EFFECTS OF FRESHWATER FLOW ON FISHERY RESOURCES IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

Perry L. Herrgesell, David W. Kohlhorst, Lee W. Miller, and Donald E. Stevens

California Department of Fish and Game
Bay-Delta Fishery Project
Stockton, California

ABSTRACT

Over twenty years of biological and hydrological studies in the Sacramento-San Joaquin Estuary have documented changes in magnitude and timing of freshwater flow associated with water development in the watershed. These changes, coupled with natural fluctuations in flow, stimulate ecological relationships that largely control the survival and distributions of various fish and invertebrates. Specifically, the magnitude of delta outflow and water diversions are major factors controlling survival of striped bass (Morone saxatilis) during their first two months of life. Likewise, annual abundance indices for young fall run chinook salmon (Oncorhynchus tshawytscha), American shad (Alosa sapidissima), and longfin smelt (Spirinchus thaleichthys) also increase directly with river flow rates during the spawning and nursery periods. High flows increase disperal of young fish which may decrease density dependent mortality. Overall abundance of opossum shrimp (Neomysis mercedis), the principal food of several fish and invertebrates, appears to be reduced by salinity-incursion (lower flows) and increased water diversions. Salinity intrusion resulting from low flows also stimulates dispersal of salt-water species into more of the estuary, while habitat for freshwater species is reduced. Although previous study emphasis and documentation of effects of water development have occurred principally in the upper estuary, freshwater flow may affect biological communities in San Pablo and San Francisco bays too. A two-year study focusing on juvenile dungeness crab (Cancer magister) in these bays concluded that high spring runoff caused crabs to move into more saline waters and probably out of the bay. Present studies are designed to examine the relationship between reduced flows and bay area fishery resources in more detail. Such studies are necessary since freshwater flow to the ocean has been approximately halved since the 1800's and will be reduced even further in the future.

INTRODUCTION

Over twenty years of biological and hydrological studies in the Sacramento-San Joaquin Estuary have documented changes in magnitude and timing of freshwater flow which are associated with water development in the watershed. These changes, coupled with natural fluctuations in flow, control the survival and distribution of various fishes and invertebrates. It is important to understand the implications of these changes and concomitant ecological relationships so intelligent management decisions can be made when the inevitable conflict between water-development projects and fish and wildlife resources occurs. It is the intent of this paper to summarize the current knowledge of the effects of estuarine hydrology on fishery resources in the Sacramento-San Joaquin Estuary. Much of the information discussed was obtained from studies completed as part of a four-agency (California Department of Fish and Game, California Department of Water Resources, U.S. Fish and Wildlife Service, and U.S. Water and Power Resources Service) agreement. The water development agencies finance roughly two-thirds of the biological research and also conduct their own studies on hydrological and water quality impacts on project operations. Part of this work was funded by Dingell-Johnson Project, California F-9-R, "A Study of Sturgeon, Striped Bass, and Resident Fishes", supported by Federal Aid to Fish Restoration funds.

DESCRIPTION OF ESTUARY

The confluence of the Sacramento and San Joaquin river systems forms a complex estuary characterized by interconnected embayments, sloughs, marshes, channels, and rivers (Figure 1).

The delta forms the easternmost portion of the estuary. It is bounded by the Sacramento River on the north and by the San Joaquin River on the south. Approximately 1,130 km (702 miles) of channels interlace this triangularly shaped area and surround large cultivated islands that were reclaimed from naturally occurring marshes in the late nineteenth and early twentieth centuries. These channels vary in width from about 50 m (164 ft) to 1.5 km (0.93 miles) and are generally less than 15 m (50 ft) deep.

Suisun, San Pablo, and San Francisco bays are to the west of the delta. They cover an area of about 1,125 km^2 (434 mi^2). The bays are relatively shallow, with a mean depth of 6 m (20 ft) at mean low water, although they are incised by narrow channels (natural and dredged) that are typically 10 to 20 m (32 to 65 ft) deep. The deepest sections of channel (e.g. Golden Gate, 110 m [360 ft] and Carquinez Strait, 27 m [88 ft]) are topographic constrictions whose depths appear to be maintained by tidal currents (Conomos 1979).

