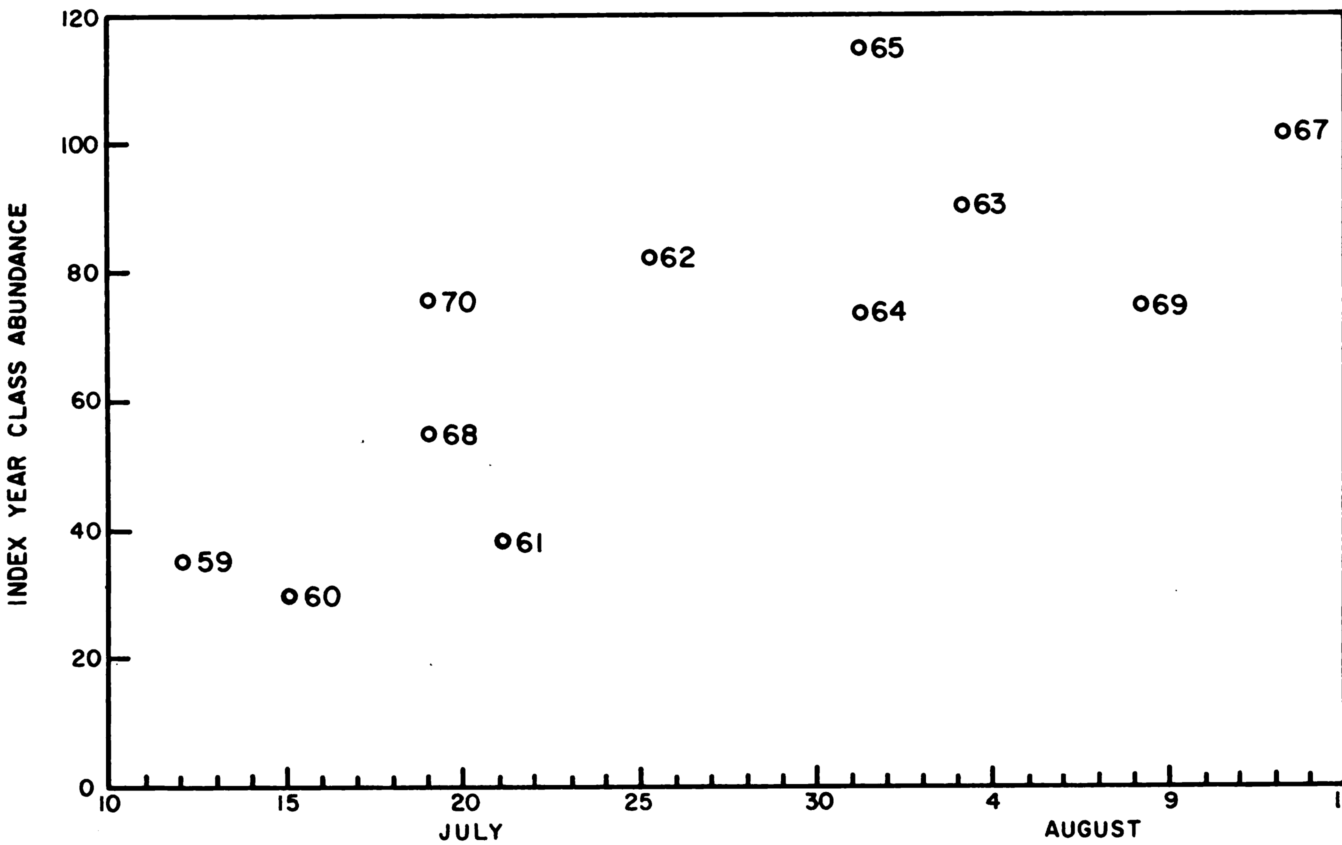

FIGURE 15—Relation between index of year class abundance of young bass and the estimated time the mean length of the population reaches 1.5 inches. Numbers on figure designate years.

In the fall the distribution of small bass remains closely related to the mixing zone of fresh and salt water, which is the same area where the *Neomysis* population is concentrated. In the late fall or winter months there is a general downstream movement toward San Pablo Bay. It is at this time that the importance of *Neomysis* declines and fish become a more important part of their diet.

Juveniles

After their first year, juvenile striped bass progressively increase the amount of fish in their diet, although *Neomysis* remains important during their second summer of life (Stevens, 1966; Thomas, 1967). In the Delta, threadfin shad and young-of-the-year striped bass are the primary fish fed upon.

Juvenile bass spread throughout the estuary and its tributaries as they grow older. They are found from San Pablo Bay to the Delta and large numbers also move into the rivers upstream from the Delta. Male bass mature when they are 2 to 3 years old, while females mature at 5 or 6 years. Once mature they take up the adult migratory pattern described earlier.

IMPLICATIONS OF WATER DEVELOPMENT

Cross-Delta Water Transport

Transporting water from the Sacramento River across the Delta to the export pumps near Tracy creates a variety of problems for striped bass. The first and most obvious of these is the loss of eggs, larvae and young fish in the export canals.

Fish screens at the canal intakes save many fish which otherwise would be lost. However, the present fish screen system is efficient only in removing fish large enough to swim well.

Essentially, all the eggs and larvae approaching the screens are lost from the Delta. In the early 1960s, this loss was estimated at 15 to 30 percent of the eggs. Without adequate facilities in the future, this loss may increase to as much as 50 to 80 percent of all eggs (Delta Fish and Wildlife Protection Study, 1964 and 1967).

The importance of these losses at the fish screens is difficult to define. In fish as prolific as striped bass, in which natural mortality rates are high for eggs, larvae and young fish, 100 percent screen efficiency obviously is not essential. On the other hand, we do not have sufficient evidence to define how great a loss is acceptable. Evidence discussed later in this report indicates that such losses presently may be a factor affecting the survival of young bass. Hence, the loss of eggs and young in diversions must be a major consideration in evaluating the effects of Delta water development. The most reasonable course of action, in our judgment, is to develop the capability to reduce losses at diversions to a very low level, while proceeding simultaneously with studies to define the essential level of protection. Presently, the Department of Fish and Game has established an objective of saving 90 percent of all bass, ¾ inches and longer, approaching screening facilities. (Testimony, Water Resources Control Board, 1969).

The eggs and young bass entering the export canals do have a value which must be considered. Recently a very popular fishery for striped bass has developed in San Luis Reservoir, a storage reservoir about 60 miles downstream from the export pumps. The reservoir was filled in 1968 and the fish population was derived from young fish entering through the Canal. Since striped bass are so prolific, it is undoubtedly possible to maintain the fishery in the estuary and still support a valuable fishery in the canals and reservoirs along the water delivery system.

The second effect of transporting water across the Delta is that as the transport rate increases, the production of food for young bass decreases. Our studies show clearly that the present populations of zooplankton, *Neomysis*, and benthic invertebrates are depressed in Delta channels used to transport water. These losses will increase as flow across the Delta is increased.

A third effect of the cross-Delta transfer of water is related to the downstream migration of adults after spawning. The export canals are far from the major migration pathways. Small numbers of adult bass now find their way to the trashracks across the canal intakes and fight the current until they die of exhaustion. As the flows towards the pumps increase, we are concerned that this loss may become serious. The extent of the problem depends on the degree to which adult bass depend upon the direction of flow to guide them in their migration. This is not known.

Outflow

There is a second group of striped bass problems related to Delta water development. These are believed to be functions of outflow primarily so their solution is independent of the means chosen for transporting water to the export pumps.

One problem concerns the effect of salinity on spawning. The location of spawning in the San Joaquin River in the central Delta is restricted primarily by salinity conditions. Both field and laboratory evidence suggest that striped bass spawning in the San Joaquin River would diminish if ocean-derived salinities greater than 1,000 mg/l TDS are allowed to intrude upstream from Antioch and water quality in the main San Joaquin River above the Delta is not improved substantially.

The most probable consequence of excessively saline water in this area during the spawning period would be to encourage more and more of the population to migrate into the Sacramento River to spawn. This is suggested by our observation of the negative behavioral response of adult bass to increasing salinity levels in the San Joaquin River on their upstream spawning migration. In addition, tagging studies have demonstrated that many striped bass have in fact shifted their spawning migrations from the San Joaquin River to the Sacramento River over the past 20 years. An excessive shift of spawning to the Sacramento River could result in limited distribution of young bass over the nursery area which may reduce survival.

The second, and possibly the more important consideration, concerns the effect of flow on the survival of bass during their first summer (Figures 13 and 14). We have tentatively identified six possible mechanisms associated with flow which could effect the survival of young bass (Turner and Chadwick, 1972). These mechanisms are: (1) effect on the distribution of young bass; (2) the supply of detritus and nutrients; (3) the time of spawning; (4) predation; (5) loss to diversions; and (6) toxicity from effluents. None can be eliminated with the available evidence. The first three all relate to the available food supply. The significance of these mechanisms vary in their relationship to flow parameters, so identification of the controlling mechanism is essential to decisions on water development. The available evidence is reviewed in the following sections.

Distribution. Since the abundance of young bass is greatest in the zone where fresh and salt water mix, presumably, conditions for survival are better in that zone. Massman (1963) referred to this as the "critical zone" in estuaries, because it is the principal nursery area for many fish.

In our estuary, at flows associated with better survival, this zone is located in the Suisun Bay area. The high proportion of shallow embayments there may enhance productivity. In the summer of 1966 the standing crop of phytoplankton in shallow embayments was about twice the crop in the adjacent channels (California Department of Fish and Game, unpublished data). Primary productivity is greater in the Suisun Bay region than either the upstream or downstream areas. (Bain and McCarty, 1965).

Detritus and Nutrient Supply. A variety of evidence suggests that high flows may increase estuarine productivity by increasing the supply of detritus and inorganic nutrients.

Detritus-feeding invertebrates are important in estuarine food chains (Darnell, 1967). The input of detritus into the estuary is probably a direct function of flow. Krone (1966) demonstrated that the annual input of total suspended solids is a direct function of river discharge, and limited evidence indicates that the percentage of organic material in total suspended solids varies little with flow (USGS, unpublished data). Therefore, the amount of organic detritus would increase greatly in years of high outflow. To the extent that detritus is retained in the estuary, it would increase the production of invertebrate food organisms. We have little direct evidence to demonstrate this.

Evidence from other estuaries suggests a positive relationship between invertebrate production and flow through the estuary. Heinle (1969) found evidence that the production of *Eurytemora affinis*, a small copepod in the Patuxent River estuary, increased greatly following the addition of organic detritus to the estuary during high spring flows. This copepod is the principal food of striped bass less than 0.6 inch long in the low salinity zone of the Sacramento-San Joaquin Estuary.

Shrimp production in estuaries has often been related to rainfall or river discharge (Hildebrand and Gunter, 1953; Thomson, 1956; Chapman, 1966). This relationship has usually been attributed to the resulting amount of habitat of suitable salinity for shrimp, but nutrient input from high inflow has also been suggested as a cause (Kutkuhn, 1966).

Spawning Time. As mentioned previously, there is a general pattern in which high outflow depresses water temepratures, thus resulting in later spawning and greater year class abundance. Later spawning may coincide with a greater availability of food when the young bass start to feed. Heubach (1969) found a rapid increase in numbers of small *Neomysis* from March through mid-summer. Turner (1966) and Painter (1966) reported rapid increases in the standing crop of crustacean zooplankton from June through midsummer in the estuary. There is some evidence though to indicate the annual peak densities of *Neomysis* are also delayed by high flow in the summer.

Predation. The turbidity of water in the Delta is controlled partly by outflow and partly by tidal currents. The zone of highest turbidity is also the low salinity zone in which the young bass are concentrated. To the extent that flow is responsible for turbidity, it may indirectly influence predation on and/or cannibalism among the young bass in the Delta.

As stated previously, the annual input of total suspended solids in the estuary is positively correlated with river discharge (Krone, 1966). However, limited measurements of light penetration in 1966 and 1967 indicate that mean light penetration was greater throughout the estuary in 1967, a high outflow year, than in 1966, a low outflow year (Chadwick, unpublished). This suggests that it is improbable that high outflows increase turbidity and hence, reduce predation.

Effect of Diversions. The fifth possible mechanism is the loss of striped bass due to water diverted from Delta channels. The primary diversions during the period of study were the Delta-Mendota Canal, Contra Costa Canal, and Delta agricultural diversions. This could be important in determining survivial. The louver-type screen on the Delta-Mendota Canal does not save eggs and newly hatched larvae, and only 50 to 90 percent of the fingerling and juvenile bass are salvaged by the louvers, depending on their size. Also, neither the numerous Delta agricultural diversions nor the smaller export canals (Contra Costa and Vallejo Canals) are screened.

The possibility that water diversions influence survival is supported by the inverse relationship between the abundance of young bass and the percentage of the water entering the Delta which is diverted (Figure 14).

Even though this relationship exists, several things suggest that water diversions are not the primary mechanism determining survival. One is that the percentage of the striped bass population in the San Joaquin Delta within the immediate influence of the Delta-Mendota Canal intake was relatively small in most years. In 1959 and in 1961 (dry years), it was about 25 percent. In all other years it was less than 20 percent and in 1968, a poor year for bass survival, it was less than 10 percent. Moreover, during the 2-month period covered by our surveys each summer, the geographical distribution of bass usually remains quite constant. In those instances when the distribution does change, there is no consistent pattern which would suggest that the fish move toward the canal intake.

Another consideration indicating that losses in water diversions are unlikely to be the primary mechanism controlling survival is that many bass are lost through Carquinez Strait in high outflow years (Stevens, unpublished data). The best observations of this phenomenon were made in 1967, and they indicated that very few of the young carried through the Strait survived. This loss, in all probability, was comparable to the loss in diversions in the driest of years yet survival from late spawning in 1967 was so great as to be the second best in the 11-year period.

While the distributional pattern indicates losses in diversions are not likely to be the major factor determining survival, it does not eliminate this possibility. The steady diversion of eggs and larvae as they move downstream through the area influenced by the pumps and the return of some young toward the pumps by tidal diffusion could result in the observed distribution pattern even though losses at the pumps were the dominant factor determining mortality.

If losses in diversions are the cause for the observed relationship, survival would not be a function of outflow, of course.

Toxicity. A final possible mechanism is toxicity. The San Francisco Bay-Delta Water Quality Control Board Program has concluded that toxicity from municipal and industrial effluents is significant in the estuary and that about 20 percent of the toxicity in the system is discharged in the region where young striped bass are most numerous (Kaiser Engineers, 1969). In order to evaluate the effect of toxicity on survival, it would be necessary to know the relationship between waste dilution and outflow, to have good estimates of toxic waste loading, and better evidence of the toxicity of the identified wastes on young striped bass. None of these are available.

None of the hypotheses that have been discussed above can be eliminated with the available evidence. It is believed, however, that the supply of available food resulting from some combination of bass distribution, detritus and nutrient supply, and spawning time is the most probable mechanism.

It should be noted at this point that we have only limited evidence that there is a direct relationship between the survival of small bass in their first summer and their later abundance as adult fish.

Some evidence bearing on this relationship is that the rate of survival of young bass between their first mid-summer and their second winter did not differ significantly from 1966 to 1970 despite significant differences in initial abundance and wide differences in environmental conditions (California Department of Fish and Game, unpublished data). The relatively uniform rate of survival means that the number of fish surviving to the end of their second winter is a function of the number surviving at the end of the first year.

Obviously, the primary concern in managing the fishery is the number of adult fish and not the number of young. Hence, the real importance of the relationship between the survival of young bass and water flow depends on whether the abundance of adult bass is directly related to the number of young bass. At present we have only limited evidence that this relationship exists.

An estimate of year class recruitment based on tagging studies and party boat catches from 1957 to 1971 suggests there is a direct relationship between amount of outflow during June and July of the spawning season and the size of year class recruitment to the fishery 3 years later (Stevens, unpublished data).

A third concern related to water flows are temperature and oxygen conditions during the summer in the Delta. Neither are functions of water flow primarily, but flows can influence both. Even small increases in temperature and decreases in oxygen could be critical to *Neomysis* because maximum summer temperatures are now very close to the maximum temperatures which this species can tolerate (Hair, 1971).

RECOMMENDED ENVIRONMENTAL CONDITIONS

Present knowledge indicates that the striped bass population can be protected or enhanced by:

1. Minimizing the losses of eggs, larvae and young fish to water diversions.
2. Reducing water velocities in the river channels in the north and south Delta in late spring and early summer to increase production of food for young fish.
3. Providing a positive net downstream flow towards the ocean to guide adult fish in their migration.
4. Maintain water quality suitable for striped bass spawning during the spring in the main San Joaquin River and adjacent sloughs from Antioch upstream to Venice Island at least.

5. Providing sufficient outflow during May through July for adequate survival of young striped bass.

6. Maintain adequate temperature and dissolved oxygen conditions during the summer and fall, with requirements of *Neomysis* being the most critical.

It is entirely reasonable that taking these steps would be sufficient to maintain and very likely enhance the population. The discussion of these requirements though pointed out areas of uncertainty as to the real necessity and extent of some of these requirements.

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CHAPTER VI

KING SALMON

By PAUL JENSEN

INTRODUCTION

King salmon are present in the rivers and tributaries of California's Central Valley from Keswick Dam on the Sacramento River near Redding to Crocker-Huffman Dam on the Merced River in the San Joaquin Valley. Historically, this range extended to the upper tributaries of the Sacramento River, such as the McCloud and Pit Rivers, and to above the present location of Friant Dam on the San Joaquin (Clark, 1929). Water developments have shrunk the range to its present size.

As individuals, salmon are seasonal occupants of Central Valley streams. However, timing of occupancy of the various races is such that some fish are present during every month of the year. Three races occur in the Central Valley. These are known as the fall, winter and spring runs and are identified largely by their migration patterns which are described later.

Central Valley salmon support a commercial as well as a sport fishery. The commercial fishery is restricted to ocean waters and to troll, or hook and line, fishing. Sport angling for salmon occurs in fresh water as well as in the ocean.

Since 1953, commercial landings of king salmon in California have ranged from a high of 958,000 fish in 1956 to a low of 338,000 fish in 1967 (Figure 16). Taken together, populations of king salmon in northern California streams are comparable in size to those of the Central Valley. However, the bulk of California's king salmon landings are produced in the Central Valley (Fry and Hughes, 1951).

Marine recreational salmon landings of king salmon, since 1953, have ranged up to 184,000 fish in 1955 (Figure 16). Again, the bulk of these fish are produced in the Central Valley. Inland landings of Central Valley king salmon amount to around 25,000 fish annually. The landings are made almost exclusively in the Sacramento River and its tributaries.

LIFE HISTORY

Population Size and Enumeration Studies

King salmon spawning populations (exclusive of winter run) in the Central Valley have since 1953 ranged from a low of 120,000 fish in 1957 to a high of 612,000 in 1953 (Figure 17). While salmon populations fluctuate naturally, those of the San Joaquin River in particular have done so quite violently. Since 1953, total populations in the Stanislaus, Tuolumne, and Merced Rivers which now consist solely of fall-run fish have ranged from a high of 70,000 in 1953 to a low of 500 in 1963 (Menchen, 1963–1969). Identifiable direct causes for some of the fluctuations in the San Joaquin River runs are discussed later in this section.

Studies of juvenile salmon in the Delta have been designed to measure timing of movement through the Delta. No measures of population size of juveniles there are available.

Adult Migrations

The estuary influences salmon populations primarily because it is the migration route between the ocean and inland spawning areas. There are at present three rather distinct upstream migrations of adult salmon in the Central Valley. Fall-run fish, which are the most numerous and support the bulk of the ocean fishery, pass through the Delta in late summer and fall and spawn in the upper rivers in fall and early winter.

Winter-run salmon, which over the past 15 years have developed into the second most numerous group, pass upstream through the Delta primarily in the winter, and spawn in the upper Sacramento River during the following summer.

The spring run, which may have numbered in the hundreds of thousands some decades prior to construction of Shasta and Friant Dams, is now the least numerous variety in the Central Valley. Spring-run adults migrate through the Delta in the spring months, and spawn in the upper rivers in early fall.

Spawning

Spawning occurs in upriver areas. Eggs are buried in clean gravel where there is a moderately rapid current (preferably 1 to 3 feet per second). Examples of downstream limits of spawning are near Vina in the main stem of the Sacramento; near the mouth of Honcut Creek in the Feather River; and near the Watt Avenue Bridge in the American. Sacramento salmon routinely spawn in eastside valley tributaries such as Mill, Deer, and Chico Creeks; less commonly in westside tributaries which are in the rain shadow of the coast range mountains.

Ideal temperatures for egg incubation range from the mid-forties to the mid-fifties. Mortality of incubating eggs increases abruptly as temperatures exceed 57°F. Eggs incubated at 50°F hatch in approximately 50 days. The relationship between water temperature and incubation period is inverse; as temperature increases, the incubation period decreases.

Salmon hatch with the yolk sac attached to their bodies, and the newly hatched fish work their way up through the gravel in which they were deposited as eggs. During this time, they assimilate nutrients contained in the yolk sac.

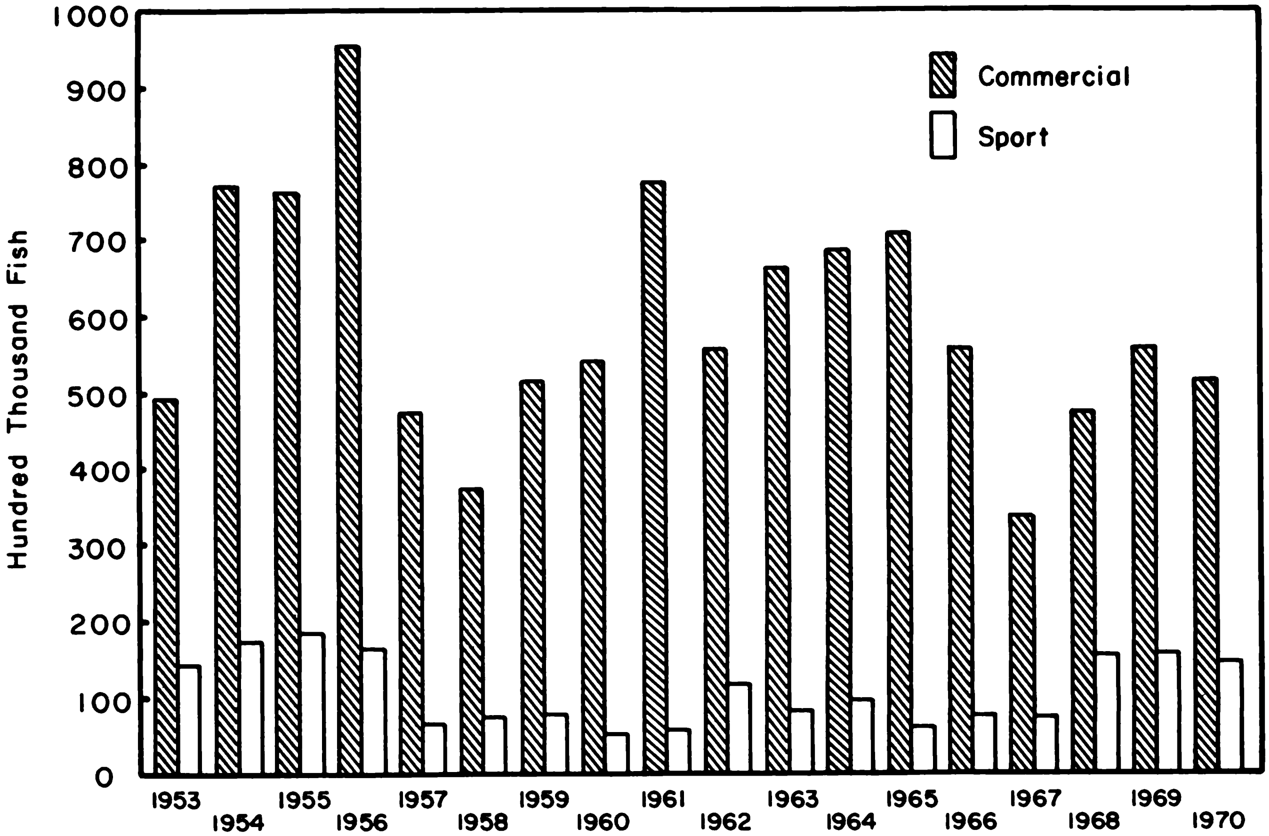

FIGURE 16—Number of king salmon landed in California in the ocean fisheries, 1953–1970.

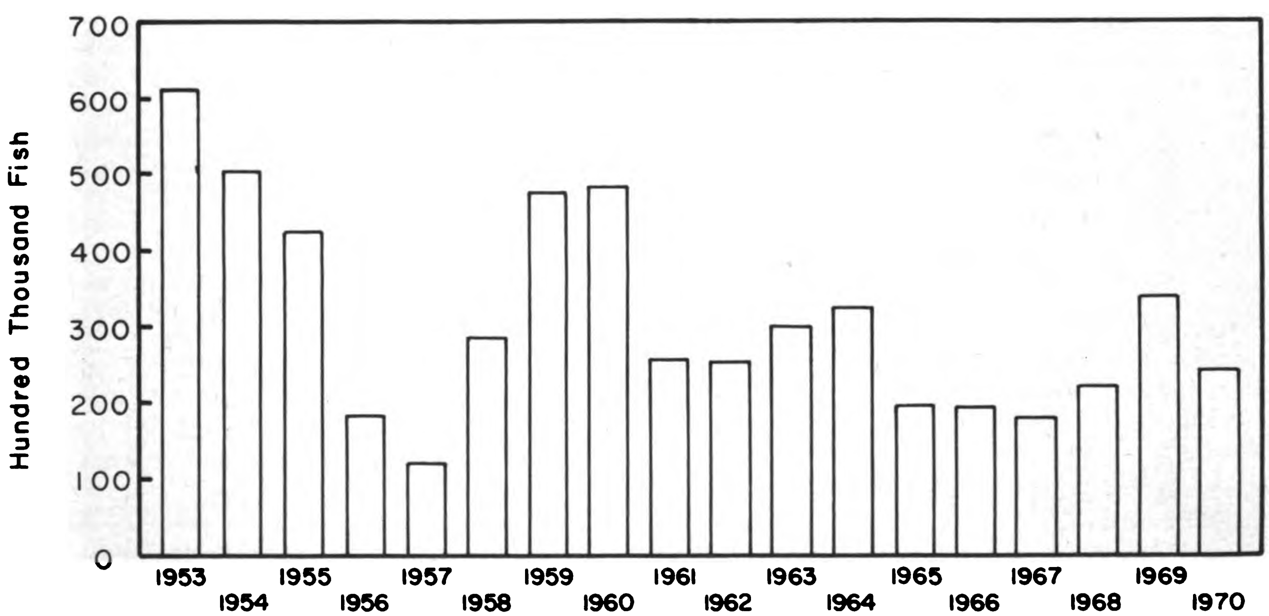

FIGURE 17—Sacramento-San Joaquin Valley king salmon spawning stock estimates, 1953–1970 (excluding winter run).

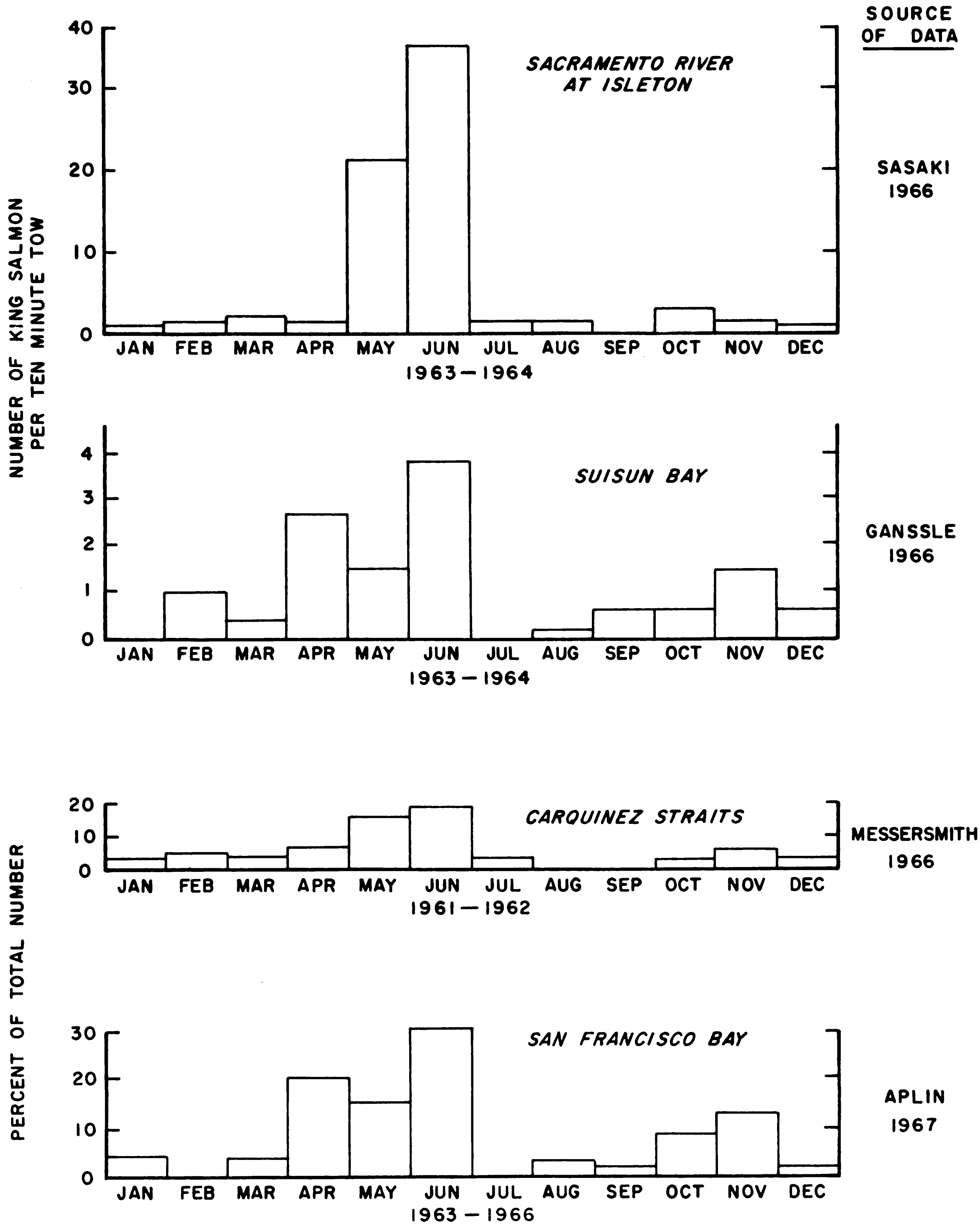

FIGURE 18—Seasonal abundance of downstream migrant king salmon in the Sacramento-San Joaquin River estuary and San Francisco Bay (after Heubach).

Downstream Migration

The young emerge from the gravel over a broad range of development, from newly hatched fish to fry with the yolk sac almost completely assimilated. In the initial stages, most downstream movement is the result of fish being carried downstream by the currents rather than deliberate downstream swimming.

Some fish start migrating downstream as soon as they emerge, but most migration follows the spawning period by 3 or 4 months. In the Pacific Northwest, spring-run juveniles normally remain in fresh water for a year and migrate to the ocean as yearlings. In the Feather River and Butte Creek in the Sacramento system though, juvenile outmigration of spring-run fish is common during the first year.

Time required for downstream migration is likely to vary with streamflow, with movement being more rapid under conditions of high runoff. Although some juveniles are migrating through the estuary in every month, the peak movement occurs in April, May, and June, with most fish being at least 3 inches long (Figures 18 and 19) (Aplin, 1967; Ganssle, 1966; Messersmith, 1966; Sasaki, 1966). However, during periods of high runoff, yolk sac fry have been captured in this area in February. It is unlikely that fish of this size would find a favorable environment in San Francisco Bay.

The coincidence in the timing of runs in all parts of the estuary (Figure 18) indicates a rapid rate of migration through the estuary.

Growth in the Ocean

Little is known regarding growth of Sacramento River king salmon from the time they leave the estuary as 3-inch outmigrants until they begin to appear in ocean sport fishery landings as 20-inch fish in the late summer of their second year of life.

A few 1-year-old salmon have been captured in midwater trawls made offshore during May and June. These fish were 11 to 14 inches in length, several inches longer than fish of the same age would be expected to reach if reared in our hatcheries. Also, adult spawners resulting from hatchery releases of yearling fish are generally smaller than those resulting from fingerling releases. Thus, we can infer that the first year of growth achieved in the ocean is greater than that produced in our hatcheries.

Growth rates achieved by adult salmon are extremely variable. Two-year-old spawning males may vary from 16 to 26 inches in length. Three-year-old males and females normally range from 26 to 34 inches and from 7 to 20 pounds. Four-year-olds may vary in weight from 12 to 35 pounds, or more.

ENVIRONMENTAL INFLUENCES AND REQUIREMENTS

Hydrology and Limnology

Flow. Upstream migrant salmon have historically demonstrated an ability to find their way at least above Carquinez Strait under conditions of extraordinarily low Delta outflow. In 6 of the 13 years immediately prior to the construction of Shasta Dam, salmon were taken in the river fishery during August when conditions of negative Delta outflow occurred (Figure 20).

Given satisfactory water quality conditions, upstream migrant salmon appear able to successfully negotiate the lower San Joaquin River at flows of 500 cfs at Stockton (Hallock, Elwell, and Fry, 1970). Additional water may be required, however, to provide optimum passage.

Because sufficient water has been available in the Sacramento River, flows necessary for adult passage have yet to be determined; they are likely to exceed those required in the San Joaquin.

Delta outflow during the spring is likely to be most critical in providing incentive and orientation for outmigrating juveniles. No way of determining the amount of outflow required in this regard exists short of observing outmigration under a variety of reduced outflows.

Salinity Gradient. Throughout their range along the Pacific Coast, king salmon demonstrate an ability to pass through a variety of salinity changes, from a very gradual one as is found in the Delta to an abrupt change from fresh to sea water, such as exists in most smaller coastal streams lacking estuaries. This is true of both adult and juvenile fish, although not all juveniles are prepared to make the transition at the same time.

It is possible that once a tolerance for salt water has been developed, a salinity gradient may act as a guide in outmigration, providing direction to fish which may be seeking increasingly saline water. Under all plans for cross-Delta water transfer except a physical barrier, a salinity gradient will exist such as to present no problems to either adult or juvenile salmonids.

It should be noted at this point that king salmon have suffered mortality from the bacterial disease, Vibriosis. The causative organism is of the same genus as that responsible for cholera in humans. Although Vibriosis presents no human health hazards, losses among salmon being penraised in saltwater in the Pacific Northwest have exceeded 80%.

Salmon, apparently, first become susceptible as downstream migrants entering salt water, and continue to be susceptible for at least the first year of marine existence.

Vibriosis has not been observed in salmon in California. Its recent occurrence in the Pacific Northwest though indicates that it should be given consideration in evaluating requirements of salmon migrating from fresh to salt water.

Water Quality. High water temperatures and low dissolved oxygen content are the two water quality factors which have had an observable adverse effect on salmon in the Delta. In the San Joaquin River near Stockton in the fall, salmon are reluctant to ascend the river when water temperatures exceed 70°F and dissolved oxygen drops below 5 mg/l (Hal-

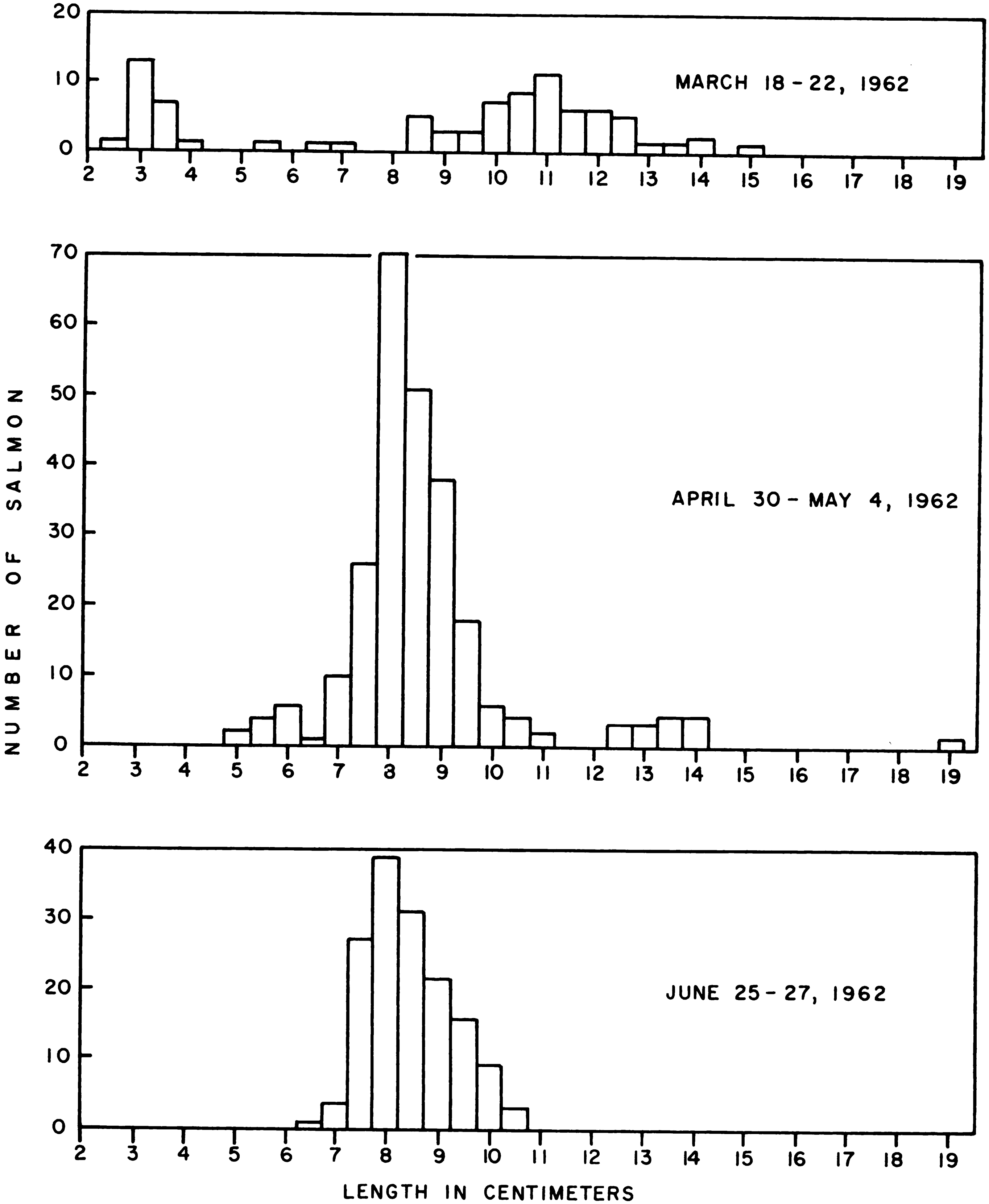

FIGURE 19—Length frequency of the downstream migrant salmon collected at Carquinez Strait, March through June 1962 (after Heubach).

lock, et al, 1970). Because the conditions of elevated temperature and depressed oxygen content coincide, it has been difficult to distinguish their relative effect on migration. It has been fairly well established that dissolved oxygen must be maintained at at least 5 mg/l, but temperature requirements are less apparent. In 1971, salmon negotiated the lower river at temperatures around 70°F, once satisfactory dissolved oxygen conditions had been established (DF&G office report).

In recent years, suitable conditions for migration have been achieved by having the Department of Water Resources construct a barrier at the head of Old River to divert more flow past Stockton and sometimes by having the Bureau of Reclamation augment flows in the river.

Cross-Delta Water Transport

In the absence of a closed system for transporting water from the northern Delta to the pumps in the south, difficulty can be anticipated in maintaining conditions adequate for upstream migrants in the San Joaquin River. Since almost all the water to be pumped originates in the Sacramento River, this water must intercept the flow of the San Joaquin on its way to the pumps. Under conditions of low San Joaquin outflow and high pumping rates, essentially all of the San Joaquin flow is delivered to the pumps; little gets past the cross flow of Sacramento River water and into the western Delta.

In the fall months of the early 1960s, this combination of conditions resulted in reversed flow in the San Joaquin River; the net movement of water was upstream toward the pumps rather than downstream to the ocean (Ganssle and Kelley, 1963). During this period, spawning populations declined to record lows, numbering only several hundred fish in the entire San Joaquin system. The steps described above have been taken to assure a positive downstream flow in the San Joaquin for the present, but with increased water export from the Delta, the flow situation for fall spawners in the San Joaquin River will become more critical. The best (and possibly the only) permanent solution to this problem would be a cross-Delta water transfer system isolated from existing Delta channels.

Juveniles migrating down the San Joaquin now are drawn to the pumps. Existing screens at the pumping sites do a fairly good job of saving small salmon, but these must then be handled and transported to the lower Delta beyond the influence of the pumps (Hallock, Iselin and Fry, 1968). Again, the most satisfactory solution would be an isolated water transport system, so that the San Joaquin would flow unimpeded to the sea.

Pumped Diversions

At the present time we have neither a measure of fish loss in, nor a practical method of screening the many relatively small diversions located in the Delta.

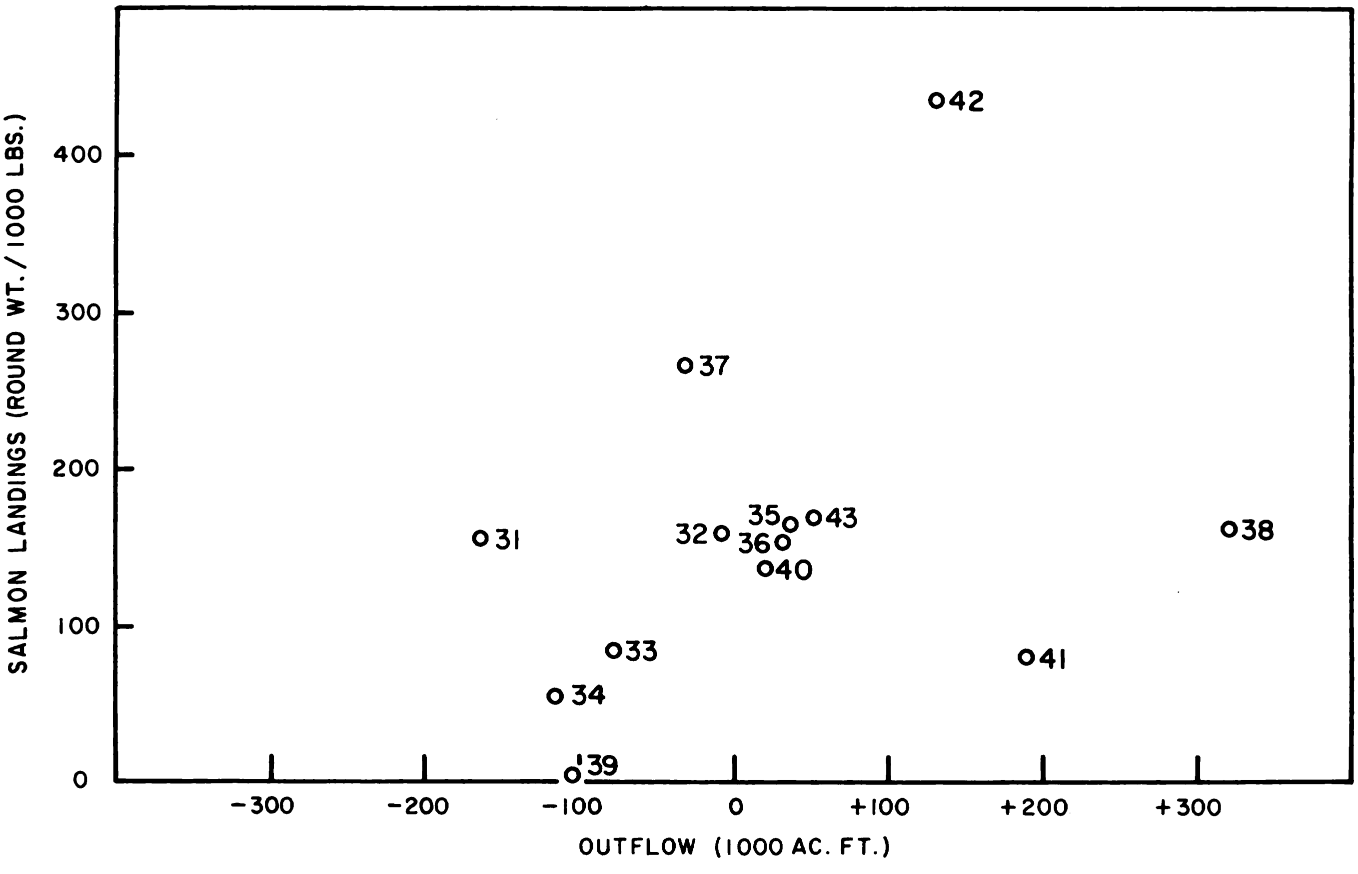

FIGURE 20—River gill net landings of salmon (above Carquinez Strait) and pre-Shasta Delta outflow during August 1931 through 1943.

Sampling of diversions in the Delta proper in 1955, although limited to four sites, indicated that downstream migrants were being lost; losses were much greater at the larger gravity and pump diversions located upstream, closer to spawning areas (Hallock and Van Woert, 1959).

Experimental evidence has been developed which indicates that hatchery outmigrants released in the Delta subsequently contribute to fishery landings at from two to three times the rate of those released at upstream hatchery sites to migrate downstream naturally (DF&G unpublished data). Accordingly, the Department is now completing, at a cost of several millions of dollars, a program of screening the larger diversions above the Delta on both the Sacramento and San Joaquin Rivers.

If reduced spring outflow significantly increases the exposure of outmigrants to Delta diversions, a program to develop and install effective fish screens will assume a higher priority.

Salvage Activities, Plans and Alternatives

The overriding salvage problem as far as salmon are concerned is screening of juvenile outmigrants from export canal intakes, wherever they may be located. This problem is discussed at greater length elsewhere in this report.

In the event that the Peripheral Canal is constructed, Sacramento River-bound adults could be attracted up dead-end sloughs by releases from canal spill sites. This is potentially a greater threat to fall than winter or spring-run fish, since fall-run fish spawn shortly after leaving the ocean and can afford to spend little time in the Delta.

Should upstream migrants be attracted to canal spill sites, several potential solutions exist. These include collection and transportation of adults, pulsing spills to avoid attraction, or complete suspension of spills during periods of upstream migration. Present operating concepts anticipate the latter.

Sonic tagging of adult upstream migrants in the Delta has indicated that the source of water in various parts of the Delta influences migration patterns. In dry years, when reduced San Joaquin flow and pumping at Tracy combined to draw more Sacramento River water into the southern Delta, numbers

Method of trapping striped bass for tagging.

of Sacramento fish present at Prisoner's Point on the San Joaquin River were higher than in relatively wet years. We have no measure of the effect of this distributional change on the salmon population in the Sacramento River, but view it as an undesirable situation. The solution again is to isolate flows of Sacramento River water to the export pumps from the existing Delta channels.

Opportunities for Enhancement

A relationship has been established between spring flow and size of spawning run in the San Joaquin River (Resources Agency of Calif., 1965). The greater the flow during juvenile outmigration, the greater the spawning run 3 or 4 years later. Certainly a large part of this relationship is determined in upstream areas of the San Joaquin River above the influence of Delta water diversions. To improve survival of juvenile outmigrants in the San Joaquin system, the Department of Fish and Game is negotiating for increased streamflows in San Joaquin tributaries and is providing fish screens for major water diversions.

Survival of San Joaquin outmigrants is likely to be further improved by additional flow and by isolating their downstream movement from the influence of Delta pumping. The latter condition could be achieved through operation of the Peripheral Canal. The canal would also provide solutions to problems faced by upmigrants to the San Joaquin River system.

RECOMMENDED ENVIRONMENTAL CONDITIONS

Water quality requirements for salmon in the Delta are fairly easy to define. It has been established that during salmon migration periods dissolved oxygen must be maintained in excess of 5 ppm and water temperatures should be below 70°F.

Outflows necessary for salmon are less simple to establish. Given adequate water quality in the Delta, salmon will be able to live there. However, they are not resident in the Delta and require flows in amounts that can be determined only by observing their migrations under low flows. This has not been done because flows during the principal salmon migration periods have not approached the minimums being considered for the future.

Upstream migrant salmon have negotiated the lower San Joaquin River when flow past Stockton amounted to 500 cubic feet per second, although this may be below the optimum. We have no corresponding measure of minimum suitable flows in the Sacramento River.

Perhaps flows during downstream migration are even more critical. Only by comparing outmigration rates under reduced flows will we be able to define water requirements in this respect.

For these reasons, we are deferring specification of salmon flow requirements pending examination of migration patterns under increased water export schedules.