The estuary has a Mediterranean climate. The San Francisco Bay area is dominated by the ocean and therefore is characterized by warm winters, cool summers, and minimal seasonal temperature variation. Average July air temperature is 15°C (59°F) while average January temperature is 10°C (50°F). The ocean's influence is modified with increasing distance inland. The delta area has a continental climate with a mean July air temperature at Stockton of 23°C (73°F) and a mean January temperature of 7°C (45°F). Kelley (1966) describes the estuary in detail.

The estuary receives runoff from a 163,000 km^2 (63,000 mi^2) drainage basin which covers 40 percent of the land area of California (Conomos 1979). Inflow into the system is highly seasonal and is composed primarily of rain runoff during winter and snowmelt runoff during early summer (Figure 2). The annual natural flow through the estuary would average about 34 km^3 (27.6 X 10^6 acre-ft), but consumptive uses and diversions in and stream from the delta have halved this amount. Ninety percent of the fresh water that enters the bay passes through the delta (Porterfield et al. 1961) and Carquinez Strait. Delta outflow is not measured directly but relative values

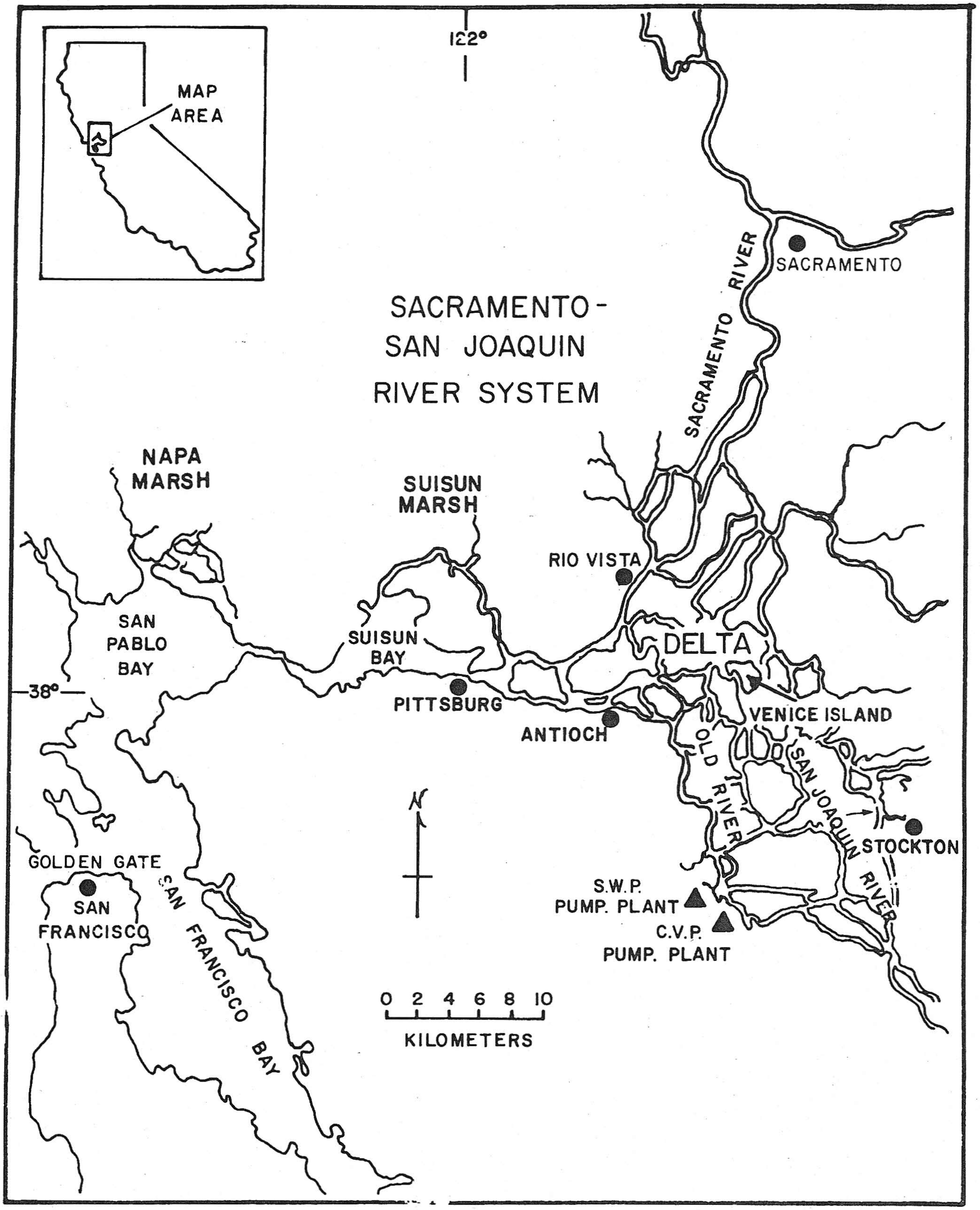

Figure 1. Sacramento-San Joaquin River System.