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CHAPTER VII

OTHER FISHES IN THE ESTUARY

AMERICAN SHAD

By DONALD E. STEVENS

INTRODUCTION

About 10,000 American shad fry, *Alosa sapidissima*, were transported from New York to the Sacramento River in 1871. In 1873, 35,000 more were stocked, and between 1876 and 1881 additional plants totaled 784,000 fry.

By 1879 several thousand shad appeared in the San Francisco markets. After 1900 and until 1945 the commercial catch was regularly over 1,000,000 pounds. From 1945 until 1957 when the gill net fishery was effectively terminated by legislation the catch generally was less than a million pounds. The roe was the most valued part of the fish. At the end of the fishery females were bringing 6 to 8 cents per pound while the price for males rarely exceeded 1 cent per pound (Skinner, 1962).

About 1950 a sport fishery developed in the upper Sacramento River and its major tributaries. The number of anglers participating in this fishery has grown tremendously in the last few years. "Elbow-to-elbow" type fishing is typical in the American, Feather, and Yuba Rivers when the shad are there. Fly rods and light spinning gear are the normal tackle.

Another exciting method of shad fishing is "bumping" which is done at night in the Sacramento, Mokelume and San Joaquin Rivers. A long handled dipnet with chicken wire mesh is held perpendicular to the stern of a slow moving boat propelled by an outboard motor. When the "bumper" feels a shad hit the net he gives the net a twist and swings the fish into the boat. Virtually all shad caught by this method are ripe males. Similar nets are also used to catch shad from the bank in the upper Sacramento and San Joaquin Rivers.

LIFE HISTORY

Population Size

We know that shad runs in the Sacramento River and tributaries are much larger than those in the San Joaquin; however, there are no precise estimates of the shad population. We do have a reasonable estimate of the striped bass population based on tagging studies (unpublished); therefore, a crude estimate of the number of shad migrating up the Sacramento River can be made from the ratio of shad to striped bass in traps set at Courtland and Clarksburg to catch striped bass for tagging.

Over a 2-year period, the numbers of shad to bass were equal. Since the total estimate of bass using the river was on the order of 750,000, the estimate of the shad run would also be about 750,000 adult fish. This is a minimum estimate since the catches almost certainly overestimate the relative abundance of bass. Our goal was to maximize the bass catch so we attempted to set the traps where bass were abundant. Painter made a crude estimate of the annual shad run based on past commercial catch records (Kelley, 1968). His estimate was 2 to 4 million fish.

Spawning Migration

Shad spend most of their life at sea. Three to 5-year old fish begin entering the estuary in limited numbers on their spawning migration in the fall. They migrate through the Delta on their way upstream principally in April, May, and June (Stevens, 1966). Hallock, Fry and LaFaunce (1957) found that the migration peaked in the Sacramento River above the mouth of the Feather River in May. Catches by anglers in the Feather and Yuba Rivers peak in June.

Spawning

Most shad spawn in April, May and June. They have been observed spawning throughout the length of the Sacramento River upstream from Hood (Hatton, 1940). It is likely that they spawn down to Isleton, since there is little change in the river conditions between Hood and Isleton. Spawning has also been observed in the Feather, Yuba, and American Rivers where the fish are most accessible to anglers. Collections of ripe, adult shad and shad eggs and larvae are evidence of spawning in the Mokelumne River, south Delta, and San Joaquin River (Stevens, 1966; unpublished data).

Kelley (1968) analyzed reports by other biologists and concluded that spawning shad require "fresh" water, "current", and water temperatures 54°F or higher. However, the eggs are tolerant of low salinities. Leim (1924) was more successful in hatching eggs in salinities of 7.5 parts per thousand, TDS, than in fresh water. A recent study on the Feather River indicates that shad do not begin spawning until the maximum daily water temperature reaches 60°F. Spawning peaks in this river when the water is about 70°F and continues until 75°F, but survival from the spawn at the higher temperatures apparently is poor (Richard E. Painter, Cal. Fish & Game, pers. communication).

Shad spawn in small schools of up to a dozen or so fish. The eggs are fertilized by the males as they are released by the female. The fertilized eggs are about $\frac{1}{7}$-inch in diameter and are slightly heavier than water. They are carried by river currents until they hatch. Hatching time is a function of water temperature which takes about 3 days at 74°F and up to 6 days at 57°F (Skinner, 1962).

Between May 3 and July 11, 1969, we studied the vertical distribution of fish eggs in the Sacramento River at Courtland. The station depth was 25 feet and samples were taken at the surface, mid-depth and bottom with a helical pump. Numbers of shad eggs increased with depth. The mean catch at the bottom was more than twice that at mid-depth and about 10 times the catch at the surface (Figure 21).

Many, but not all, shad die after spawning. This mortality may be related to water temperature. On the Feather River a large number of carcasses are observed after the water warms to 70°F, but few are seen when the water is colder (Richard E. Painter, pers. communication). On the Atlantic Coast, many shad native to streams north of Cape Hatteras, North Carolina, survive spawning, but almost all shad in streams south of Cape Hatteras die after their initial spawning run (Talbot and Sykes, 1958).

Those shad that survive spawning, migrate downstream to the ocean. They pass through the Delta and Suisun Bay as late as August and September (Stevens, 1966; Ganssle, 1966).

Migration of Young

Many of the young shad spawned in the rivers above the Delta apparently travel downstream toward the ocean immediately after hatching. There is evidence from fine-mesh net catches in the Feather River suggesting that these fish migrate primarily from dusk to midnight. Some young remain in the rivers as late as September and October and move downstream when they are several inches long (Richard E. Painter, pers. communication). The bulk of the young shad emigrate from the Delta and pass through San Pablo Bay from September to November (Stevens, 1966; Ganssle, 1966).

A few remain in the Delta over the winter (Delta Study, unpublished). Aplin (1967) trawled almost every month from 1963 to 1966 in San Francisco Bay. He usually caught some shad in each haul from November through May, but caught few in the summer and early fall. Nothing is known about young shad once they enter the ocean.

Growth of Young

Young shad are about 0.4 inches in length at hatching. Individuals in the Delta in July range from that length to about 5 inches (Stevens, 1966), with the average size about 1.2 inches (Erkkila, et al, 1950; Stevens, 1966). The average size increases to about 3.2 inches in September and 4.5 inches in November (Stevens, 1966).

Food

Young shad feed on zooplankton, primarily cladocerans and copepods. *Neomysis* is the principal food of

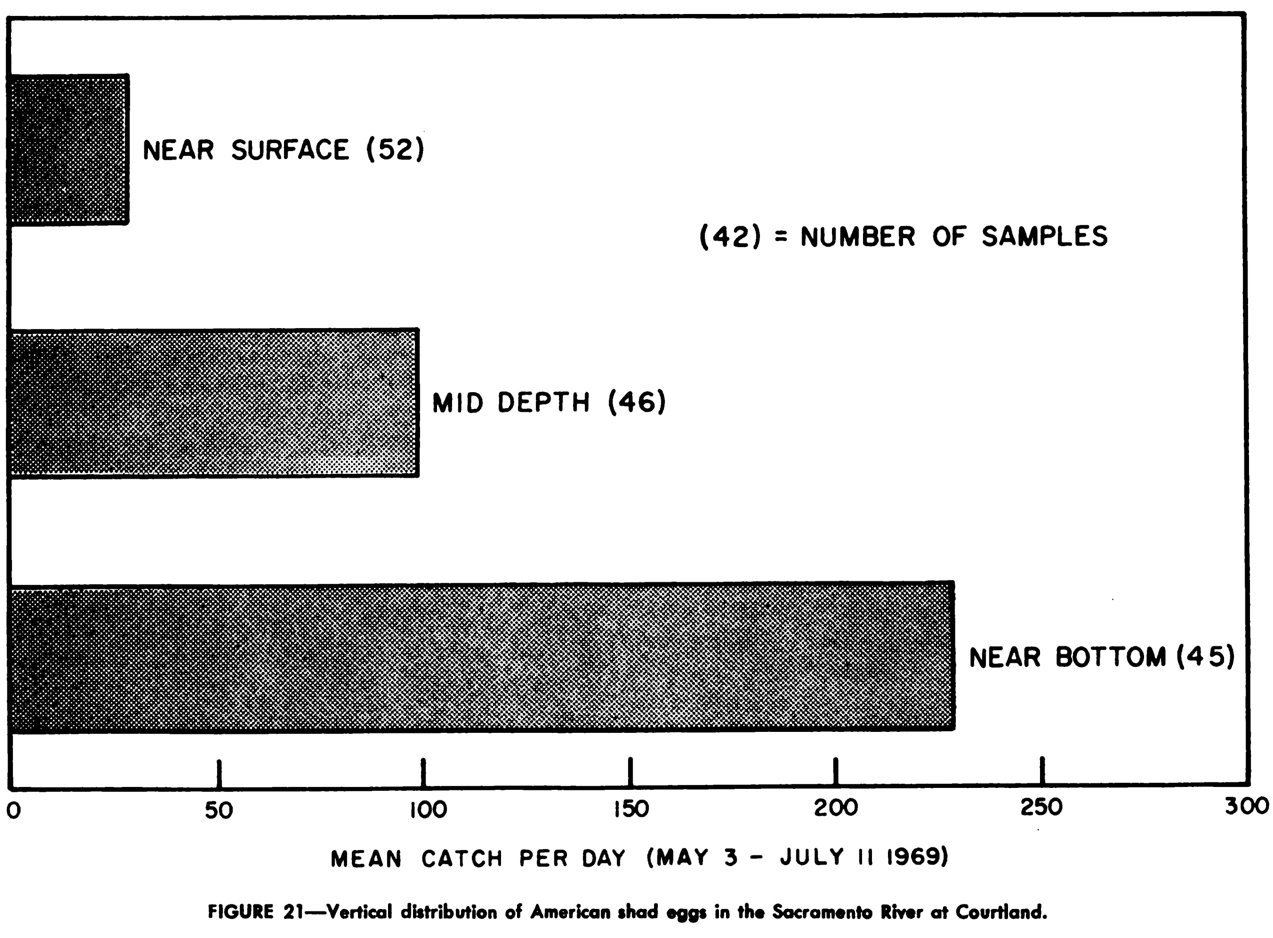

FIGURE 21—Vertical distribution of American shad eggs in the Sacramento River at Courtland.

adults in the Delta, although adults also consume fair quantities of cladocerans and copepods (Stevens, 1966).

Predators

Food habits of all predatory fishes in the Delta have been studied (Calif. Dept. Fish & Game, Fish Bulletin No. 136). Young shad were not consumed in quantity by any of them. On occasion, however, a few small shad were eaten by striped bass (Stevens, 1966) and black crappie (Turner, 1966b).

Adult shad are subject to virtually no predation in the Delta, although 2 adults were once observed in the stomach of a large striped bass (about 40 pounds).

RECOMMENDED ENVIRONMENTAL CONDITIONS

Although we do not know which environmental factors have the most effect on population size, we do know that we must maintain conditions that permit adult shad to migrate upstream during the spawning run and the young to descend to the ocean. A reverse salinity gradient, poor water quality, or lack of flow would probably be deleterious (Kelley, 1968). Suitable spawning conditions should also be maintained in the Delta and streams above the Delta during April, May, and June. Water temperatures between 60° and 70°F, fresh water, and good currents are probably needed for good spawning. Net downstream flows in the summer and fall are probably helpful in guiding young shad toward the ocean. Shad, like many other fishes, are probably most capable of performing their normal activities and surviving environmental stress at dissolved oxygen levels near saturation (Kelley, 1968). *Neomysis* should also be maintained to provide a food supply for both young and adult shad.

It is highly probable that satisfying the recommended environmental conditions for striped bass in the estuary would provide suitable conditions for American shad. The principal additional requirement is that young shad migrating down the Sacramento River must be kept out of diversions.

WHITE STURGEON

By LEE W. MILLER

INTRODUCTION

Sturgeon are an ancient group of fishes. They are remnants of the paleoniscoids which gave rise to modern bony fishes (Lagler, Bardach, and Miller, 1962). All species are confined to the Northern Hemisphere above the 30th parallel (Magnin, 1959). The white sturgeon, *Acipenser transmontanus*, is a native of the Sacramento-San Joaquin Estuary. It ranges from Northern California north to northwestern Alaska. It is the largest freshwater fish in North America. Major population concentrations are found in the Fraser River (Semakula and Larkin, 1968), the Columbia River (Craig and Hacker, 1940), and in the Sacramento-San Joaquin River system (Skinner, 1962).

White sturgeon share the estuary with green sturgeon, *Acipenser medirostris*, but green sturgeon are considerably less abundant than white sturgeon and are rarely caught by anglers.

CHARACTERISTICS OF THE FISH AND FISHERY

Individual sturgeon vary greatly in growth rates and the age at which they reach sexual maturity. Male white sturgeon in the Fraser River reach sexual maturity at 11 to 22 years and females from 11 to 34 years (Semakula and Larkin, *op. cit.*). Pycha (1956) mentioned that females do not mature before 11 to 12 years on the Columbia but gave no reference. In the Sacramento-San Joaquin system, we have found ripe female sturgeon ranging from 12 to 20 years old. These fish ranged in size from 45 to 69 inches in length.

The interval between spawnings has not been determined with absolute certainty for any species although numerous authors report intervals of 2 or more years. (Nikolskii, 1961; Cuerrier, 1966; Roussow, 1957; Magnin, 1966; and Bajkov, 1949). Female white sturgeon in California probably spawn about every 5 years (unpublished data). We have no similar data for males. Semakula and Larkin (1968) report intervals of 4 to 9 years for females in the Fraser River.

Six ripe white sturgeon from the Sacramento River had numbers of eggs ranging from 100,000 eggs in a 49-inch fish to 190,000 in a 65-inch fish (unpublished data). An extremely large female weighing 462 pounds taken in the Sacramento River had an estimated 4,700,000 ripe eggs (Skinner, *op. cit.*).

Commercial catch figures dating from 1875 have been recompiled by Skinner (*Ibid.*). From 1875 to 1884, the catch averaged 280,000 pounds. The average was 780,000 for 1885 to 1894, and from 1895 to the closure in 1901 the mean catch was about 200,000 pounds. Commercial fishing was allowed in 1909, and again in 1916–17 when catches were 15,178 and 9,882 pounds respectively (*Ibid.*).

The stocks apparently recovered during the 35-year closure from 1918–1953. A sport fishery was initiated in 1954 with a 40-inch size limit and a one-fish-per-day-bag limit. The initial party boat fishery caught many sturgeon by snagging which was subsequently outlawed. In 1956, the size limit was raised to 50 inches, due to the observations of Pycha (*op. cit.*) that spawning success was sporadic. In 1963, the size limit was again lowered to 40 inches since the estimated harvest rate of 2 to 10 percent was not excessive (Chadwick, 1959).

In 1964, shrimp were tried as bait for sturgeon and an immediate surge in fishing success occurred (Miller, 1971). The party boat fishery since 1964 has been relatively stable in terms of effort, numbers caught, and mean size of fish caught. In 1969, gaffing of undersized sturgeon was banned to minimize mortality on undersized fish.

LIFE HISTORY

Population Size and Enumeration Studies

Historic abundance of sturgeon in the Sacramento-San Joaquin system can only be inferred from commercial catch data. The catch from 1875 to 1899 totaled 7,852,500 pounds which undoubtedly represented the rapid depletion of virgin stocks. This represented an estimated mean annual harvest of 374,000 pounds.

The present total catch for the Sacramento-San Joaquin River system can be estimated from recent data collected on the sport fishery. From 1967–69, tag returns from party boats comprised 21 percent of the total returns. Since the mean party boat catch was about 1,800 fish, the mean annual catch was about 8,500 sturgeon.

The mean weight of sturgeon caught from 1964–69 was about 32 pounds, so our best estimate of the annual catch in weight is on the order of 270,000 pounds or about 70 percent of the average commercial catch from 1875 to 1899.

The white sturgeon population in 1967 was estimated to be about 115,000 with 95 percent confidence limits of 72,000 to 212,000 (Miller, 1972a). This estimate of 115,000 agrees well with an estimate of 122,000 which can be made independently from the estimated total catch and the exploitation rate.

Migrations

White sturgeon are considered an anadromous fish since they spend part of their life in estuaries and spawn in fresh water. Data collected by Pycha (1956) indicated a winter-spring migration upstream followed by a summer downstream migration of adult fish in the Sacramento-San Joaquin River system.

The 1954 tagging study in the Sacramento-San Joaquin Estuary revealed very little concerning migrations. No upstream recaptures were made although one tagged fish was recaptured in Oregon (Chadwick, 1959).

Tagging studies in 1967 and 1968 have provided the best information to date on migrations (Miller, 1972b). Most of the recaptures during the fall and winter were from Suisun Bay and San Pablo Bay. A portion of the population migrates to the lower Sacramento River in the winter prior to spawning. From March through June some tags were returned from upriver areas. They apparently move downstream after spawning. Large aggregations of sturgeon are found in San Pablo Bay from September to November.

Spawning

The first significant evidence regarding the timing and location of sturgeon spawning in the estuary came from sturgeon larvae collected in 1966, 1967, and 1968 (Stevens and Miller, 1970). The larvae were most likely white sturgeon and were collected between mid-March and early June. There was some annual variance in their occurrence. A total of 126 larvae were collected, 100 from the Sacramento River system, 13 from the lower San Joaquin River and 13 from Suisun Bay. All of these larvae could have originated from the Sacramento River system. One larva was caught in the Sacramento River above the mouth of the Feather River indicating that at least some spawning occurs above that point. Few larvae were caught in the Delta except in 1967 when the April Delta outflow averaged about 50,000 cfs—more than twice the flows in 1966 or 1968. In the Sacramento River near Sacramento most of the larvae were near the bottom. River temperatures at the time of larvae collecting ranged from 59° to 70°F.

Nikolskii (1961) indicates that most sturgeon spawn on gravel or rocky substrate. In the Sacramento River this type of bottom occurs primarily from 120 to 220 miles above the mouth of the Feather River (Stevens and Miller, 1970). In the Feather River, gravel substrate occurs from 44 to 58 miles above its mouth.

In 1968, tagged adult fish were caught in the Sacramento River as early as March 26 and as late as June 9 (Miller, 1972b), corroborating the long spring spawning period inferred from larval sampling.

Egg and Larval Development

Virtually nothing is known of the very early embryology of white sturgeon. The eggs are apparently adhesive after being fertilized and stick to vegetation and rocks (Bajkov, 1949).

Larvae collected in the Sacramento River ranged in size from 10.3 to 17.6 mm (0.4–0.7 inches). Larvae longer than 18.5 mm had depleted the yolk (Stevens and Miller, 1970). Yolk sac larvae are darkly pigmented and the yolk sac is greyish in color. The size of the Atlantic sturgeon, *Acipenser oxyrhynchus*, larvae at hatching is about 11 mm (Mansueti and Hardy, 1967).

Morphologically, the larvae are recognizable as sturgeon at 21 mm (0.8 inch). At 41 mm (1.8 inches) in length, they are sufficiently differentiated meristically, that species identification is possible.

Growth

Pycha (1956) published data on sturgeon growth in California. Sturgeon attain a mean length of 10.4 inches during their first year. Growth, from then until legal size (40 inches), which is reached at about age 7, is rapid. Subsequently, growth slows to about 2.1 to 2.5 inches per year.

Food and Feeding

McKechnie and Fenner (1971) published a comprehensive analysis of adult sturgeon food habits in San Pablo and Suisun Bays. Benthic invertebrates were the dominant organisms. Small crabs, *Rhithropanopeus harrisii* and *Cancer magister*; bay shrimp; and clams, *Gemma gemma*, *Macoma* and *Tapes semidecussata*, comprised most of the diet; except in San Pablo Bay during the winter and spring when herring eggs comprised 20 and 80 percent by volume of their food. Striped bass, anchovy, midshipman, staghorn sculpin, and herring were all eaten in small numbers.

The opossum shrimp, *Neomysis awatschensis*, and the amphipod, *Corophium*, make up most of the diet of juvenile sturgeon in the Delta (Schreiber, 1960; Radtke, 1966).

It is apparent that benthic organisms are important in the diet of sturgeon, hence, the importance of large shallow tidal areas for food production. The concentrations of sturgeon in San Pablo Bay, Suisun Bay and south San Francisco Bay attest to the importance of these areas.

ENVIRONMENTAL INFLUENCES AND REQUIREMENTS

There is little knowledge of the environmental parameters that affect the abundance of sturgeon either in this estuary or in the other river systems of the West Coast. Although this species may be defined as anadromous there is little indication it spends lengthly intervals in the ocean. San Pablo Bay, an important feeding area in the fall and winter, is characterized by salinities ranging anywhere from 6 to 16 parts per thousand, TDS, during this period, depending upon outflow. White sturgeon also frequent San Francisco Bay where surface salinities may range from 11 to 31 parts per thousand, TDS, (Aplin, 1967). The principal features of these areas appear to be the broad mud flats with large populations of benthic invertebrates.

Yolk-sac larvae coming down the Sacramento River during the March to June period will be susceptible to water diversions, particularly large export diversions. Since yolk-sac larvae have negligible swimming capabilities, measures will be necessary to prevent their diversion with the water. Provision should be made for efficient screens and/or pumping curtailment.

Juvenile sturgeon are found in the Delta (Radtke, 1966) and the lower bays. Their survival and growth apparently depend upon adequate populations of *Neomysis* and *Corophium* (Radtke, 1966; Schreiber, 1960). Therefore, conditions which are optimum for these species, particularly *Neomysis*, will enhance survival and growth of both young-of-the-year and juvenile sturgeon. Further research on the food habits of very small sturgeon (20–100 mm) might reveal an importance of other zooplankton or benthic organisms which could be affected by changes in the ecosystem.

Environmental conditions necessary for successful migration and reproduction are unknown. Such environmental factors as photoperiod, temperature, and the usual copious winter and spring flows could be important stimuli for migration and spawning. Areas utilized for spawning should be determined and actions taken to protect these areas from degradation.

RECOMMENDED ENVIRONMENTAL CONDITIONS

Sturgeon requirements may be stated in general terms as follows:

1. Maintenance of oxygen and temperature conditions adequate for optimum populations of food organisms, particularly *Neomysis* and *Corophium* in the Delta for young-of-the-year sturgeon.
2. Maintenance of viable mud flats and bays suitable for optimum production of benthic organisms.
3. Adequate downstream flows should be provided in the river system and estuary for migration to and from spawning areas and to maintain a viable, resident population and a fishery.
4. Protection against loss of young in diversions.

The uniqueness as well as the real and potential economic value of this ancient, native fish makes its protection through adequate research and proper management imperative.

RESIDENT FRESHWATER FISHES OF THE DELTA

By JERRY L. TURNER

INTRODUCTION

The principal resident fishes of the Sacramento-San Joaquin Delta are white catfish, brown bullheads, black crappie, bluegill, largemouth bass and threadfin shad. None of these species are native to the Delta. All were introduced from the eastern United States in the last quarter of the 19th Century except for threadfin shad which were brought into California in 1953 (Skinner, 1962). Resident fishes as discussed here are distinguished from the migratory or anadromous species such as salmon, striped bass, American shad and sturgeon.

The resident fishes support a popular sport fishery and some provide an important food supply for the larger predatory fishes. Over half of the catfish caught by anglers in the State are taken in the Delta. Most of these are white catfish. An important sport fishery exists for members of the centrarchid or sunfish family such as black crappie, largemouth bass and bluegill. Threadfin shad are an important food for such game fish as striped bass, largemouth bass and black crappie.

CHARACTERISTICS OF THE FISH AND FISHERY

Distribution

Most resident fish are found in the quiet sloughs off the main channels of the Delta (Pelgen, 1954; Pelgen and McCammon, 1955; Turner, 1966). Centrarchids and bullheads are taken in greatest numbers in the dead-end sloughs. Threadfin shad are also abundant in dead-end sloughs and in the San Joaquin River near Stockton. White catfish are found throughout the Delta but are most abundant in quiet backwaters and flooded islands such as Franks Tract. Channel catfish are an exception with most living in the swifter water in the principal channels upstream from the central Delta.

The downstream distribution of resident species is limited by salinity conditions in the western Delta (Ganssle, 1966). Centrarchids rarely occur when chlorides reach 1 to 3 parts per thousand. Adult white catfish are more tolerant, occurring regularly in low numbers in Suisun Bay where chlorides reach 8 to 10 parts per thousand.

Reproduction and Nesting

White catfish spawning occurs in the Delta during June and July when the water temperature reaches about 70°F (Turner, 1966a; Borgeson and McCammon, 1967). Spawning has not been observed in the Delta but elsewhere they construct a nest on the bottom in which they deposit adhesive eggs. The eggs are reported to hatch in 6 to 7 days at a water temperature of 80°F. Young-of-the-year white catfish have been taken throughout the Delta but are most common in the southen area.

Reproductive habits of the centrarchid family in the Delta have not been observed. It is reasonable to assume from evidence gathered elsewhere that they make nests on various types of bottoms. Black crappies and largemouth bass spawn in the spring after the water temperature reaches 60°F. Bluegill spawn later as the temperature warms up and the spawning period often extends until fall.

Threadfin shad spawn in the spring as the water reaches 70°F. Threadfin hatched in the spring may themselves spawn the following fall. Few survive to spawn twice. The eggs are released in open water, sink, and being adhesive become attached on the bottom.

Food Habits

Catfish are omnivorous, feeding on whatever is available on the bottom (Turner, 1966a). *Corophium, Neomysis,* and tendipedids were the most frequent food items for all sizes of catfish. The importance of larger food items such as fishes and crayfish increases as the size of the catfish increases. A comparsion of their food habits differs by environment and available food.

Young centrarchids feed on small crustacean zooplankton. *Neomysis* and *Corophium* were the most common food item found in all sizes of black crappie (Turner, 1966b). As black crappie increase in size, fishes become important in their diet. *Corophium* was the major food item of bluegills. Crayfish and fish were common food items of largemouth bass. The food habits of the centrarchids are similar to that reported by workers in other areas except that here mysid shrimp and amphipods rather than aquatic insects are the major invertebrates eaten.

Phytoplankton and zooplankton, particularly cladocerans and copecods are the major food items of threadfin shad (Turner, 1966c).

Growth

The growth rate of resident fishes appear to be much slower in the Delta than for the same species in other environment (McCammon, 1957; Turner, 1966a,-b). White catfish and black crappie do not become as large as they do elsewhere. Fish are also less important as a food item for young white catfish than they are elsewhere. The Delta being very turbid probably limits the ability of predatory game fish to sight their quarry, thereby restricting their diet and food intake and reducing growth rates.

RECOMMENDED ENVIRONMENTAL CONDITIONS

Problems facing the resident fish populations are not serious compared to the anadromous fish populations. However, several of them are quite similar. The present transport of water from the Sacramento River across the Delta to the export pumps at Tracy creates problems for resident fish by affecting the abundance of food organisms such as *Neomysis* and *Corophium.* Our studies show that the present populations of these food organisms are depressed in those Delta channels used to transport water. Elimination of the use of these channels as conduits to transfer water would increase the available food.

Another effect of transporting water across the Delta is the loss of larvae and young fish via the export pumps near Tracy. Fish screens at the canal intakes save many fish but are efficient only in removing fish large enough to swim well. The present loss of young resident fish to the diversion pumps is probably kept to a minimum because of their preference for quiet water and their nesting habits on the bottom. These losses will surely increase as flow across the Delta is increased.

While net velocities should be reduced, they should not be reduced too much.

Some fish food organisms, such as *Neomysis* for example, have demanding temperature and oxygen requirements which presently are not met in the San Joaquin River just below Stockton in late summer (Heubach, 1969). Numerous fish kills, suspected to be caused by low dissolved oxygen conditions, have been reported in this section of the river. The river above Stockton experiences daily fluctuations in dissolved oxygen concentrations of 6 to 8 mg/l. These are associated with phytoplankton blooms and they are probably detrimental even though minimum concentrations remain above saturation. Although neither temperature nor oxygen are functions of water flow primarily, flows influence both.

Salinity incursion into the western Delta would affect the resident fishes in that area. The extent of the problem would, of course, depend on the amount of incursion. The principal species affected would be the white catfish. Most of the present population of centrarchids is found in the dead-end sloughs in the eastern and southern Delta.

Some consideration has been given to releasing water from the proposed Peripheral Canal into the dead-end sloughs to improve water quality conditions. Low dissolved oxygen levels do frequently occur in the upper ends of some of these sloughs and freshwater releases could raise dissolved oxygen levels (unpublished data). However, releases of water through these sloughs should not be excessive since this would destroy the present quiet water environment and reduce the resident fish population.

Test site in Suisun Marsh

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CHAPTER VIII

WILDLIFE RESOURCE REQUIREMENTS WATERFOWL AND THE SUISUN MARSH

By ROLF MALL and GLENN ROLLINS

INTRODUCTION

The study of Suisun Marsh was prompted by two considerations: (1) the Suisun Marsh plays a very important role in providing wintering habitat for waterfowl of the Pacific Flyway, and (2) reduced outflow would increase water salinity around the marsh and might thereby alter the waterfowl food supply.

Consisting of almost 55,000 acres of marsh land and another 30,000 acres of bays and sloughs (Figure 22), the marsh comprises almost 10 percent of the remaining natural wetlands in California. This habitat type has been disappearing at an alarming rate. The Suisun Marsh is unique, considering that it lies within 30 miles of the San Francisco Bay megalopolis.

Peak numbers of wintering ducks and geese are usually observed in the marsh during November and have been as great as 1,500,000 birds. During years of drought, the area becomes particularly important to waterfowl by virtue of its large expanse of aquatic habitat and the scarcity of such habitat elsewhere. Under such conditions, up to 20 percent of the wintering duck population within California has been attracted to and held within the Suisun Marsh. The majority of the wintering population consists of pintail, one of the State's most sought after species of duck.

Aside from its importance to waterfowl of the Pacific Flyway, the Suisun Marsh provides critical habitat for a host of other wildlife forms. Such endangered, rare or unique species as the peregrin falcon, white tailed kite, bald eagle, California clapper rail, black rail, salt-marsh harvest mouse and Suisun shrew, also depend on it. Some are permanent residents. The existence of this wide variety of wildlife is due to: (1) the relatively large expanse of unbroken native habitat and, (2) the diversity of vegetation and aquatic conditions that prevail in the marsh.

WATERFOWL FOODS AND HABITAT

The major factors which render the area so attractive to waterfowl are the widespread presence of water and the abundant source of food. With respect to the food supply, it is noteworthy that of over 180 species of plants known to occur in the marsh, only about 20 percent regularly appear in the diet of ducks. Studies have shown that seeds from two plant species in particular provide the bulk of the winter food supply. These are alkali bulrush and brass buttons (Figure 23). Alkali bulrush, by itself, is the single most important food for ducks that spend the fall and winter in the Suisun Marsh. On the other hand, some plant species are more abundant than these two, yet provide little in the way of food. These include pickleweed, saltgrass, and cattail.

WATERFOWL FOOD PLANT REQUIREMENTS

The above mentioned plants, along with others, compete for living space within the marsh environment. Results from our studies indicate that, in general, there are two primary controlling factors which determine the presence or absence of a given plant species and its overall productivity. The first is the length of time the soil is flooded, and the second is the concentration of salt in the root zone of the soil.

The flooding aspect essentially divides marsh plantlife into upper and lower groupings, the upper tolerating prolonged periods of dryness and the lower requiring extensive flooding. It is from the lower flora that most ducks derive the bulk of their sustenance. Common plants associated with long periods of flooding, in descending order of tolerance include cattail, alkali bulrush, brass buttons, and pickleweed (Figure 24).

The general salinity tolerance of these plants is inverse to their tolerance to submergence. Pickleweed displays the greatest tolerance of the group while cattail displays the least tolerance to high salt concentrations. Alkali bulrush, the major duck food, is intermediate in its ability to grow in saline soils. Our investigations have shown that soil salinity levels during the spring are the principal determinant of the amount of seed this plant will yield. The level of salinity which permits the optimum production of seed is centered around 9 parts per thousand of total dissolved solids (9 ppt TDS). Levels exceeding 16 ppt effectively inhibit seed production (Figure 25).

MAN'S INFLUENCE IN THE MARSH

Man is an integral part of the present marsh ecosystem and, to a significant extent, controls the two environmental factors discussed above. In the first instance, man exerts a major influence on the floral characteristics through water management practices in the marsh. This capability has existed since the late 1800s when the first levees and water controls were installed. At the present time almost all flooding activities, in fact almost all land use, are directed toward management of the marsh for the purposes of hunting and/or observing waterfowl and, to a certain extent, to reduce crop depredation by waterfowl in the Central Valley. Besides the 10,000 acre State-owned Grizzley Island Wildlife Area, there are over 200 private duck clubs devoted, in varying degrees, to these activities. Flooding of the marsh is normally initiated in late

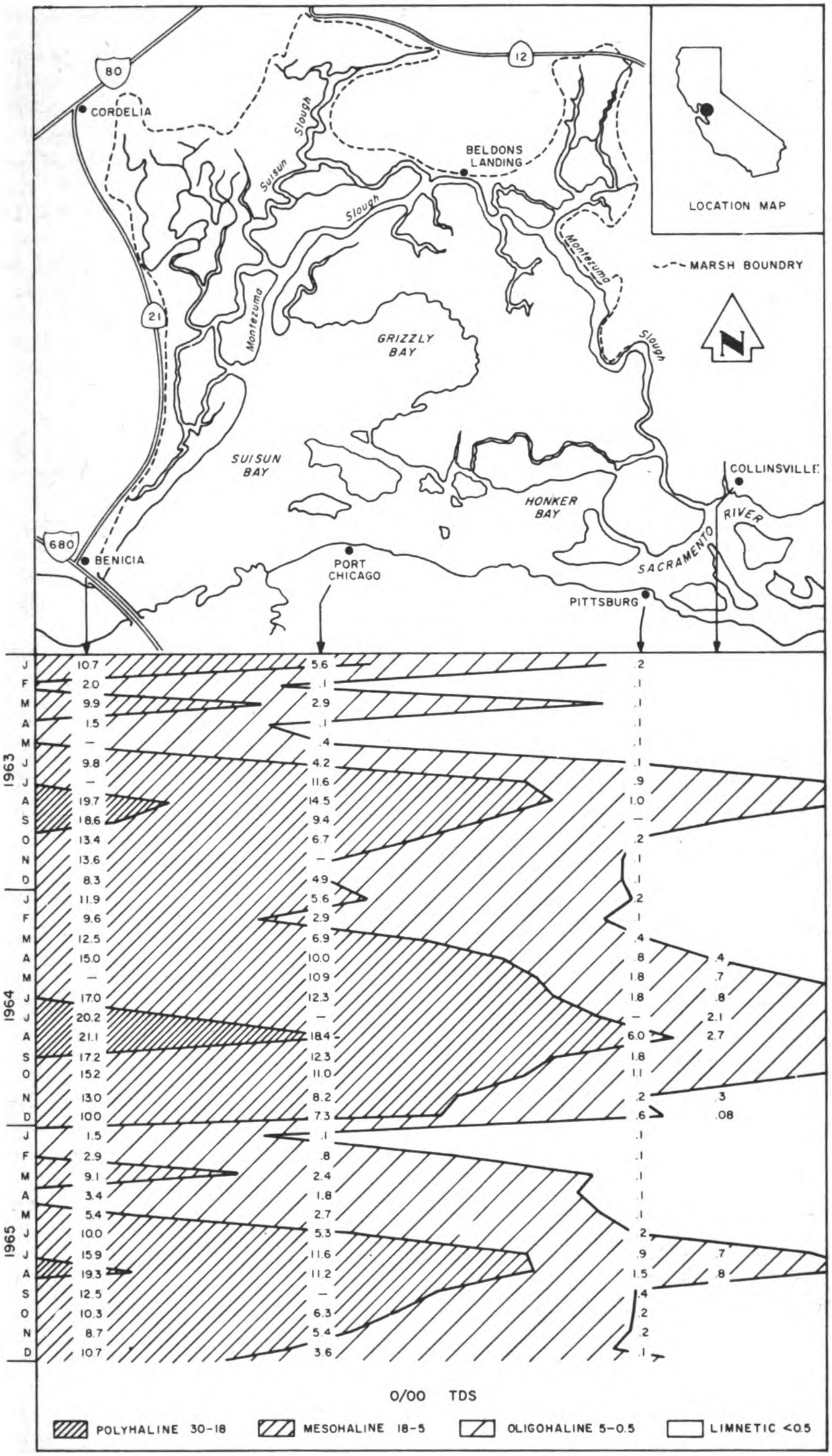

FIGURE 22—Map of the Suisun Marsh showing salinity data from the adjacent Sacramento River channel for the period 1963 to 1965. Salinity values are parts per thousand TDS. Salinity zones shown are based on the Venice system of estuary classification. (Data from Calif. Dept. Water Resources, 1963–1965.)

September and some continues until mid-June. Most flooding activity, however, occurs during the period October–January.

Man has influenced salinity in the surrounding sloughs and bays by a variety of upstream diversions and storage reservoirs. These works have effectively reduced the average outflow of the Sacramento River System into the estuary from about 30 million acre-feet during the early 1900s to about 16 million acre-feet at the present time. Although regulated river flows now provide greater stability and prevent the greater salinity intrusions into the Delta which occurred historically, there has been an overall increase in the average salinity of the waters surrounding the Suisun Marsh. At the present time, the salinity of waters available for application to the marsh during the period from October through January averages 7 ppt TDS. The salinity of ocean water, for comparative purposes, contains 35 ppt TDS.

FUTURE IMPACT OF WATER DEVELOPMENT

Future proposed reductions of outflow to the estuary would increase the salinity of water surrounding the Suisun Marsh. Our studies have demonstrated that the anticipated increase in channel water salinity would cause a corresponding increase of salt in the soils to which it is applied.

Earlier predictions of conditions under the 1990 level of development (Mall, 1969) [1] indicate that under dry or normal year outflow regimes the lower limit of polyhaline waters (18 ppt TDS) would move up the river as far as Honker Bay (Figure 26). Comparison of future with present conditions reveals that over 75 percent of the marsh would experience salt concentrations that are now detected only briefly during late summer at the far western end of the area (Figures 22

[1] Current planning by the Department of Water Resources indicates that what is termed the 1990 level of development here would not be reached until after 1990 (DWR Bulletin 160-70).

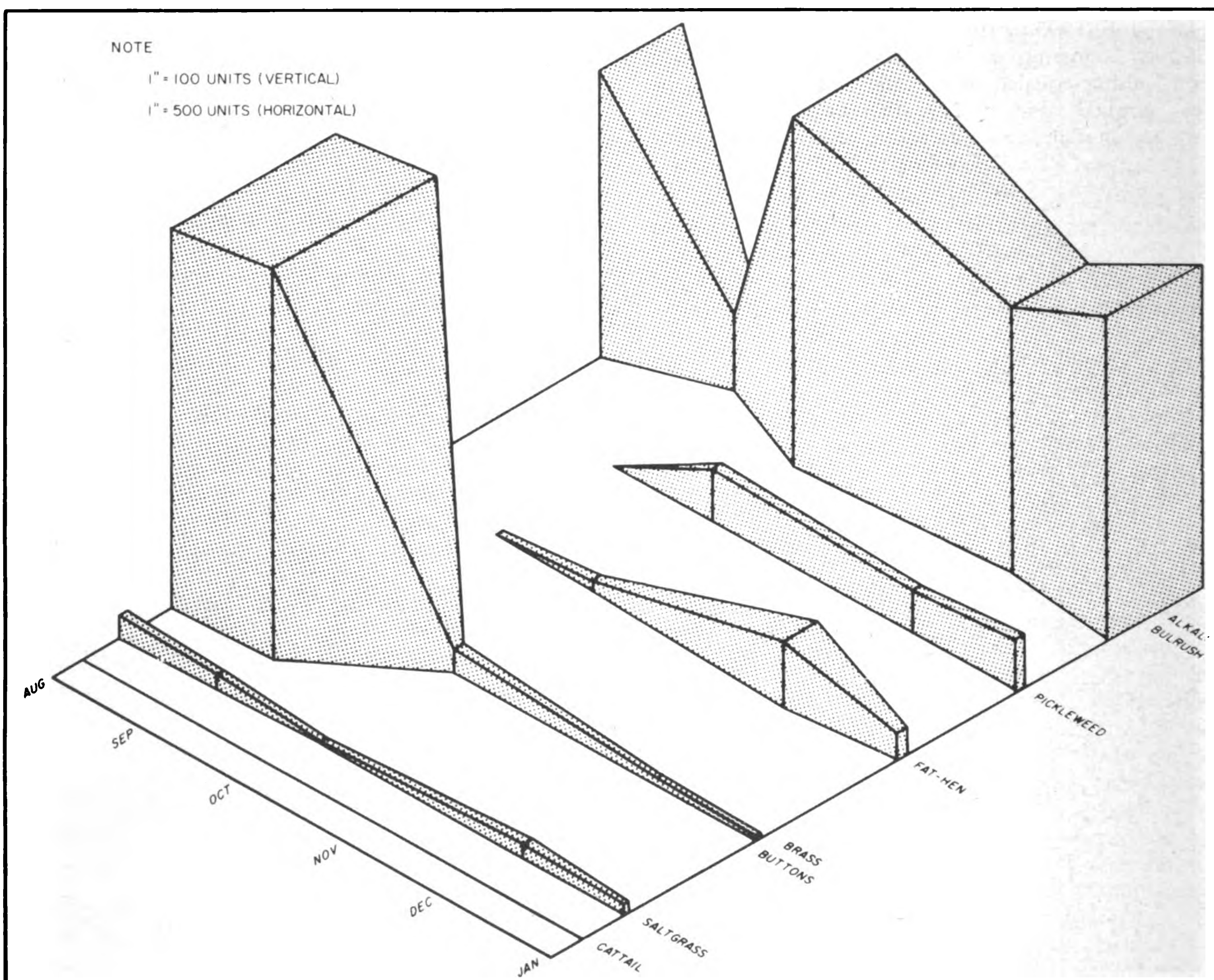

FIGURE 23—The relative food use (vertical axis) and food selection (horizontal axis) of six Suisun Marsh plants for ducks during fall and early winter.

and 26). Water applied to the marsh during the period from October through January would average about 20 ppt TDS and 17 ppt TDS, respectively, under dry and normal outflow conditions as compared with 7 ppt TDS currently. Outflow during wet years under future (1990) conditions would result in salinity patterns which approximate those now associated with normal outflow. But, such conditions would occur about 20 percent of the time at most. Hence, high fall and early winter salinities in excess of 18 ppt TDS could be expected to occur in the vicinity of Honker Bay approximately 80 percent of the time in the future (1990).

A two-year investigation designed to determine the interrelationship between soil salinity and the salinity of applied water was conducted under the Delta Fish and Wildlife Protection Study. This study placed emphasis on observing the changes in soil salinity from the application of saline water similar to that which would occur under future conditions.

Simulated spring flooding with water of the quality predicted for 1990 produced substantial increases in soil salt. Following all such tests, the resulting soil salinity either equaled or exceeded the salinity of the water applied (Figure 27). Presently, low salinity water is generally available and when applied reduces the salinity of the soil. Under existing marsh management practices and capabilities the anticipated increase in spring soil salinities projected for the future can be expected to result in an overall yearly increase in soil salinities throughout the marsh.

The predicted salinity increases would adversely affect important waterfowl food plants by lowering or eliminating their seed production and by increasing the competitive advantage of marsh plants of inferior value to waterfowl. Based on comparisons with other local salt marshes dominated by these inferior food plants, the capacity of Suisun Marsh to attract and hold waterfowl would be reduced from a current density of 5 ducks per acre to about 1 duck per acre. A reduction of this magnitude projected to the total marsh results in an estimated loss in carrying capacity of one-quarter million ducks, a significant proportion of the wintering population of waterfowl in the Pacific Flyway.

RECOMMENDED ENVIRONMENTAL CONDITIONS AND PROTECTIVE MEASURES

Protective measures must be developed and implemented in order to maintain the quality of habitat that makes the Suisun Marsh one of California's most valuable areas for wintering waterfowl. These protective measures fall into four categories: (1) establishment of environmental criteria, (2) improvement of present water management practices, including drainage and other water control facilities, (3) provisions for supplemental water supplies to assure their availability when needed and, (4) development and implementation of plans and policies to protect the marsh from development or invasion by excessive human use.

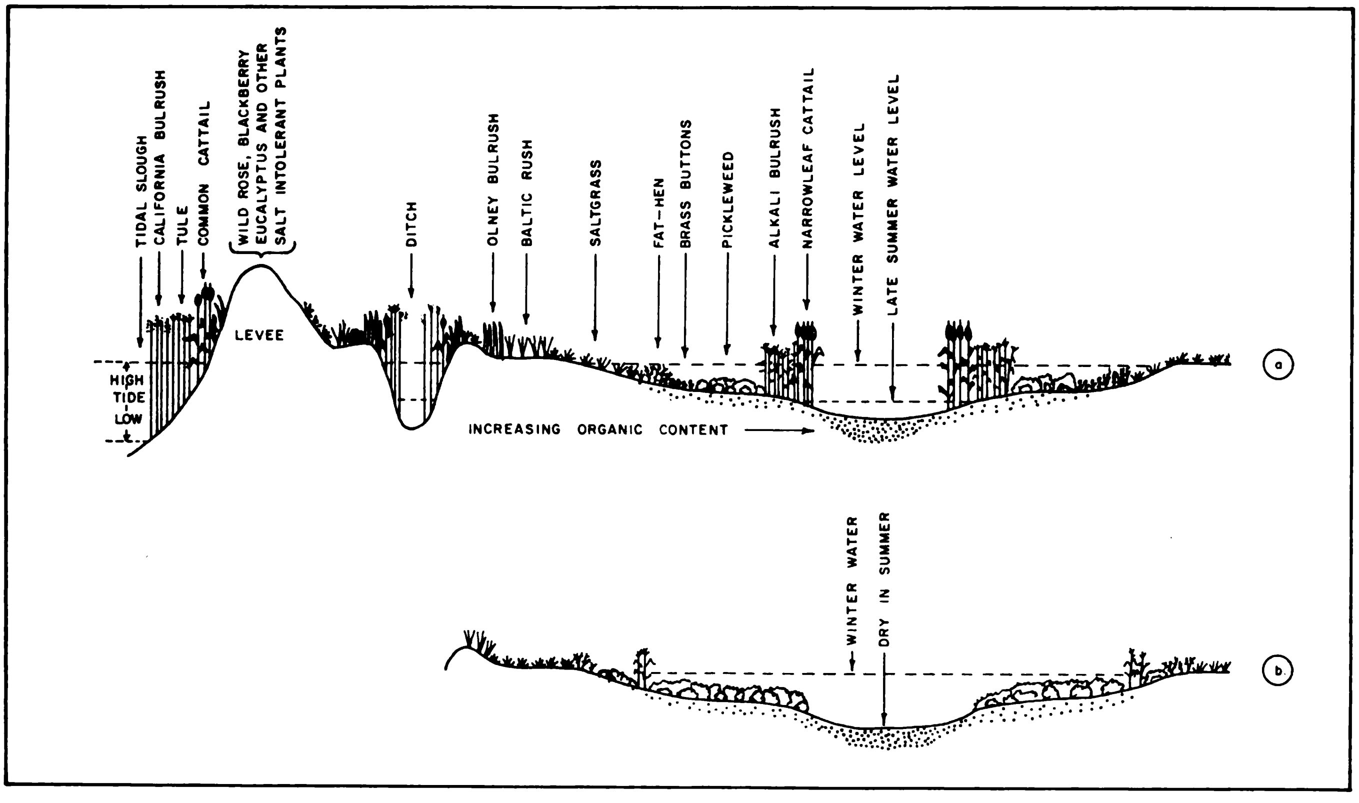

FIGURE 24—Schematic representation of plant distribution in the Suisun Marsh in relation to two kinds of water management: (a) maintenance of pond water into early summer and (b) early spring water removal.