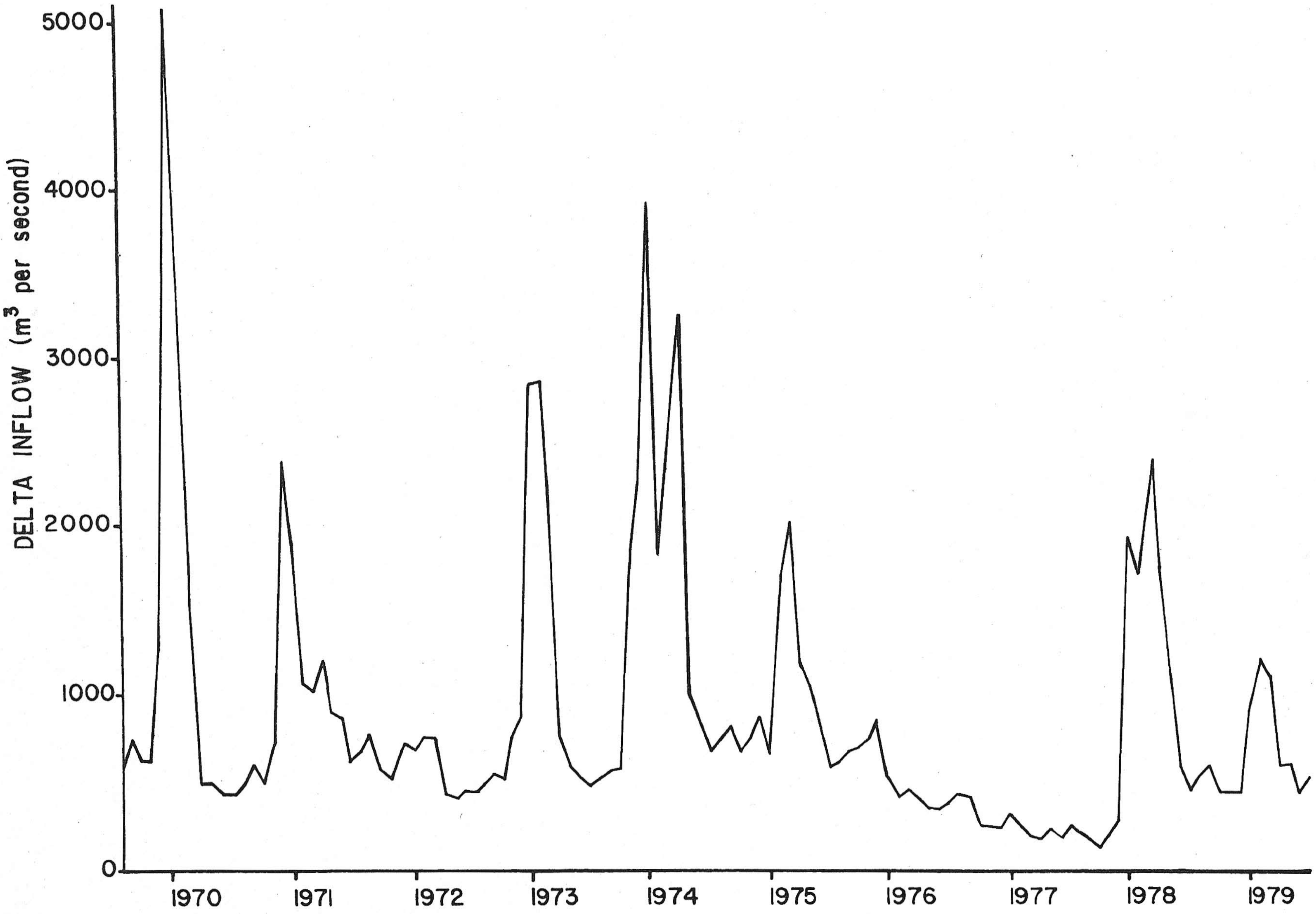

Figure 2. Inflow into system by month.

Seasonal changes in salinity distributions within the system result from tidal exchange and river inflow. River inflow varies widely so it has a greater system-wide seasonal effect (Conomos 1979). San Francisco Bay is usually nearly as saline as the ocean. The gradient from sea to fresh water generally begins in San Pablo Bay and extends about 80 km (50 mi) to the western delta. This longitudinal salinity gradient ranges from 30 ppt at the Golden Gate to less than 1 ppt at the Delta. The general region of the gradient where the landward flow of seawater compensates the seaward flow of fresh water has been termed the "null zone" (Conomos and Peterson 1974, Peterson et al. 1975). In about the same general region occupied by the null zone certain suspended materials (including the biota) accumulate in what has been termed the "entrapment zone" (Arthur and Ball 1978). The location of this area is largely dependent upon the amount of freshwater flow, but is usually in Suisun Bay during the spring through fall period.

Nontidal currents in the estuary are generated by winds and river flow. Velocities of such currents are one-tenth those of tidal currents, yet they are important in transporting dissolved and particulate substances into and from the bay (Conomos 1979). These landward-flowing bottom currents are driven by gravitational circulation and are affected by the magnitude of delta outflow. These currents are strongest and most consistent in the central and northern reaches of the bay because of the influence of the delta outflows and greater stratification which occurs there (Peterson et al. 1975). Gravitational circulation is much weaker in South Bay since there are few freshwater inputs in that part of the system. Other high outflow related processes such as "increased dilution discharge" and increased baroclinic circulation enhance circulation there (Fischer and Kirkland 1978).

Increased demand for domestic and agricultural water in the more arid southern part of the State has resulted in the construction of large State and Federal water development projects. These projects have altered the hydrology of the estuary through dam and reservior construction, estuarine and upstream diversions, and transport facility construction and operation. The San Joaquin drainage has been almost completely developed for upstream use. Development of the Sacramento system has been designed to transport water through the delta for use in the south. Inflows from the two river systems into the delta are not equal. From 1970 to 1975 an average of 88 percent of the inflow to the delta came from the Sacremento River.

Water is exported to the south by two large pumping plants in the southwestern delta (Figure 1). These plants, built by the U.S. Water and Power Resources Service and the California Department of Water Resources have a combined pumping capacity of 300 m^3/s (10,500 cfs). Typical export rates substantially exceed the flow of the San Joaquin River; therefore most water comes from the Sacramento River. Sacramento River water must pass through channels too small to carry the required diversion flows, so export rates greater than 100 m^3/s (3,500 cfs) draw water up the San Joaquin River and delta channels from their junctions with the Sacramento River. Such net upstream flows in the San Joaquin River are typical in the spring, except in wet years, and in the summer and fall of all years.

EFFECTS OF DIVERSIONS AND FRESH-WATER FLOW ON FISHERIES

Changes in distributions and survival of various fish and invertebrates in the Sacramento-San Joaquin Estuary have occurred in response to direct and indirect effects of diversions and project-altered amounts of freshwater flow.