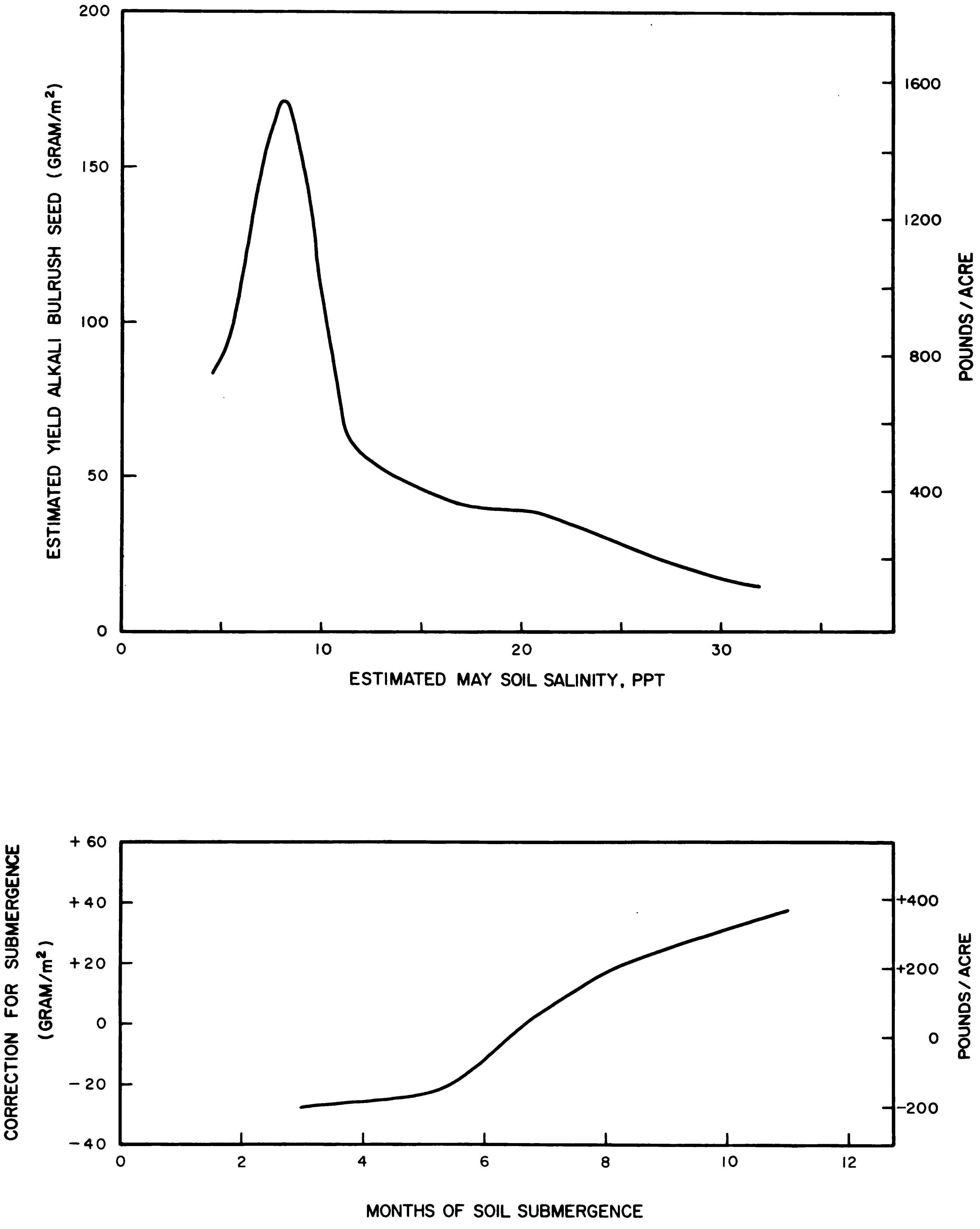

FIGURE 25—Relation of alkali bulrush seed yield to May soil salinity and length of soil submergence.

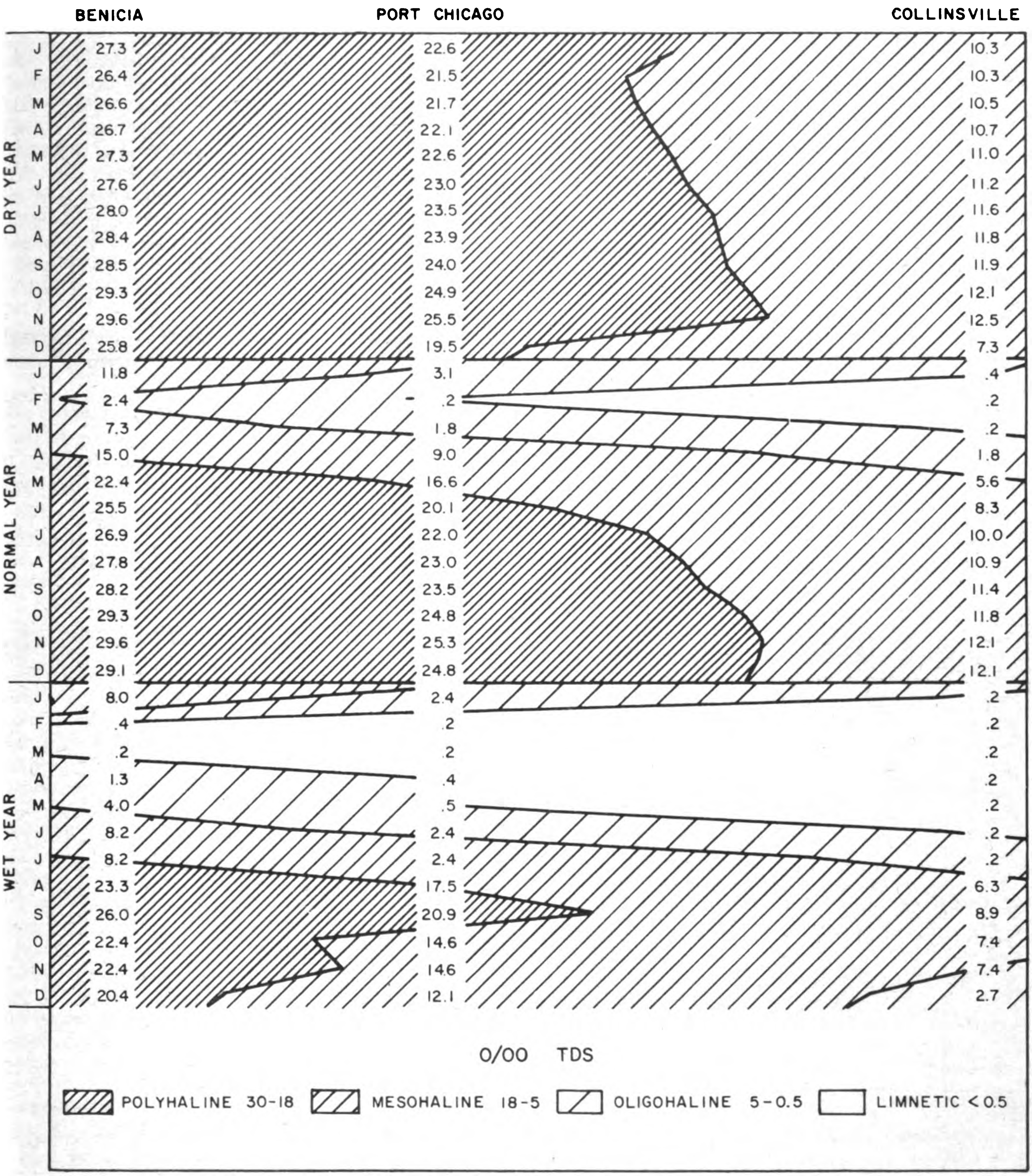

FIGURE 26—Predicted seasonal changes (1990 water project conditions) in salinity for the Suisun Bay system for various water conditions. Salinity zones shown are based on the Venice system of estuary classification. Figures are in parts per thousand total dissolved solids.

Environmental Criteria

Studies conducted by the California Department of Fish and Game have established some baseline criteria for the production of valuable waterfowl food plants. More specifically, these criteria are aimed at optimizing conditions for alkali bulrush and, in part, were recommended to the State Water Resources Control Board to protect the Suisun Marsh until more permanent measures can be established. These recommendations are that there should be available by February 1 of each year, water sufficient in quantity and quality so as to produce under reasonable management practices, between April 15 and June 1 of each year, an average salinity of 9,000 mg/1 TDS (9 ppt) in the first 12 inches of soil. Further, that the mean monthly salinity of the natural channels and the bay surrounding and adjacent to the marsh should not exceed 18,000 mg/1 TDS until a suitable alternative water supply is provided.

Water Management

Waterfowl food production in the marsh can and is being increased substantially under present conditions by the improvement of water control and water management practices. The Department of Fish and Game, in cooperation with the U. S. Soil Conservation Service, is currently engaged in an intensive program to encourage duck club owners and operators to improve their facilities and adopt sound management practices designed to optimize conditions for alkali bulrush.

Such practices as the drainage of shooting ponds immediately following the waterfowl season in January and not reflooding them again until late September must be discouraged or utilized only when necessary. This procedure produces soil salinities during the spring and summer that effectively discourage the growth of desirable food plants. It has been demonstrated that leaching the shooting ponds with the relatively fresh water (2 to 3 ppt TDS) presently available in the winter and spring results in a substantial reduction of soil salt in the root zone. Each successive leaching cycle removes additional salt. Obviously, the limit of salt reduction by this method, even under ideal conditions, will be reached when the soil salinity equals the salinity of the applied water. Soil salinity cannot be reduced below that of the water applied to it.

The following water management schedule has been formulated as a guide to marsh management under existing water qualities:

Early October. Flood in October as rapidly as possible to achieve the desired shooting level by the first day of the waterfowl season. Care should be taken to be sure that flooding time and procedures are consistent with mosquito abatement regulations.

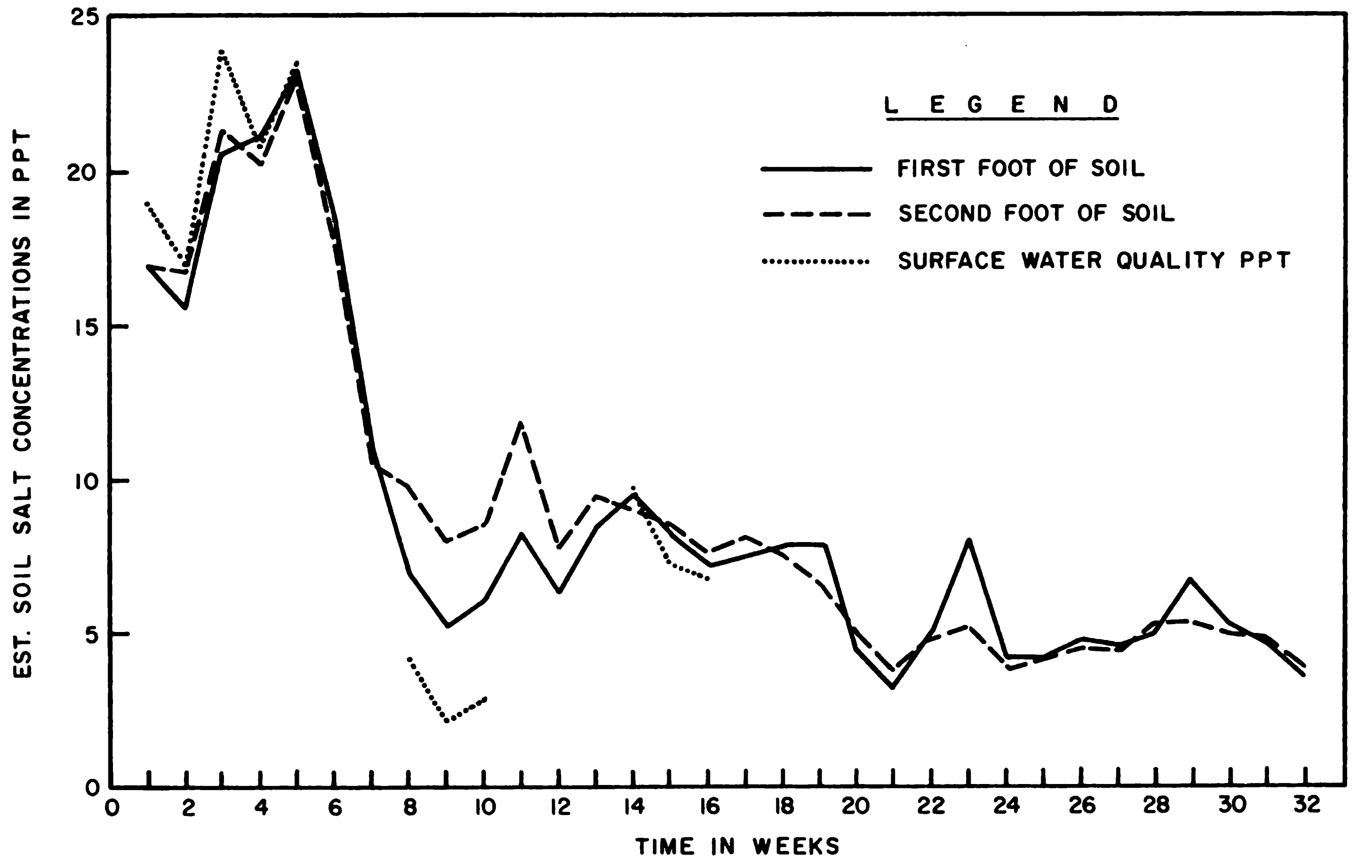

FIGURE 27—Weekly mean soil and surface water salinities of test plots flooded with water containing 20 parts per thousand of total dissolved solids.

Mid October through mid January. Inlet gates should be set to allow maximum water flow through the ponds during the waterfowl season, while maintaining the water at shooting level.

Mid January. Post season draining should begin by mid January or even before the last day of the hunting season. Close all inlets and remove all flash boards to allow ponds to drain as rapidly as possible.

Late February. Reflood as soon as the ponds have drained, even if a few hard to drain areas still contain water. Open all inlets and allow the water to rise quickly to about shooting depth.

Early March through late March. When the pond level approaches shooting depth, drain and reflood to the same level. This flood and drain cycle should be repeated at least twice to leach salt from the soil. Leaching is far more effective than continuous circulation for removing soil salt.

April 1. The leaching cycles should be so timed that by no later than the first of April water levels are stabilized at one-half shooting depth. This will comply with mosquito abatement regulations.

April through May. Circulate water by setting the inlet gates and flashboards to allow maximum flow through the ponds without increasing water depth. Extreme care must be taken to eliminate fluctuations in pond levels which would favor the propagation of mosquitoes.

Early June through late September. Drain the ponds about the first week in June, or when the majority of alkali bulrush and other waterfowl food plants have set seed. Close inlets, remove flashboards and allow complete drainage.

It is important to note that this management program is not always appropriate. It is recommended primarily: (1) when pond areas consist of large, dense stands of pickleweed or salt grass or, (2) when spring channel salinities exceed 7 ppt TDS and the salt concentration in the root zone of pond areas is in excess of 14 ppt TDS. Leaching with water more saline than 14 ppt would not achieve soil salinities within the desired range for optimum production of alkali bulrush seed. When spring channel salinities are less than 7 ppt TDS repeated leaching is not necessary.

Just as it is possible to produce too much salt in the soil, it is also possible to freshen the soil to the extent of providing conditions which favor the invasion of undesirable plants such as cattail, tules, Baltic rush (wiregrass) and Olney bulrush. The invasion of these less desirable plants may be averted by modifying the recommended schedule. This may be done by either drying the ponds sooner or modifying the leaching process or both.

Supplemental Water

Finally, consideration must be given to that point in time when upstream diversions result in channel salinities which exceed the capability of water management alone to maintain the established criteria. It will then be necessary to develop alternate water supplies. This points to the need for a feasibility study with the following objectives: (1) preparation of a water supply plan or plans, (2) determination of the cost or costs and any associated benefits along with an initial definition of the allocation of the costs among the various interested groups and, (3) recommendation of procedures for implementing the plan selected. The U. S. Bureau of Reclamation has been assigned primary responsibility for administering the feasibility study, with development and conduct of the program receiving the full participation of the U. S. Bureau of Sport Fisheries and Wildlife, the California Department of Water Resources, and the California Department of Fish and Game.

Plans and Policies

In view of the scope of development in the Bay area, it is not difficult to foresee inroads into the marsh in the near future in the form of residential, commercial or industrial developments. The protective measures described above will be of little benefit if the marsh is subjected to such development. Consequently, if the goals of preserving the marsh are to include preservation of its waterfowl holding capacity and retention of the diversity of its fauna, it is imperative that plans and policies be formulated to implement these goals. Such plans and policies should be designed to accomplish the following:

Preserve the integrity of the marsh. Perhaps the greatest asset of the marsh, in terms of its ability to attract and hold waterfowl, is its large size and unbroken character. Division of the marsh or intrusion by developments of one kind or another would almost certainly result in impairing its wildlife value far beyond their obvious effects. The fundamental basis for this statement is, of course, that far ranging wildlife forms such as eagles and falcons are essentially incompatible with such developments. In addition, developments have a habit of growing, and bringing along with them all sorts of related or secondary developments such as roads, service stations, stores, restaurants and supplier or service agencies. Lastly, development in almost any area or segment of the marsh would reduce its attractiveness to waterfowl and hence impair its value to private duck clubs. As a consequence, clubs so affected would undoubtedly sell their holdings eventually and thus encourage further development.

Assure continued wildlife use of the Suisun Marsh. Continuation of the present or improved wildlife management programs in the marsh, to a large extent, depends on favorable economic conditions. More specifically, lands in the marsh should not be vulnerable to sale in the highly competitive market for commercial and industrial site development. Private holdings in the marsh, however, must be regarded in this light at the present time. It is essential therefore, that consideration be given to programs and policies that would assure retention of the existing large tracts of private land in the marsh for waterfowl and wildlife use.

Possibilities to accomplish this goal include: (1) state or federal acquisition, (2) favorable tax incentives to duck club owners, (3) direct government subsidy similar to the land bank program or agricultural subsidies, and (4) assistance by way of preferential treatment in providing improvements such as water supplies and control structures and drainage facilities in return for owner guarantees that their properties will continue to be used for wildlife purposes.

Another approach to achieving this objective involves establishing zoning ordinances.

OTHER WILDLIFE

INTRODUCTION

While maintenance of suitable conditions for waterfowl in Suisun Marsh has been the primary concern related to wildlife, the requirements of other wildlife species have been evaluated during the Delta Fish and Wildlife Protection Study. These are reviewed in this section. This review is restricted to requirements bearing some relationship to water development plans.

The species of wildlife involved vary tremendously in their nature and requirements. They include waterfowl using parts of the estuary other than Suisun Marsh and a variety of other aquatic or semiaquatic birds. The latter includes shorebirds, herons, cranes, rails and gallinules. There are also several species of semiaquatic mammals including muskrats, beaver and otter. The wildlife of concern also includes nonaquatic forms such as pheasants, mourning doves, rabbits, raccoons and a host of other small birds and animals.

Requirements pertaining to these species, and which are related to water development, largely involve maintaining certain types of habitat. These habitats are typically used by many species for a diversity of purposes, so the discussion is organized around habitat types rather than species.

LEVEES

Levee vegetation provides cover, nesting sites, and food for many species of wildlife. The importance of this habitat varies seasonally. For pheasants it is probably particularly important during late winter when most cultivated fields in the Delta are either barren or flooded for leaching. Levee maintenance programs which maintain substantial cover varying in nature from trees to annual plants will increase the number and diversity of wildlife in the Delta.

MARSH REMNANTS IN THE DELTA

Only small remnants of original tidal marsh remain in the Delta. These are either "tule berms" along the edges of levees or small unreclaimed islands. They are the principal habitat of river otters and beaver, as well as being important to many more ubiquitous birds and animals. They provide important cover for pheasants particularly during the hunting season and in winter when fields are barren.

The contribution of these marsh remnants to the total production of fish and wildlife in the Delta is limited because this type of habitat is scarce. The high density of wildlife in these remnants and their esthetic value warrants placing high priority on maintaining them.

THE BAYS AS WATERFOWL HABITAT

The entire open-water area of the bays from Suisun Bay to the Golden Gate is an important habitat for diving ducks during the winter. It is especially important for canvasbacks, since over 50 percent of the Pacific Flyway population of this species utilize it (U. S. Fish and Wildlife Service, 1961).

Besides open-water area, habitat preservation must include suitable conditions for benthic invertebrates. A variety of these invertebrates are the major food of many diving ducks. Some pertinent requirements were discussed in Chapter IV.

WINTERING SANDHILL CRANES

About 2,000 sandhill cranes, a relatively rare species, winter along the northern part of the alignment of the Peripheral Canal. This crane's large size and striking beauty give it great esthetic value.

These cranes generally require low, open wetlands for roosting. The irrigated pasture of duck clubs in the Hog Slough area are the only source of this type of habitat in early fall. It is essential that either this habitat be maintained and protected from excessive human use or similar substitute habitat be provided.

This subject is discussed in more detail in Delta Study Annual Reports 4 and 5.

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CHAPTER IX

CONCEPT AND OPERATION OF THE PERIPHERAL CANAL

By California Department of Water Resources

Environmental changes in the Delta resulting from water development have occurred in the past and will, undoubtedly, occur in the future due to continued increases in population, agriculture, and industry throughout California. Demands for water will be met first, through local water development for use within the Central Valley; second, through local water projects that divert from the Central Valley, such as the City of San Francisco's Hetch Hetchy Project, and East Bay Municipal Utility District's existing Mokelumne River Aqueduct and proposed American River Aqueduct; and third, through the construction and operation of both the federal Central Valley Project and the State Water Project.

ROLE OF THE DELTA

Releases of water from the Central Valley Project and the State Water Project reservoirs in the Sacramento Basin augment river flows entering the Delta from the north. Delta channels now serve as conduits for conveying this water across the Delta for diversion into aqueducts of the federal Central Valley Project (CVP) and the State Water Project (SWP). Water transported by these aqueducts is supplied to a myriad of water service agencies to the west and south of the Delta, which in turn, furnish the water to meet the domestic, agricultural, municipal, industrial, and recreational water needs within their boundaries.

Use of Delta channels as conduits for conveying project water began in 1940 with completion of the Contra Costa Canal, the first unit of the CVP. During 1970, over 2.3 million acre-feet of water was conveyed through Delta channels for the CVP and SWP. Annual water transfer across the Delta by these projects will increase to about 5.0 million acre-feet by 1980, and beyond the year 2000 to 8.5 million acre-feet (4.1 million acre-feet for the CVP and 4.4 million acre-feet for the SWP). The general service area and annual amount of water to be conveyed across the Delta for delivery by the existing and authorized units of these projects is shown in the following tabulation (Table 2).

Until corrective action is taken, environmental problems associated with conveying project water through Delta channels can be expected to worsen with time as the amount of water pumped increases. These problems are discussed elsewhere in this report.

THE PERIPHERAL CANAL

The Peripheral Canal has been adopted as the Delta water transfer facility of the State Water Project and is recommended for the federal Central Valley Project. This action was taken on the basis of: (1) recommendations by the Department of Fish and Game following the first 3 years of the Delta Fish and Wildlife Protection Study; (2) studies and recommendations by the Interagency Delta Committee; (3) the favorable reaction to the plan expressed at public hearings before the California Water Commission (1964); and (4) the independent studies and review of the plan by the California Department of Water Resources and the U. S. Bureau of Reclamation. All concluded that the Peripheral Canal was the only plan that could protect the fish and aquatic resources of the Delta, and also provide opportunities for their enhancement, while meeting the Delta water transfer requirements of the state and federal projects.

Under the 1959 California Water Resources Development Bond Act, the Department of Water Resources has authority to construct the Canal alone or by joint venture. The Bureau of Reclamation has completed a feasibility report on the Peripheral Canal;[4] the State has reviewed that report and recommended the joint venture.[5] The State review included a public hearing by the Senate Committee on Water Resources and the Assembly Water Committee. Now, authorization by Congress is needed for the Bureau to participate in the joint project.

Description

The principal features of the Peripheral Canal Plan are shown on Figure 28. The Canal will be 43 miles long, about 30 feet deep, and over 400 feet wide. It

[4] Peripheral Canal Unit, Central Valley Project—A Report on The Feasibility of Water Supply Development—September, 1968.

[5] Letter from Norman B. Livermore, Jr., Secretary for Resources, The Resources Agency of California, to Honorable Walter J. Hickel, Secretary of the Interior, U. S. Department of the Interior, dated April 28, 1970.

TABLE 2—PROJECTED EXPORTS OF WATER FROM SACRAMENTO-SAN JOAQUIN DELTA

General Service Area	Annual Amount, Acre-Feet
State Water Project[1]	
South Bay	188,000
San Joaquin Valley	1,355,000
Central Coastal	82,700
Southern California	2,497,500
Unavoidable Losses	293,652
Total, State Water Project	4,415,852
Federal Central Valley Project[2]	
Contra Costa Canal (and Future Kellogg)	400,000[3]
Delta-Mendota Canal (including exchange contract)	1,506,000
San Luis Unit	1,625,000
San Felipe Division	273,300
Unavoidable Losses	282,700
Total, Central Valley Project	4,087,000
Total	8,503,852

[1] Table B-6, DWR Bulletin No. 132-68.

[2] Page 46, USBR Feasibility Report on Peripheral Canal. Does not include water for the yet to be authorized East Side Canal, planned to be conveyed through the enlarged section of the first 2½ miles of the Peripheral Canal.