Direct Effects of Diversions

The most obvious biological impact of the water projects is the transport of young fish and pelagic fish eggs to the diversion sites. Attempts are made to "salvage" the large numbers of fish which arrive at the pump facilities each year. Annual "salvage" estimates for 1968-1979 have ranged up to 42 million striped bass (Morone saxatilis), 4 million American shad (Alosa sapidissima), 500,000 chinook salmon (Oncorhynchus tshawytscha), and 18 million individuals of 43 other species (Stevens and Chadwick 1979). Unfortunately, due to behavioral peculiarities or poor swimming ability, many more fish are not salvaged because they pass through the project louver screens. Skinner (1974) estimated that 31 percent of the striped bass, 25 percent of the chinook salmon, and 78 percent of the white catfish (Ictalurus catus) were lost through the screens. The estimate for striped bass is a minimum because Skinner's estimates did not include larvae, for which louvers are entirely ineffective. Additional losses of "salvaged" fish which occur during holding, trucking, and release have not been thoroughly evaluated, but they probably are substantial. Preliminary information suggests that handling and trucking causes mortality on the order of 20 to 60 percent.

From 1959 to 1976 variations in survival of young striped bass were directly correlated with variations in river flow and inversely correlated with rates at which water was diverted from the delta by local agriculture and Federal and State water projects (Chadwick et al. 1977). Abundance of young bass was reduced as outflows decreased and as diversion rates increased apparently because the diversions removed a greater fraction of the flow and fish when flows were not high enough to transport the young fish to Suisun Bay. We concluded (Chadwick et al. 1977) that diversions acted as a density-independent source of mortality, actually cropping a portion of the population during the first few months of life. However, in 1977, 1978, and 1979 young bass abundance indices averaged 32 percent lower than expected from the prior relationships between abundance, flow, and diversion rates. Hence, some additional factor(s) has caused recent abundance to fall below levels accounted for by the analysis for previous years and at present we can not explain why.

Indirect Effects of Diversions

Several examples of indirecteffects of diversions which adversely impact the Sacramento-San Joaquin fishery resources have been documented. (1) Flow reversals, associated with pumping in the south delta, cause young and adult anadromous fish to migrate across the delta toward the pumps, rather than through the delta to the ocean. Such deviation from direct migration routes to the ocean apparently leads to increased mortality of young salmon (Kjelson et al. 1981) and probably other species. (2) A few post-spawning adult striped bass, American shad, and white sturgeon (Acipenser transmontanus) follow these flows to the trashracks at the salvage facilities (Stevens and Chadwick 1979). Here these fish fight the current until they die of exhaustion. (3) Starting in 1961, salmon runs of the San Joaquin, but not of the Sacramento, suffered a disastrous collapse due in part to delayed migration resulting from poor water conditions and flow reversal in the San Joaquin part of the delta. Salmon orientation apparently was affected by the large flow of Sacramento River water which was diverted through various delta channels and sloughs (Hallock et al. 1970). (4) Export pumping increases flow velocities in channels that carry Sacramento River water across the delta to the pumping plants. This results in reduced standing crops of important fish food organisms, benthos, and zooplankton such as copepods, cladocerans, and Neomysis mercedis (Hazel and Kelley 1966; Turner 1966; Heubach 1969). High flow velocities depress populations of benthic organisms because sandy channel bottoms become unstable, and plankton populations do not get a chance to grow when "residence times" are short.

Amount of Freshwater Flow

The amount of freshwater flow passing seaward through the delta affects the distribution of fish and fish food organisms in the estuary. For example; (1) The proportion of young striped bass in downstream nursery areas increases as flow increases (Turner and Chadwick 1972). (2) The opossum shrimp (Neomysis mercedis) is hydraulically and behaviorally concentrated just upstream of the "entrapment zone." Since the zone's location moves in relation to flow, changes in shrimp distributions also occur (Orsi and Knutson 1979). (3) River flow controls the distribution of young salmon, shad, and longfin smelt (Spirinchus thaleichthys) in the system because high flows disperse them to downstream areas (Stevens and Miller, Calif. Dept. Fish and Game MS; Kjelson et al. 1981). (4) Ongoing studies in central and south San Francisco Bay indicate that freshwater flow-related bay circulation affects the distribution of English sole (Parophrys vetulus). Stronger and more consistent bottom flows in the northern area generally cause more ocean-spawned young sole to be swept into North Bay than to the South Bay where gravitational circulation is less. However, from 1980 data (Figure 3), we hypothesize that high flows (high enough to initiate baroclinic circulation) may disperse sole in the bay by carrying greater numbers of young into the South Bay. (5) In response to large delta outflows and subsequent reduced salinities throughout the bay, dungeness crabs (Cancer magister) consolidate in areas of salinity greater than 10 ppt before emigrating out of the bay (Tasto, Calif. Dept. Fish and Game MS). This flow-regulated consolidation occurs in April-May and by the end of summer movement out of the bay and mortality account for the loss of greater than 90 percent of the outgoing class. (6) The species composition of fish in the Suisun and Napa Marsh sloughs varies with salinity and flow (Figure 4). During a 1975 to 1978 survey of 10 sloughs in these marshes, we collected 40 freshwater, estuarine (euryhaline or anadromous), and marine species (Table 1). Salinity increased substantially in both marshes in 1977 due to a prolonged