[3] Amount over 195,000 acre-feet contingent on authorization of Kellogg Unit and future yield capability of federal Central Valley Project.

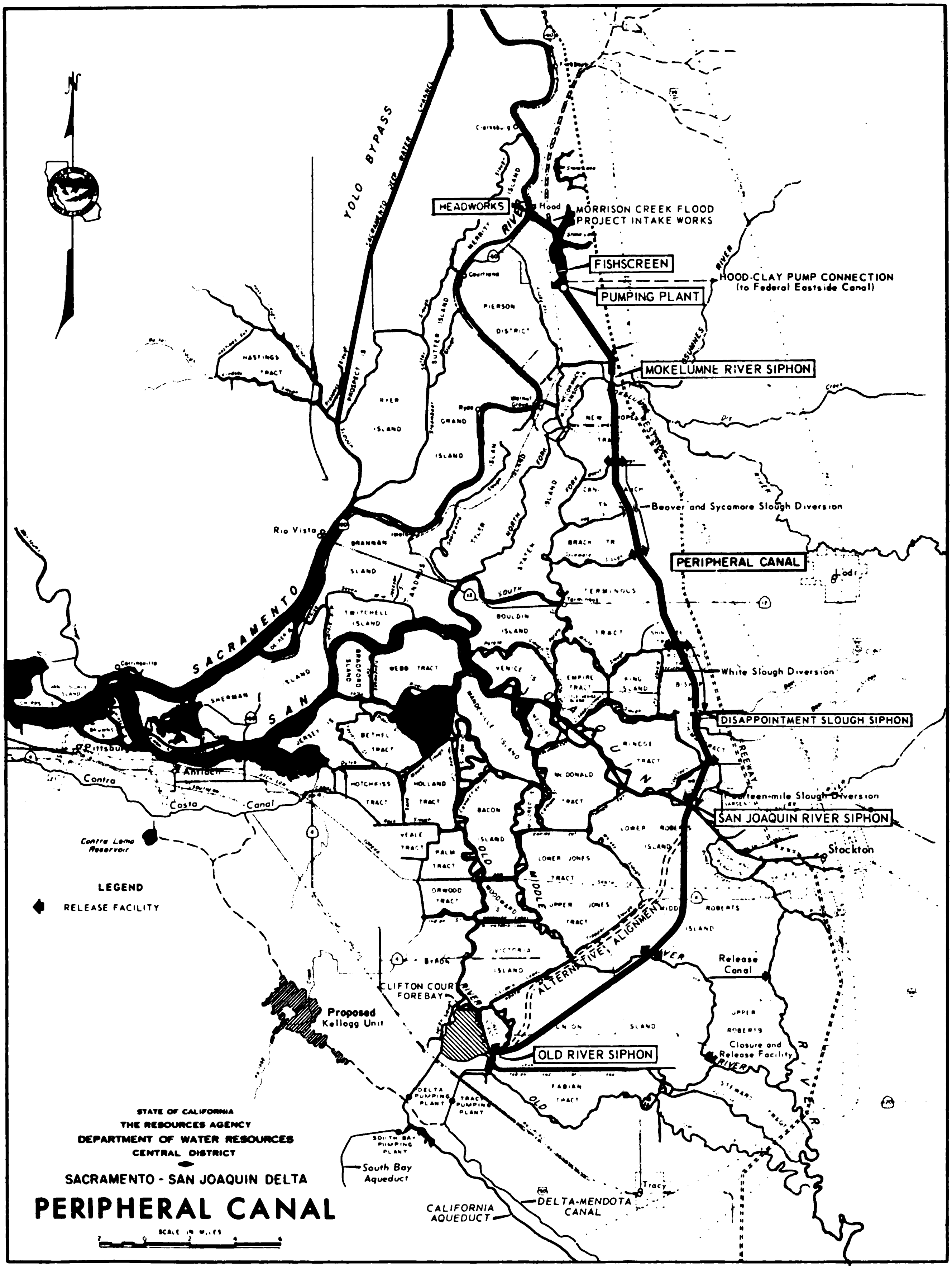

FIGURE 28—Location and features of Peripheral Canal.

will be an unlined canal, similar to existing Delta channels, but hydraulically isolated from all of the Delta channels except for the intake from the Sacramento River at Hood, 20 miles below Sacramento. From Hood, it will be routed to the west of Stockton and continue southwesterly across the southern Delta to the project pumps near Tracy.

The Canal will be siphoned under the four major stream crossings—the Mokelumne, San Joaquin, and Old Rivers, and Disappointment Slough—to allow for flood passage, fish migration, and navigation. On the west side of Old River, the Canal will divide into two branches—the south branch, terminating at the Bureau's Tracy Pumping Plant intake canal, and the west branch, terminating at the State's Clifton Court Forebay to the Delta Pumping Plant of the California Aqueduct.

The planned capacity of the headworks will be 26,800 cfs, which includes 5,000 cubic feet per second (cfs) for freshwater releases back into the Delta channels and also 5,000 cfs in the first 2½ miles for the Hood-Clay Pump connection of the proposed Eastside Canal of the CVP. The terminal capacity of the Canal will be 16,800 cfs (10,300 cfs for the SWP and 6,500 cfs for the CVP).

The alignment of the Canal and the lower reaches of the floodway for the proposed Morrison Creek Flood Control Project in Sacramento County may be combined, thus providing for acceptance of floodflows into the Canal. Right-of-way acquisition for the Canal is being coordinated with construction of the West Side Freeway (Interstate 5) in San Joaquin and Sacramento Counties so that excess earth from the Canal excavations can be used as fill material for the freeway. Coordination of the Peripheral Canal with the freeway project would result in 400 fewer acres of agricultural land being taken out of production and save up to 16.8 million dollars in public funds.

Fish protective facilities will be installed near the Peripheral Canal headworks, and a fish screen bypass will return salvaged fish to the Sacramento River. Just below the diversion works and fish facilities, a pumping plant will lift the water 10 feet. From that point the water will flow by gravity to the state and federal pumps near Tracy. Turnout gates or pumps, shown by arrows on Figure 28 will be installed at the major rivers and sloughs where the Canal crosses. High-quality water will be released at these points for irrigation, water quality control, and aquatic life.

Development of recreation facilities along the Canal will include campsites, picnic areas, swimming areas and boat launching facilities. The Canal will be available to the public for boating, water skiing, and fishing. These new recreation opportunities will help meet the large increase in demand projected for the Delta area.

Concept of Operation

The joint use Peripheral Canal will be operated in conjunction with the reservoirs of the CVP and SWP to meet the diversion requirements for federal and state service areas and local Delta uses, including water quality criteria established by negotiation and by the state and federal control agencies.

The Peripheral Canal will neither add new service areas, nor increase the authorized amounts of water slated for delivery by these projects.

Providing water for salinity control, i.e., Delta outflow in summer and fall, is independent of operation of the Peripheral Canal. This is now accomplished by the release of water from upstream storage reservoirs. Such releases have been provided from reservoirs of the CVP since 1944, and more recently, the SWP. In fact, of the many water projects that divert Central Valley water supplies, only the CVP-SWP system provides water expressly for salinity control. Through the coordinated operation of these projects, high winter and spring runoff is controlled and the low flows of summer and fall are augmented. The continuation and future level of salinity control will be governed largely by laws and policies pertaining to operation of these reservoirs.

The proposed Peripheral Canal is simply a needed conveyance facility of the CVP-SWP system. It can, however, make the most efficient use of water allocated for Delta outflow in managing the aquatic environment of the Delta. The Canal would have the capability to deliver high quality water to the interior and eastern Delta and correct existing flow problems that are detrimental to the Delta environment and fish life.

The basic premise for the Peripheral Canal concept is that a portion of the Delta water requirements, both consumptive and inchannel, would be served through operation of the Canal each year. The remaining portion of the Delta requirements would continue to be met from precipitation and from water flowing into the Delta via the Sacramento and San Joaquin Rivers and other tributaries. Each hydrologic year is different; hence, the exact amount and timing of releases from the Canal to provide the desired environmental conditions in the Delta will differ from year to year, month to month, and day to day. Final operational criteria can best be established from a period of trial operation and monitoring following completion of the Canal. Such a trial period will provide the experience required to achieve the desired results.

The concept upon which operation of the Peripheral Canal is based involves distribution of the total amount of fresh water needed in the Delta in a manner that will best achieve a balance among agricultural and environmental uses and water quality control. The following example illustrates the flexibility that would be provided by this operational concept.

During the winter months, when flows in the Sacramento River are normally high, the leaching of salts from Delta agricultural lands constitutes the primary use of water and would govern operation of the Peripheral Canal. Even though water is not required

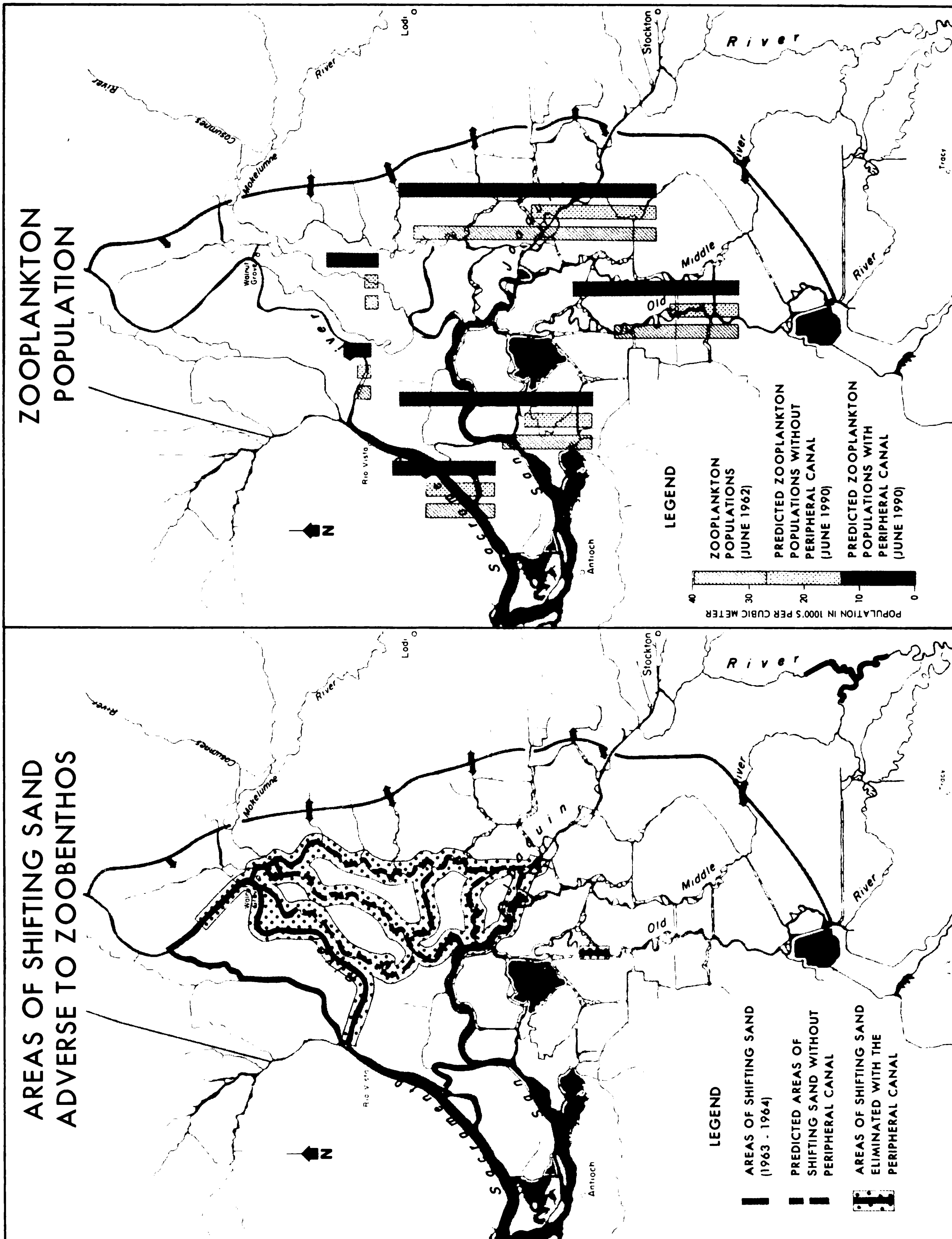

FIGURE 29—Present and probable changes in benthic organisms and zooplankton in relation to water transfer alternatives.

for consumptive use in the winter, good-quality Sacramento River water would be conveyed through the Canal and released to upgrade the quality of San Joaquin River water.

During the spring months when striped bass spawn, water would be released from the Peripheral Canal to improve water quality in the Old, Middle, and Mokelumne River systems to encourage striped bass to move into them and spawn.

During the spawning period (approximately 5 weeks), diversions into the Canal would be minimized to permit the free-floating eggs and larvae in the Sacramento River to drift past the intake into the central and western Delta, thus, permitting them to hatch and grow away from the influence of the export facilities.

In early summer, after striped bass spawning is completed, Canal releases would be adjusted to reduce velocity and allow moderate increases in the concentration of dissolved minerals and nutrients in Delta channels. The slower velocities and moderately increased nutrients would stimulate growth of zooplankton, and thereby increase the supply of fish food for the newly hatched bass and resident fishes. By using the Peripheral Canal rather than the natural channels for conveyance of export water, scour, erosion and the shifting sands of channel sides and bottoms will be reduced and should also result in increased production of benthic organisms (Figure 29).

About mid-July, young striped bass usually change their food supply from zooplankton to *Neomysis*, which are most abundant in the western Delta. Increased releases would be made from the Canal to meet the high consumptive use and water quality requirements in the eastern and southern Delta. These increased releases would assure positive downstream flows in most Delta channels to prevent the excessive buildup of salts, and would provide irrigators with good quality water throughout the remainder of the summer (Figure 30).

As fall approaches and the king salmon spawning migration begins, releases of Sacramento River water from the Canal would be reduced, consistent with maintenance of adequate levels of dissolved oxygen, to assure a high proportion of homestream water in the various migration channels.

Scheduling

The Peripheral Canal must be built soon—not later than 1980 if possible. The Delta environment and fishery resources need it now. Operation studies conducted by the Department of Water Resources show that the state and federal projects will need it by 1980 to prevent risk of water quality degradation or shortage in water deliveries. Since it is unlikely that congressional authorization, design, and construction could be accomplished before 1980, the present target date for completion of the Canal is 1980.

Setting a gillnet to sample larger fishes in the Delta.

FIGURE 30
Delta Flow Patterns

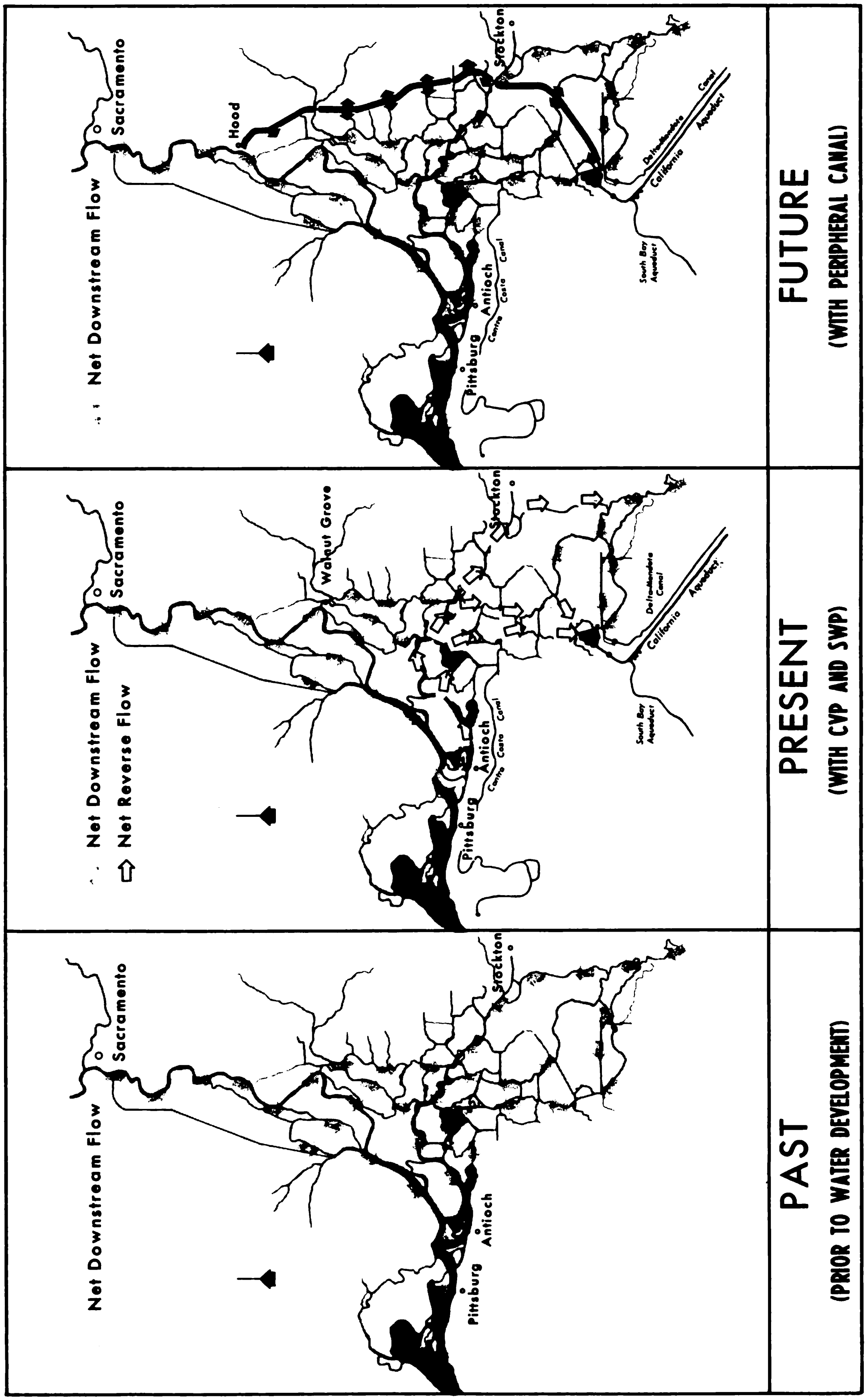

FIGURE 30—Delta flow patterns

CHAPTER X

EVALUATION OF WATER PLANS IN RELATION TO FISH AND WILDLIFE

By JOHN E. SKINNER

The process of establishing the environmental requirements of the resources in relation to Delta water plans must be based on firm knowledge, yet must be flexible enough to permit changes as new information is developed regarding either the resources or water plans.

Earlier annual reports of the Delta Study presented an assessment of the problems and impact of water development and established the nature and direction of the study program. This chapter is an evaluation of the present status of water plan concepts in relation to environmental considerations involving the fish and wildlife resources of the estuary. The evaluation will consider first the broader effects of water development and then review the specific effects of various Delta water transfer plans.

ENVIRONMENTAL IMPACT OF WATER DEVELOPMENT

It was seen in Chapter II that the diversion and storage of water has been a continuing process since 1850. Up until 1940 most development was by private and local public agencies. After 1940 the federal Central Valley Project became a major factor, and since 1964 when Oroville Dam first began to store water, the State Water Project has been an influential constituent affecting water management in the estuary. The analysis presented here considers the effects of all developments.

Following is a general summary of the environmental impact of water development on the Delta:

Regulation. Whether influenced by absolute increases or reductions, or by seasonal regulation, the quantity of water allowed to enter and pass through the Delta can have a substantial impact on the living resources. For example, there must be adequate flow to maintain appropriate water quality conditions and turbidity, guide or carry outmigrant fish to the ocean, provide the recruitment of nutrients and flush the estuary. On the other hand, releases which augment the low summer and fall flows appear desirable to prevent excessive salinity intrusion, and thus maintain low salinity conditions in the Delta for *Neomysis*, an important constituent in the diet of young striped bass and other fishes.

Direction of Flow. Most water users have little concern about the direction water flows. To migratory fishes, however, whether moving upstream to their spawning grounds or their progeny moving downstream to the ocean, direction of flow appears to be critical (Harden Jones, 1968). It is important, therefore, that there be positive downstream flows in all major channels of the Delta.

Water Velocity. Excessive water velocity causes a reduction of the biota in the water transfer channels. High velocities also scour channel banks and bottoms, thereby impairing the growth of animals which live on these media. Consequently, water development plans for the Delta should include provisions to optimize velocity conditions for phytoplankton, zooplankton and benthic animals.

Water Quality. Water quality in the Delta, particularly that associated with salinity, is largely a function of the volume of water flowing through the Delta. Hence, the amount of water passing through the system can be critical in terms of providing proper conditions for the spawning and migration of anadromous fish as well as a healthy environment for growth and development of resident animals.

Foreign Water. It is well known that salmon depend on their olfactory senses to reach their homestream, Harden Jones, 1968; Hasler, 1966). It is believed the effect of transferring large quantities of Sacramento River water into the San Joaquin portion of the Delta on the way to the pumps near Tracy and Byron creates conditions adverse to the expedient passage of adult salmon to their spawning grounds.

Sacramento River salmon are attracted into the central Delta when Sacramento water is abundant in the San Joaquin system, thus delaying their movement up the Sacramento River. San Joaquin fish on the other hand must negotiate the barrier of Sacramento water to reach their native water in the San Joaquin River drainage.

Similar reasoning suggests that the mixing of waters from the two drainages is inherently adverse to downstream migrant salmon and steelhead.

Temperature. The rate of flow affects water temperature by influencing the time which water temperature has to reach equilibrium with air temperature. At least in some seasons this affects temperatures in the estuary. For example, mean June water temperatures at Antioch are about 3°F cooler at a mean Delta outflow of 40,000 cfs than at 3,000 cfs (unpublished data). Hence regulation of flow and manipulations of water movement throughout the entire system, from storage reservoirs to pumping plants and the ocean, probably affects the temperature of the water in the Delta. The extent to which storage and regulation has affected temperature is probably small.

Even small changes may be important though, since summer temperatures appear to be reaching the critical level for *Neomysis* (Heubach, 1969; Hair, 1971) and for the upstream migration of salmon in the San Joaquin system (Hallock, Elwell and Fry, 1970).

ASSESSMENT OF DELTA WATER TRANSFER ALTERNATIVES

Over the years a great many concepts and plans have been devised to use the Delta and even the downstream bays for salinity control and to salvage and store water for transfer to areas of deficiency. Although the impact of such plans on fisheries was recognized in 1931 (Division of Water Resources Bulletin No. 2) it was not until the federal Central Valley Project was authorized that fish and wildlife became a significant consideration in water development plans. In the case of the Delta-Mendota Canal the principal concern was the prevention of fish losses through the Tracy pumps into the canal (U. S. Fish and Wildlife Service, 1950).

In the early 1950s as the California Water Plan (including the State Water Project) evolved, fish and wildlife received increased attention because the Delta was an integral part of all concepts for getting water from Northern to Southern California (Pelgen, 1955). Some of the concepts for implementing the California Water Plan, even on gross examination, would have had catastrophic consequences on the Delta's fishery resources. Others were recognized as being amenable to modification or operational changes to minimize or eliminate adverse impact on the resources.

By 1963, as a result of a comprehensive effort by State and Federal water development agencies, all but four concepts were eliminated from consideration with respect to further implementation of the State Water Project and the Central Valley Project. The remaining four were studied intensively in 1963 and 1964 to ascertain their relative merits in terms of cost, water project objectives, protection and enhancement of fish and wildlife, navigation and commerce, flood control, water quality and recreation. The four concepts reviewed were: (1) The Hydraulic Barrier; (2) Chipps Island Physical Barrier; (3) The Delta Waterway Control Plan; and (4) The Peripheral Canal (See Figures 28 and 31).

The Peripheral Canal was the plan of development ultimately selected by the Interagency Delta Study Task Force in consultation with economists, biologists and recreation specialists after intensive study of the four concepts. The report of the Task Force (September, 1964) and the Delta Fish and Wildlife Protection Study Annual Report No. 3 (1964), review the studies and bases for the selection. Key resource considerations in relation to each concept are summarized in Table 3.

From a fish and wildlife point of view, each of the four concepts may be summarized as follows based on our current understanding:

Hydraulic Barrier Concept. Under this concept surplus natural runoff and releases from storage are pumped from the south Delta, via the state and federal pumping plants on Old River. The quality of water at the pumps and in the Delta is maintained by natural outflow during high runoff and releases from storage during periods of low outflow. This outflow forms a hydraulic barrier in the western Delta which prevents the intrusion of salt water from the ocean.