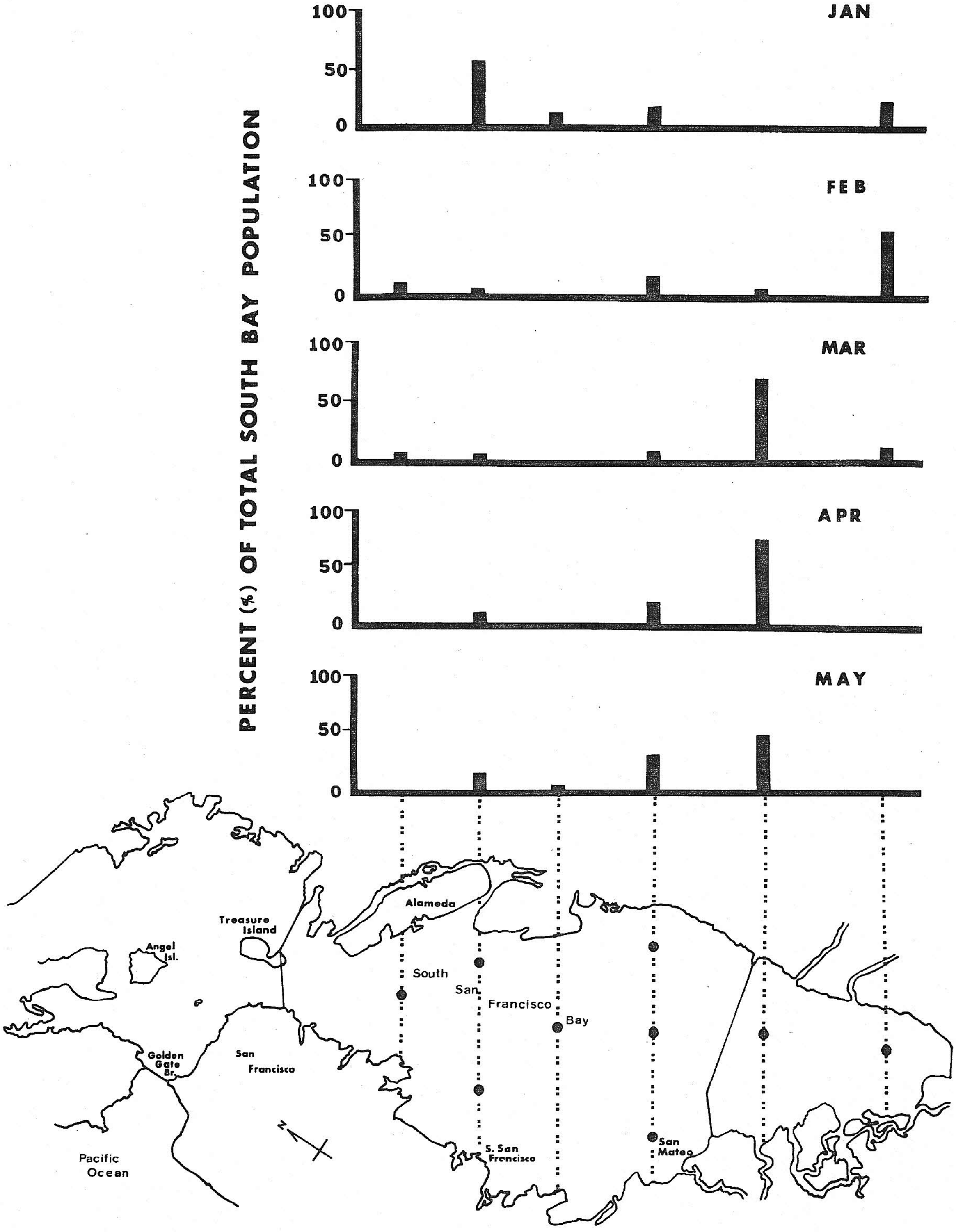

Figure 3. English sole (Parophrys vetulus) distribution in south San Francisco Bay during January - May, 1980 based on catch-per-unit-effort. Mean conductivities (micromoles) for the period were: January - 27145, February - 19870, April - 33856, May - 30602.

drought. In the Suisan Marsh the salinity increase caused abundance of freshwater fish to decrease markedly and abundance of marine species to increase slightly. In the Napa Marsh, except during high freshwater flows in winter, salinities always were intolerable to most freshwater species so their abundance always was low. The low abundance of estuarine species in the Napa Marsh in 1976 and 1977 was striking. Possibly this reflected low "dispersion flows" rather than salinity tolerances. As expected, marine species increased in the Napa Marsh in 1976 as salinity was increasing during the first year of the drought. However, abundance of marine fishes decreased in 1977 even though salinity was higher then. Apparently other factors limited the invasion of the marsh by marine species that year.

The amount of freshwater flow also affects the abundance of fish and their food organisms. As explained previously, from 1959 to 1976 young-of-the-year striped bass abundance indices were directly correlated with flow (Turner and Chadwick 1972; Chadwick et al. 1977). Also, increased survival associated with increased flow was a major factor affecting abundance of recruits 3 years later (Figure 5) (Stevens 1977).

Abundance indices for young fall run chinook salmon, American shad, and longfin smelt are highly correlated with river flow rates during spawning and nursery months (Stevens and Miller, Calif. Dept. Fish and Game MS). Likewise, a multiple regression analysis for data collected during 1969 through 1978, indicates that 88 percent of the variation in N. mercedis abundance is due to salinity near Pittsburg (a reflection of the magnitude of delta outflow) and mean chlorophyll a concentration (Knutson and Orsi Calif. Dept. Fish and Game MS).