Evaluation. The process of drawing water across the Delta creates several problems:

1. The lack of residence time of water being transferred across the Delta depresses the standing crops of phytoplankton and zooplankton in the water. In addition, it causes channel scouring, erosion and shifting of bottom sands thus reducing benthic organisms.
2. Cross-Delta water transfer actually reverses the net direction of water movement in the principal transfer channels during periods of low flow or high pumping. In effect, the net flow in Old, Middle and the San Joaquin Rivers is upstream under such conditions. These flow reversals are believed to interfere with the migration of both adult and juvenile anadromous fishes, especially salmon (Hallock, et al., 1970).
3. Tremendous numbers of eggs, larvae and juvenile fish are drawn toward the pumps where a substantial percentage is lost to the Delta. (Many fish passing through the fish screens survive to support fishing in project canals, forebays or storage reservoirs.)

Physical Barrier Concept. This plan would result in a large, low level dam or barrier at or near Chipps Island with appropriate locks for navigation and fishways. It would in effect, create a huge freshwater lake from which water would be diverted for both local and export purposes.

Evaluation. The physical barrier would create insurmountable fishery problems:

1. An adequate salinity gradient is essential as anadromous fish migrate between fresh water and salt water. These fish undergo profound physiological changes in their osmoregulatory systems and hence must have both adequate time and a suitable salinity gradient to adapt to the change. It is doubtful that the physical barrier could provide adequate conditions for all sizes and species of fish affected.
2. The freshwater lake would lack tidal movement and adequate oceanward currents. Hence, striped bass eggs and larvae spawned upstream would either settle to the bottom and die or be carried to the export pumps.
3. Assuming provisions could be made to provide passage for anadromous fish such as salmon over or through the barrier;
   a. It would probably be difficult for migrant fish to find their way either upstream or downstream through such a large relatively static body of water, and;
   b. It is probable that a substantial proportion of these fish would be drawn to the pumps with the flow.

TABLE 3—KEY RESOURCE CONSIDERATIONS IN RELATION TO DELTA WATER TRANSFER ALTERNATIVES [1]

Key Resource Considerations	Present Operation	Hydraulic Barrier Plan	Staged Waterway Control Plan	Peripheral Canal
Downstream net flow toward the ocean for fish migrations	Downstream flows prevail north of San Joaquin River. Flows in San Joaquin River and South Delta subject to increasing reversal in future.	Downstream flows would prevail north of San Joaquin River. Reverse flows in San Joaquin River and South Delta may often occur year-round.	Early stages would result in severe flow reversal in South Delta but ultimately only in channels isolated for water transfer.	Net flows always downstream in all channels except for eastern portion of Middle River where releases would be made to augment the San Joaquin River flow.
Exclusion of foreign water for salmon migrations	In most years Sacramento water dominates San Joaquin system in fall and impedes salmon migrations.	Conditions would become more severe than at present.	Ultimately amenable to correction through curtailment of Sacramento water releases. Possible need to augment San Joaquin flows.	Amenable to correction through curtailment of Sacramento water releases. Possible need to augment San Joaquin flows.
Retention of tidal currents	No effect.	No effect.	Eventual loss in channels isolated for water transfer.	No effect.
Suitable water velocities for zooplankton and benthos	Poor in Sacramento River and Delta channels north of San Joaquin River because of high net velocity.	Poor in Sacramento River and north Delta channels due to high net water velocity. Gradual deterioration in South Delta channels.	Expect zooplankton and benthos to increase in Sacramento River and north Delta channels. Poor in channels isolated for water transfer because of high net velocity.	Expect zooplankton and benthos to increase substantially in north Delta channels and Sacramento River.
Fish losses at export diversions	Substantial losses of striped bass eggs, larvae and young fish, and San Joaquin salmon fingerlings.	Losses would increase substantially without better protective facilities. Benefits from pumping curtailment small.	Increasing losses from both San Joaquin and Sacramento Rivers. As plan is implemented San Joaquin losses will diminish and Sacramento River losses will increase. Can be minimized by curtailment and good screens.	San Joaquin fish losses would be eliminated. Losses of Sacramento fish could be minimized by effective screening facilities or curtailment of diversions.
Water quality (low salinity) for striped bass spawning	Always suitable.	Always suitable.	Can easily be accomplished but will depend on operational assurances.	Can easily be accomplished but will depend on operational assurances.
Water quality (4°/₀₀ chlorides) at Chipps Island for *Neomysis*	Not met in dry years.	Would probably require specific supplemental releases except in wet years.	Can easily be accomplished but will depend on operational assurances.	Can easily be accomplished but will depend on operational assurances.
Adequate flow for young striped bass survival	Survival is below historical average and will decrease further as exports increase.	Can easily be accomplished but will depend on operational assurances.	Can easily be accomplished but will depend on operational assurances.	Can easily be accomplished but will depend on operational assurances.
Retention of turbidity	No significant reduction apparent in relation to historical conditions.	Easily implemented but may require greater flows than planned for other project purposes.	Easily implemented but may require greater flows than planned for other project purposes.	Easily implemented but may require greater flows than planned for other project purposes or adjustment in timing of water exports.
Adequate flow for migrating salmon	No apparent overall problem. Low flows at Stockton on San Joaquin River in fall inhibit upstream movement of adults and may need augmentation for downstream migrants in the spring.	No apparent overall problem. Low flows at Stockton on San Joaquin River may worsen and further impede adult migrants in fall and downstream migrants in spring.	May require greater flows than planned for other project purposes including possible augmentation of San Joaquin flows during spring and fall.	May require greater flows than planned for other project purposes including possible augmentation of San Joaquin flows during spring and fall.
Maintenance of adequate dissolved oxygen	Annual problem at Stockton on San Joaquin River in late summer and early fall.	Probably same as present conditions but some alleviation possible.	May require greater flows than planned for other project purposes in interior Delta.	May require greater flows than planned for other project purposes in interior Delta.

[1] **Since the Chipps Island Barrier is not presently under consideration it has not been included in this table.**

4. Part of the Delta's productivity and the food supply for small fish is attributed to the physical reactions that occur along the extensive natural salt-water-freshwater interface. This area would largely be eliminated.

5. The absence of tidal conditions and a salinity gradient in the reservoir behind the barrier would probably result in a substantial if not total loss of *Neomysis awatschensis* (See Chapter IV).

Staged Waterway Control Plan. Under this concept a series of 10 to 13 barriers and control structures would be constructed in the natural channels of the Delta to create a meandering waterway across the Delta. The structural works would provide for water release facilities, navigation locks, and a siphon under the San Joaquin River. Implementation of this concept would occur in several stages implemented over 29 or more years timed to meet water export requirements.

Evaluation. The Waterway Control Plan has both advantages and disadvantages:

1. By siphoning under the San Joaquin River the loss of eggs, larvae and juvenile fish from the San Joaquin system would ultimately be reduced. On the other hand, losses of fish from the Sacramento system would be greater unless adequate screens were constructed at the point of diversion from the Sacramento River.

2. The zooplankton and benthic fauna should improve in some areas, but would be even more depressed in the channels used for water transport.

3. Eventually, the flow reversal problem could be eliminated except for the channels used for water transport where the problem would be even more intense and prolonged.

4. Eventually, there would be a loss of tidal currents in the water transfer channels.

5. The barriers and control structures would inhibit recreational navigation including sport fishing traffic.

This plan then has the inherent disadvantage of greatly reducing the contribution of the water transfer channels to the system's productivity, and because of its probable staged implementation, it would result in considerable other adverse effects in the immediate future.

Peripheral Canal Concept. The proposed Peripheral Canal would, as the name implies, be a large canal that would skirt the eastern periphery of the Delta. It would be hydraulically isolated from the natural channels, and would be siphoned under the Mokelumne, San Joaquin and Old Rivers and Disappointment Slough. Large, low head pumps would divert water from the Sacramento River near Hood. The volume of water diverted would depend on the capacity and specific projects included, but the canal would be sized to a capacity of 22,000 to 26,800 cfs. The intake would include a sediment basin, trash rack and fish protective facilities. At selected points along the Canal, facilities would be provided to release water to maintain Delta water requirements for agriculture and for fish and wildlife.

Overriding considerations in the selection of the Peripheral Canal were:

1. Compliance with the water quality and transfer objective as set by the Interagency Delta Committee which was stated as follows:

> "To provide a means for meeting projected Delta export demands taking into account the following elements: (1) requirements for meeting the Central Valley Project's contractual quality limits at the Tracy and Contra Costa Canal diversions; (2) requirements for meeting the State's contractual quality objectives at the Italian Slough and Lindsey Slough diversions; and (3) requirements for providing and maintaining protection from ocean salinity intrusion and degradation by waste discharge in channels where such protection is economically justified and consistent with the beneficial use of water."
>
> "In determining the extent of protection to be provided, the following factors were considered: (1) quality requirements for local agricultural and urban users; (2) quality requirements for fish and wildlife resources; and (3) quality requirements for water pollution and public health, as related to recreation use."

2. The inherent potential of the concept to protect and enhance the fish and wildlife resources of the Delta as provided in the following planning objective adopted by the IDC:

> "*To protect*, and where possible, enhance the fish and wildlife resources of the Delta by assuring that the environmental requirements of the important Delta animals are provided for in the construction of Delta water facilities."

Evaluation. In operational concept the Peripheral Canal and Delta Waterway Control Plan are somewhat similar. Being isolated from the Delta, however, the Peripheral Canal would not physically interfere with the natural channels nor the resources dependent on them. Plans call for it to be constructed as a single unit over a relatively brief time span. Hence, it has the potential advantages of the Waterway Control Plan without the disadvantages of that plan. Hydrologically, it would return the Delta to a semblance of pre-Central Valley Project conditions by eliminating the direct effect of the pumps.

In brief, the Peripheral Canal, properly operated, could eliminate or minimize virtually all of the serious problems that exist now and that are associated with each of the other concepts. However, it will be necessary to incorporate certain essential features into the design and operation of the project in the interest of compatibility with fish and wildlife resources. These are:

1. First and foremost, as in the other plans, provision must be made for proper operation of the

project to assure adequate flows and water quality conditions for the maintenance of the fishery resources.

2. The Peripheral Canal will need to be provided with appropriate facilities and measures to minimize the loss of fish by direct diversion and prevent prolonged delays or losses of upstream migrant salmon. Both of these needs would exist regardless of which Delta water transfer alternative is selected.

The most recent Delta water plan is the so-called Modified Folsom-South Project. In concept, this plan would divert some of the export water near Hood, transport it to an enlarged Folsom-South Canal (now under construction by the Bureau of Reclamation), and provide for releases of water down the Mokelumne, Calaveras and Stanislaus Rivers. In preliminary form the project design includes: (1) deliveries to the state and federal pumps; (2) large releases down the Stanislaus River to freshen the southeastern Delta and; (3) positive downstream flows in the San Joaquin River for fish preservation. It has not evolved beyond the conceptual stage, but from a fish and wildlife point of view, it does not overcome some of the most serious objections to the present system. Specifically, under this proposal, large amounts of water would still be transferred across the Delta and the releases of Sacramento water into the eastern tributaries would continue to create problems for migrant salmon which may be insoluble.

The principal considerations described in the foregoing analysis were described almost 10 years ago. Much has been learned since then about fish and wildlife requirements, but none of the new knowledge would lead to a different conclusion as to the relative merits of the four water transfer alternatives considered then. Neither has any better water transfer plan been proposed, nor is it reasonable to expect that any better plan could be proposed if one accepts the requirement that water being transferred to the export pumps should be isolated from the Delta for the protection of fishery resources.

Following adoption of the Peripheral Canal concept as the recommended plan of development, the Delta Study Program was reoriented largely in line with the resources needs identified with this concept, including operating criteria. Nevertheless, much effort has been devoted to obtaining fundamental knowledge about the environmental requirements of the resources, recognizing the application of such knowledge to any plan of water development or transfer. Many of the specific requirements described in Chapters III through VII result from these studies and are pertinent to defining Canal operating criteria. It can be expected though, that a period of testing will be required after the Canal is completed to prescribe definitive criteria.

The criteria should involve the following:

1. A highly efficient screening system or curtailment of diversions during peak downstream migrations of young fish.
2. Maintenance of flows adequate for striped bass spawning and the survival of young striped bass.
3. Maintenance of flows sufficient for *Neomysis*.
4. Provision for net downstream flows in all major channels.
5. A predominance of San Joaquin River water in the southeastern Delta during upstream salmon migrations.
6. Releases from the Canal sufficient in timing and amount to maintain good water quality in the Delta without suppressing productivity or attracting upstream migrant salmon to the release points.
7. Establishment of a management system and water supply suitable to maintain appropriate soil salinities and waterfowl foods and habitat in Suisun Marsh.
8. Regulation of diversions so that turbidity is not reduced significantly.
9. Maintenance of adequate flow rates for the upstream and downstream migrations of salmon.

Most of these criteria are operational in character and can be achieved by the adoption and implementation of objectives designed around resource requirements.

The most severe technical challenge associated with the Peripheral Canal concerns the development of a system to prevent the diversion of fish, eggs and larvae. Although we are optimistic that a screen concept will be developed, pumping curtailment is a viable alternative. The Interagency Delta Study Task Force (1964) stated that curtailment would be feasible 80 per cent of the years.

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CHAPTER XI

FISH PROTECTIVE FACILITIES

By JOHN E. SKINNER

INTRODUCTION

The term fish protective facilities embraces a wide range of mechanical or structural devices designed to prevent or minimize the loss or damage to fish. In the Delta we are concerned primarily with systems which will: (1) minimize the diversion of fish; (2) effectively separate (screen) fish, eggs, and larvae from water diversions; and (3) safely return those which are salvaged to the river to continue their life cycle.

In discussing fish protective facilities, it is convenient to separate them into those which are now in existence and operating and those that are relevant to future Delta water plans.

EXISTING DELTA FISH FACILITIES

There are now two major fish salvage facilities in operation in the Delta. These are the federal Tracy Fish Collecting Facility which is located at the Old River intake to the federal Delta-Mendota Canal, and the State's Delta Fish Protective Facility at the intake to the California Aqueduct. Water for the latter facility is also diverted from Old River. However, instead of pumping the water directly from the river as the federal operation does, the water must first enter the 2,300 surface acre Clifton Court Forebay. Radial gates at the forebay intake are opened on floodtide to allow water to enter and are closed before the tide begins to ebb so that the water is retained in the forebay. It is then pumped from the intake channel which opens directly to the forebay. The Delta Fish Protective Facility is located on the intake channel between the forebay and the pumps.

System Concept

Both facilities employ essentially the same fish salvage and return systems, although the state facility, being of more recent origin, incorporates several more recent design concepts that were intended to increase its effectiveness (Figure 32). The fish "screen" concept employed is the so-called louver system. The concept was originally developed in the early 1950s to salvage fish at the Tracy Fish Collecting Facility from water being pumped into the Delta-Mendota Canal (U. S. Dept. Interior, 1957). It consists of a row of vertical metal slats running on an angle across the channel. It may be compared to a venetian blind placed on its side. The metal slats are spaced an inch apart and are perpendicular to the flow of water.

The theory behind the concept is that it allows water to pass between the slats, but fish which approach the slats will react to avoid going through them. In so doing, the fish swim in a direction somewhat perpendicular to the row of slats and are thereby guided or deflected along the line of louvers until they reach a bypass which they enter either voluntarily or as a result of the higher velocities entering the bypass.

From the bypasses the fish are carried into another louver and bypass array called the secondary system where they are further concentrated and the volume of water reduced by the same process. From the bypass of the secondary system the fish are conveyed to large cylindrical collecting or holding tanks. Here the fish are held until a sufficient number is collected to be hauled away in specially designed trucks, and returned to the Delta away from the influence of the intakes.

Fish Salvage

In excess of 30 species of fish are collected at these facilities. Striped bass are the most abundant followed by threadfin shad, catfish and smelt. The numbers of salmon salvaged are not high in relation to the above named species but are significant in terms of their contribution to the salmon runs of the Central Valley.

The numbers of fish salvaged at the federal facility have ranged from about 3.5 million during the first 2 years of operation in 1957 and 1958 to over 44 million during the dry year of 1966 when pumping was high. The average numbers salvaged annually are about 18 million striped bass, 2.3 million catfish and 112,000 salmon. In excess of 400,000 salmon were salvaged in both 1970 and 1971.

The state facility has been operating only since early 1968. It rarely has been operated at anywhere near its peak capacity. Hence, the numbers of fish salvaged are low in comparison to those at the federal facility. Through 1970 the state facility has salvaged an average of 6.4 million striped bass, 1.3 million catfish and 42,000 salmon annually.

Salvage Efficiency

Both facilities have been evaluated in recent years, the federal facility in 1966 and 1967 (Hallock, et al., 1968) and the state facility in 1970 and 1971 (MS.). In addition, the Department of Water Resources (1967a and 1967b) conducted tests at the Tracy facility to assess louver slat spacing and bypass tests. Several factors including the high runoff of 1967 combined to limit the usefulness of results at the federal facility. The tests conducted at the state facility, however, provide a measure of the gross effectiveness of both installations.

The testing programs at both installations demonstrated that several variables affect the efficiency of the fish salvage operation. The most significant factor was the size of the fish, which is correlated with

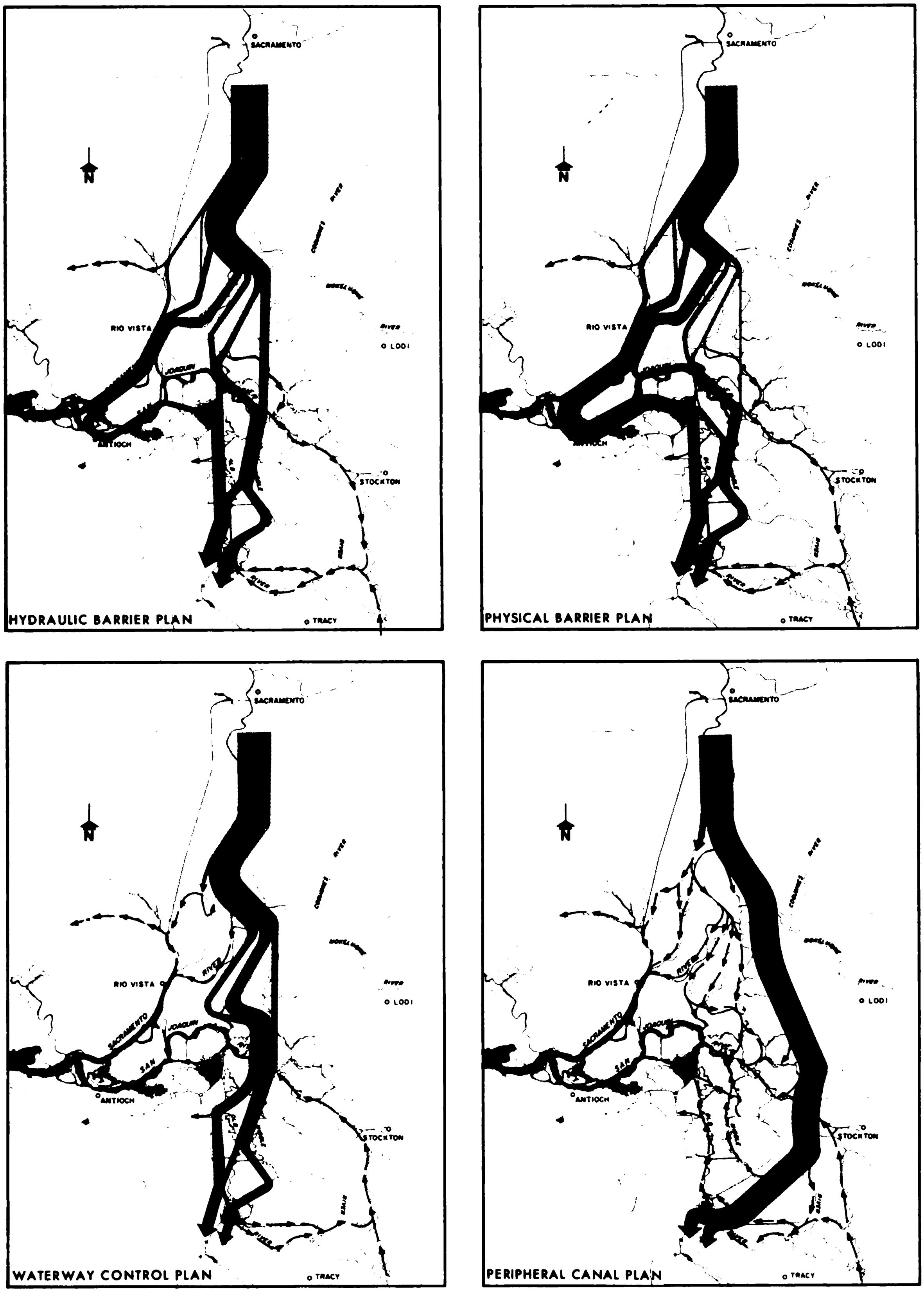

FIGURE 31—Schematic distribution of flows during typical summer operation of the four water plans

swimming ability and hence, potential to be deflected by the louvers and guided to a bypass. Other factors affecting efficiency include the velocity of the water, the bypass and screened water velocities, size of the bypass, presence or absence of guiding walls, and the side fish enter the secondary channel. The latter is a factor because fish entering on one side have less time to orient themselves before reaching the louvers and must traverse more of the louver than fish entering on the other side.

It is difficult to generalize about efficiency because of interaction among the variables. However, at the state facility for the complete range of test conditions, the overall efficiency (combined primary and secondary systems) for striped bass was about 50 percent for 1-inch fish and over 80 percent for the largest fish. Fish less than one-half inch long have very limited ability to be louvered. These tests involved over 1.3 million bass up to 4 inches in length.

The tests showed that salmon, which normally range in size from 2 to 4 inches when they reach the facility, are louvered at an efficiency of about 80 percent overall. The efficiency for salmon less than 2 inches in length is 60 to 70 percent. These results compare favorably with the results of Ruggles and Ryan (1964) who obtained efficiencies of 65 to 75 percent for a single line of louvers.

Louvers are much less effective in salvaging small catfish. Overall, only 16 percent were successfully bypassed to the holding tanks. Size was the most important factor affecting efficiency. Of more than 87,000 catfish involved in the tests, 67 percent were greater than 1 inch. The modal length was between 1¼ and 1½ inches. Efficiency ranged from about 5 percent for fish less than 3/5 inch to 90 percent for fish over 3 inches.

Tests by Hallock, et al., (*op. cit.*), of the primary louvers at the federal facility demonstrated similar results for striped bass. His results were inconclusive for salmon and catfish.

Bates and Logan (1960) reported efficiencies of 90 percent or better in the secondary system of the Tracy Facility for fish over 1 inch in length. They did not test the primary system. Using the same efficiencies in the primary that they obtained in the secondary would produce overall efficiencies similar to those obtained at the state facility for most fish over an inch in length. Bates and Logan, however, reported much greater efficiencies for white catfish than were obtained during tests at the state facility.

Prognosis

Based on the foregoing, it is apparent that overall, the existing facilities are capable of salvaging at least 80 percent of the salmon, 50 percent of the striped bass and 15 percent or more of the catfish entering them. Fish over 2 inches in length are screened consistently at an efficiency of 80 to 90 percent.

Based on the average numbers of bass, catfish and salmon actually salvaged and the overall efficiencies indicated above, fish losses at the two facilities have probably averaged about 19 million bass, 19 million or fewer catfish and 39 thousand salmon annually. Although projected water exports are 3 to 5 times the present rate it is improbable that fish losses under future conditions will increase proportionately. Much of the water exported will be pumped in the winter and early spring when fish abundance is generally low. The critical period will be from March through June for salmon, May through July for striped bass and July and August for catfish. Fish losses will probably increase directly with the increase in pumping during these periods.

More important than the numbers lost, however, is the impact on the resource. It is conceivable that striped bass losses of the anticipated magnitude will not deplete the resource. (This is discussed at length in Chapter V.) On the other hand, it is probable that the potential increase in salmon losses from the San Joaquin system would, over a number of years, seriously impair that resource. Obviously, losses cannot continue to escalate without becoming harmful at some point. Recent declines in striped bass and salmon suggest that past losses may have adversely affected resource levels. Hence, we must be pessimistic about the effect of such large losses until evidence is obtained to the contrary. It is imperative, therefore, that these facilities be operated to achieve the maximum efficiency practicable.

As long as the diversion of export water occurs in the south Delta, there is little promise of reducing the loss of fish substantially. The present salvage facilities can both be operated and modified to improve efficiency moderately, but any changes to offset the expected increase in fish losses due to increased water exports would need to be very substantial and costly.

Curtailment of pumping is possible but this cannot be done as a practical matter for long enough periods to be effective for salmon. In the case of striped bass the effectiveness of curtailment is limited because a good share of the fish will remain within the influence of the pumps. Even those salvaged, and returned to the river near Antioch, could conceivably be drawn back toward the pumps under future conditions.

Up to the present time these facilities have attracted few adult fish. There is a possibility, however, that the accentuated and prolonged period of flow from the Sacramento River to the pumps could attract increasing numbers of adult fish. This would create a virtually insoluble problem, since no system is present to salvage adults.

FISH FACILITIES IN RELATION TO FUTURE DELTA WATER PLANS

Except for the Peripheral Canal, the proposed water transfer plans entail fish salvage considerations similar to those discussed above for the present water transfer operation. They vary, however, in terms of their potential impact on the resources (Table 3), their amen-

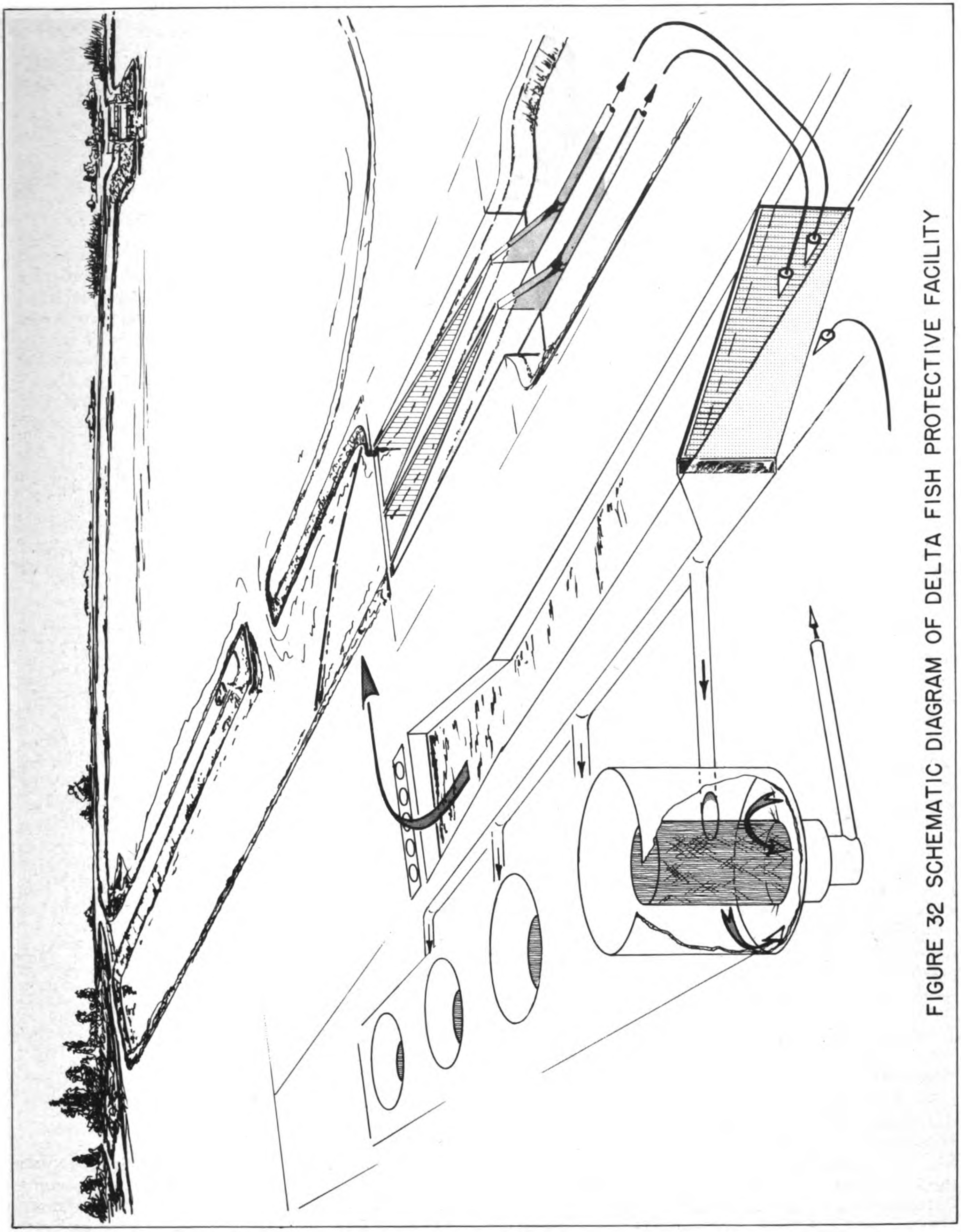

FIGURE 32—Schematic diagram of Delta Fish Protective Facility

ity to modification and the degree of protection possible.

All things considered, the Peripheral Canal offers the most discrete and best long-term solution to fish losses as well as to other ecological considerations related to the cross-Delta transfer of export water. Consequently, the Peripheral Canal concept has been studied intensively with respect to protection of the fish resources and the facilities essential to this purpose.

The magnitude of the resources that could be affected by the Peripheral Canal is not precisely known but a reasonably good judgment is possible from existing data. Estimates of the adult striped bass population (fish over 16 inches in length) indicate that about 750,000 adults migrate up the Sacramento River (unpublished data). In addition about 250,000 juvenile and subadult (8-16 inches) bass probably are at or above the Peripheral Canal intake site.

In addition to striped bass it is assumed that 90 percent or more of the American shad and steelhead spawn above the Canal, adding perhaps another 750,000 or more fish to the number of large fish susceptible to the Peripheral Canal diversion.

It is not practical at this time to try to establish estimates of the actual numbers of eggs, larvae and juvenile fish suscepible to diversion. Striped bass are prolific spawners. The total number of eggs spawned are astronomical. Salmon and shad are less prolific but tens of millions of eggs and small fish are involved. Since natural mortality at the egg and larval stage is very high, it is almost meaningless to discuss numerical estimates for striped bass and shad. Hence, to put the problem into perspective it is convenient and perhaps more meaningful to simply allude to the proportion of the annual reproduction of each species that must pass the diversion site. This amounts to 90 percent or more of the annual reproduction of the king salmon, steelhead, white sturgeon and American shad from the Central Valley and two-thirds of the striped bass. In general, it is assumed that without adequate fish facilities, eggs, larvae and small fish would be diverted in proportion to the fraction of water diverted from the Sacramento River.

Considering the total scope of the Canal and its appurtenances, five primary considerations emerge regarding the design and operation of fish facilities. These are:

1. The design and operation of the facility to minimize the delay or interference with downstream migrant adult fish, especially striped bass, American shad, white sturgeon and steelhead trout.
2. Development of a screen concept to salvage the eggs, larvae and small fish that pass the intake site.
3. Development of a system to return salvaged eggs, larvae and fish safely to the river.
4. Operation of the facility to minimize the delay of upstream migrant salmon at canal water release sites.
5. Development of operational plans and assurances for fish protective facilities.

The potential of the Peripheral Canal with respect to these considerations will be discussed in relation to the physical features of the Peripheral Canal.

Intake System

The following elements of the intake system could affect the normal passage of fish and their survival.

Location and Design of the Intake

The location and design of integral features of the intake are important considerations in successfully bypassing adult fish in the river and salvaging small fish from the Canal. Adult anadromous fish, with the exception of salmon, migrate downstream after spawning. Eggs and larval fish are simply carried with the currents.

Water movement is an important mechanism in guiding the downstream passage of these fish. Since the Peripheral Canal will divert large volumes of water from the Sacramento River, it is logical to anticipate that large numbers of eggs and fish will be diverted with the flow.

The two principal concerns involving the intake facilities are: (1) the entrapment and delay of downstream migrant adult fish; and (2) the diversion of eggs, larval, and juvenile fish.

Downstream Migrant Adult Fish. The location and design of the intake could have a profound effect with respect to its potential to entrap fish or deter them from entering the intake system. This problem is not unique to the Peripheral Canal although it is likely that a much greater number of adult fish would be affected than with other Delta water transfer plans. However, with the Peripheral Canal, the alternatives to minimize or prevent adverse effects are far more practical and desirable. Fish drawn to intake facilities in the south Delta are dead-ended and if salvaged would probably need to be hauled away by truck. In contrast, at the Peripheral Canal, the downstream flow of water past the intake would allow many fish to bypass the intake entirely. Fish which are drawn into the facility can be guided to facilities and returned to the river below the intake to continue their migration. Since the problem is affected by tidal flow at the intake site, physical model studies appear desirable to improve our knowledge of hydraulic patterns at the intake site to aid in the design of appropriate facilities and their operation.

Potential solutions to minimize the entrapment and delay of downstream migrant adult fish, therefore, should involve the following considerations:

1. Model studies to determine the hydraulic conditions that will prevail at the entrance to the intake.
2. Studies to determine the routes and conditions under which adult fish migrate in the river near the intake site.

3. An intake design that will deter entry into the Peripheral Canal.

4. A system to guide and collect adult fish and return them to the river below the intake beyond the influence of the pumps.

5. A study of pumping operations under project conditions to determine the feasibility of pumping curtailment to assist in bypassing fish.

Eggs, Larvae and Juvenile Fish. The most apparent approach to preventing the loss of eggs and small fish would be a device to screen them from the flow in the Canal and a system to return them to the river. Because of the large volume of water that will be diverted and the extremely small size of the fish and eggs, this is a difficult challenge. Striped bass eggs and newly hatched larvae are about ⅛ of an inch in diameter and length respectively.

Since virtually all striped bass spawned above the Peripheral Canal will reach the intake site either as eggs or newly hatched larvae, louvers will not salvage them. Most American shad and sturgeon will probably not be of louverable size as they pass the intake site. Hence, if these fish are to be salvaged by screening at the canal intake another screening concept will be necessary.

Most salmon on the other hand will be 40 mm or larger as they pass the site so 65 to 76 percent could be salvaged with louvers.

Alternatives

Potential alternatives are:

1. **Development of a New Screening Concept.** Presently developed screening concepts in the United States and Canada have been considered carefully but show little promise. A great deal of progress has been made toward development of the so-called horizontal traveling or matching velocity screen. This concept appears to offer substantial potential for salvaging striped bass, American shad and sturgeon at the diversion site. Considerable biological and engineering research will be necessary, however, before the concept can be recommended for the Peripheral Canal.

A more recent development, involves the principle of greatly increasing the surface area of the diversion, so that the velocity at any point will be much less than that of the water flowing past. This concept appears worthy of much more intensive investigation. In the event such a proposal proves to be engineeringly feasible, it would conceivably solve not only the screening problem but also negate the need for facilities to return the fish to the river and solve the adult fish problem as well.

Louvers should continue to be considered in combination with any new concept that may be developed. Since eggs, larvae and small fish occur only during the late winter, spring, and early summer, the louver concept might be adequate most of the year.

2. **Timed Curtailment or Suspension of Peripheral Canal Pumping.** As an alternative to or in conjunction with screening, pumping could be curtailed or suspended to allow eggs, larvae and small fish to move downstream past the intake when they are most abundant. This solution was anticipated by the Interagency Delta Committee when it recommended the Peripheral Canal in 1964. Data for the years 1963–67 indicate that it would be necessary to suspend pumping between 25 and 40 days to allow 90 percent of the striped bass eggs and larvae to pass the intake site. Median dates to allow 90 percent to pass the intake would run from May 11 through June 12.

The Peripheral Canal has a very definite advantage over the other transfer concepts in terms of the effectiveness of diversion curtailment. Namely, once the eggs, larvae, and small fish pass the Peripheral Canal intake site, they will continue downstream into the Delta and will no longer be susceptible to export diversions. One of the major concerns of the present system of transferring water across the Delta is that the small fish are susceptible to the pumps in the south Delta at all times.

Return System

Once fish are salvaged they must be returned to the river far enough downstream that they are not carried back to the intake by either the tide or the draft of the pumps. The number and small size of the fish virtually precludes transporting them by truck. Handling and circulation in the trucks would cause substantial mortality of eggs and larval fish and the capital and operational costs would appear prohibitive.

A tentative solution would involve a collection system, pumps, and a closed conduit to return the fish directly to the river several miles below the intake. It has been demonstrated that pumps can be used to pass larger fish without excessive damage or mortality. However, before this concept can be implemented it may be necessary to assess the effects on eggs and larval fish from: (1) pressure, (2) conveyance in the conduit, and (3) mechanical injury from pumps.

Canal Appurtenances

Evidence from existing pumping operation in the Delta and elsewhere indicate that the Periperal Canal pumps may kill some fish passing through them but such losses would not be significant.

Thirteen turnouts are presently planned along the Canal to provide consumptive water requirements in the Delta and to maintain water quality standards. The water released into the Delta from these turnouts will be of Sacramento River origin and will be released in greatest quantity in the south and east portions of the Delta where under historical conditions the water was of San Joaquin River origin. Such conditions will probably attract Sacramento salmon into the central Delta and away from their normal migration routes and constitute a barrier of foreign water to upstream migrant San Joaquin salmon. It is essential, therefore, that the sytem be operated to assure a preponderance of San Joaquin River water in the southeastern Delta during the fall period.

PROGRESS OF FISH FACILITY RESEARCH AND DEVELOPMENT

After the Peripheral Canal concept had been adopted, an assessment was made of its implications to the fishery resources and a research program was initiated to resolve the most apparent problems.

Following an intensive search of the literature, studies were undertaken to determine the best means of guiding fish in the hope of developing a system by which they could be prevented from entering the Canal. Most conventional systems were thoroughly investigated and substantial work was done on the use of electrical and sonic devices. Up to 1966 it was generally concluded that the louver concept was the most effective system for large diversions and for a wide range of fish sizes and species. None of the sytems or concepts investigated, however, were capable of salvaging eggs and larval fish. Consequently, curtailment of Peripheral Canal diversions was considered as the primary means of preventing the loss of eggs and larvae.

In mid-1965, the horizontal traveling screen concept emerged, partly as a result of these studies. The concept has been under development by the U. S. National Marine Fisheries Service since that time. This concept seemed to offer the most promise and has been given the greatest effort up to now.

Presently, a low velocity or sieve-type system is being considered. In concept, this system would involve distributing the diversion over a very large surface area of porous material or fine-meshed screen.

The early work of the program also entailed studies of concepts to return salvaged fish to the river. These studies involved the investigation of pumps capable of passing fish without excessive mortality and field tests to assess the effects of pressure. These tests were undertaken when it was concluded that the most practical system would involve pumping the fish into a closed conduit under pressure and allowing them to return to the river by gravity several miles below the intake works. Results indicate that pressures, within the range anticipated in the system, may not cause excessive mortality.

Recognizing that the discharge of enormous numbers of small fish at a particular location might attract large numbers of predatory fish, studies were undertaken to assess this potential problem. Field studies involved netting fish at the sites where fish are released after being salvaged at the Tracy Fish Collecting Facility. These studies showed that substantial predation does in fact occur. Subadult striped bass were heavy but, by virtue of their migratory behavior, sporadic predators. Black crappie were considered more detrimental since they remain in the vicinity of the release sites. Stomach analyses of black crappie taken at the sites frequently revealed large numbers of small fish, usually in direct proportion to the species released from the trucks. As a result, facilities were constructed in the Delta which minimize this problem and plans are under consideration to provide for the intermittent use of multiple release sites in deep water for the Peripheral Canal System.

Substantial progress has been made in developing biological criteria for the design of a fish screen. In particular, the swimming capabilities of larval and juvenile fish have been fairly well determined as well as their tolerance to impingement. Consequently, we are or soon will be in a position to determine the biological feasibility of many of the various mechanical screening devices that have been suggested. More important, the data developed will permit us to specify the hydraulic characteristics of fish salvage facilities with reasonable assurance of their effectiveness. Future research will involve the extension of our present knowledge of fish response to water velocities and other hydraulic characteristics to experiment with various devices in a model flume to assess their capability for deflecting or guiding small fish.

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CHAPTER XII

FUTURE ENVIRONMENTAL EVALUATIONS

By HAROLD K. CHADWICK

There is good reason to believe that resources in the estuary can be protected from potential adverse effects, since both federal and state laws and policies require protection as a responsibility of development projects. However, a prerequisite to achieving protection is documentation of resource requirements.

The environmental evaluations completed in the estuary indicate that the Peripheral Canal needs to be built to correct some existing problems, and they also indicate the general and some specific operating criteria for the Canal. Establishment of definitive operating criteria for the Canal though will require monitoring and evaluation from now through a testing period after the Canal is completed.

The Department of Fish and Game, the California Department of Water Resources, the U.S. Bureau of Reclamation and the U.S. Bureau of Sport Fisheries and Wildlife have entered into a cooperative agreement to guide the conduct of future evaluations. This agreement defines principles governing the need for evaluations and the responsibility and procedures for implementing them. It also describes evaluations necessary in the immediate future and provides for their funding.

The evaluations defined in the agreement will all contribute to ecological understanding necessary to evaluate water development projects, but several also have a major bearing on other management functions of the Department of Fish and Game. The latter will be funded and carried out by the Department of Fish and Game, while the others will be funded by the development agencies and carried out cooperatively.

Briefly, the evaluations needed immediately are:

1. **Survival of Young and Juvenile Striped Bass.** Objective: To determine the factors controlling the survival of young and juvenile striped bass and identify management options which will increase survival. Primary emphasis will be placed on increasing understanding of the factors controlling the relationship between water flows in late spring and early summer and the survival of young striped bass.

2. **Adult Striped Bass.** Objective: To provide a continuing assessment of population size and mortality rates to establish a basis for evaluating angling regulations and managemental actions related to environmental protection.

3. **Salmon Adult Population Inventory and Management Research.** Objective: To inventory salmon resources throughout the Central Valley so management actions can be evaluated and to undertake specific management evaluation investigations.

4. **Water Supply for Upstream Migration of Salmon.** Objective: To determine how the Peripheral Canal and San Joaquin Valley water development projects can be operated to provide suitable conditions for salmon to migrate upstream through the Delta.

5. **Factors Controlling Phytoplankton Growth in the Western Estuary.** Objective: To ascertain how changes in hydraulic conditions and waste loadings may affect phytoplankton populations in the western estuary and to evaluate management options for preventing adverse conditions.

6. **Turbidity.** Objective: To predict how turbidity will change in the estuary as a result of changes in hydrology, so that the biological effects of any changes in turbidity can be evaluated.

7. **Peripheral Canal Fish Facilities.** Objective: To plan and develop the facilities necessary to prevent unacceptable losses of fish at the intake of the Peripheral Canal and at the release points from the Canal into the Delta if operation studies indicate that this is likely to be a problem.

8. **Suisun Marsh Water Supply and Management Study.** Objective: To complete a feasibility study of alternative means of providing suitable freshwater supplies to the Marsh.

Each of these evaluations is being implemented during the 1971–72 fiscal year. They will all take a number of years to complete, and the agreement provides for continuing evaluation and adjustment of the studies to keep them responsive to study results and changing needs.

The agreement also provides for the determination of the magnitude of water flows through the Delta required to facilitate the upstream and downstream migration of salmon. This study is to start 3 years before Peripheral Canal construction.

As well as can be anticipated at this time, these studies will provide a reasonable basis for anticipating and preventing any adverse effects of water development on fish and wildlife resources in the estuary. The studies obviously are not exhaustive and development plans change from time to time, so the studies must be reviewed frequently to keep them responsive to current needs.

One aspect of particular concern is the effects of large reductions in winter flows. Other than possible reductions in both turbidity and the annual flushing of pollutants, no effects having probable adverse consequences have been identified. However, the biological consequences of such a change cannot be predicted with a high degree of confidence from either theoretical considerations or experience, as comparable situations have not been studied. Hence, the reasonable course of action is to observe effects as changes are implemented gradually.

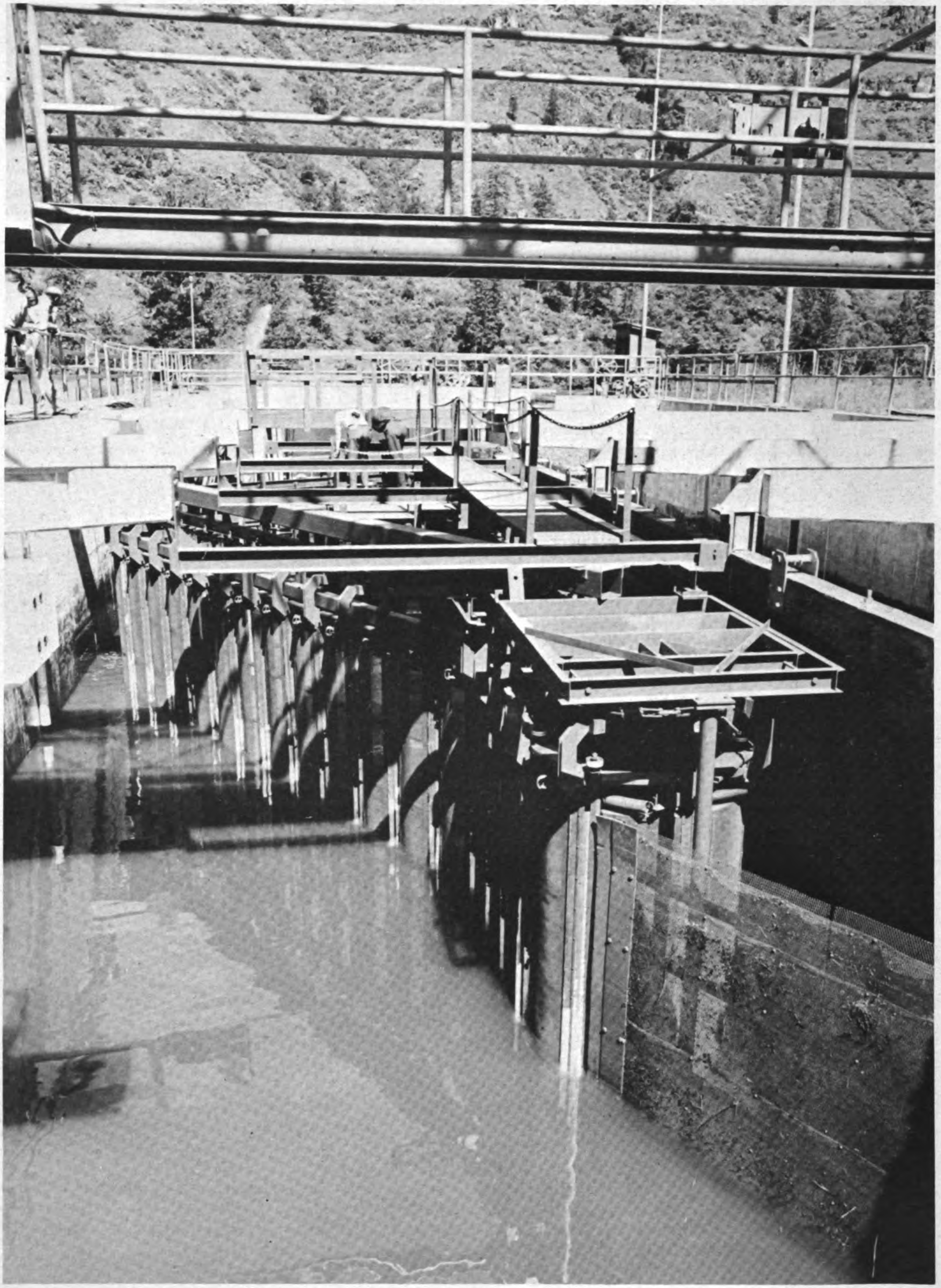

PHOTO 7—The traveling fish screen shown here has been under development since 1965. It is under consideration as a possible solution to screening the Peripheral Canal. The screen, located at Troy, Oregon, is being tested by the National Marine Fisheries Service.

APPENDIX

PUBLICATIONS CONCERNING DELTA FISH AND WILDLIFE 1961–1971

The decade encompassed by this report has produced considerable knowledge about the ecosystem. A good deal of this knowledge has been published by the Delta Fish and Wildlife Protection Study in scientific journals, annual reports and informally as administrative or letter reports.

In addition, other functional units of the Department of Fish and Game have also been engaged in studies within or having a bearing on the Delta and its resources.

Since the purpose of this report is to assemble the existing knowledge in summary form, it is appropriate to include all relevant publications of the Department which either emanated from the Delta Study or which contributed to this report. The publications listed below are restricted to those involving Department personnel since the Delta Fish and Wildlife Protection Study was initiated in 1961:

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