The relationships between distribution and survival of the various species and amounts of freshwater flow are potentially caused by several mechanisms, the importance of which may vary among the species. These mechanisms include: (1) Flow-regulated transportation towards or away from diversions: Increased flows carry young fish seaward thus decreasing their vulnerability to diversion. (2) Increased habitat availability: Increased flows disperse young fish into areas not otherwise available, probably resulting in decreased inter- and intraspecific competition and less predation than when the young fish are concentrated in a smaller part of the river system. (3) Increased food availability: In the estuary, nutrient supplies which form the basis of the food chain may increase with flow, causing increased productivity (Turner and Chadwick 1972). Also, productivity of the entrapment zone (Ball 1977, Arthur and Ball 1978) and abundance of a major food organism (Neomysis mercedis), for fish are affected by the location of the salinity gradient which is determined by flow (Knutson and Orsi, Calif. Dept. Fish and Game MS). (4) Suitability of spawning habitat: Extremely low flows such as in 1977 reduce striped bass spawning habitat because salinity intrudes into the delta and water in the San Joaquin River upstream from the delta is of poor quality due to a high proportion of the flow being formed by agriculture waste water. Secondly, in the river above the delta, salmon mortality probably increases when reduced flows cause redds to become exposed (Stevens and Miller, Calif. Dept. Fish and Game MS).

Table 1. Classification of fishes collected in the Suisun and Napa Marshes in 1975-78 into freshwater, estuarine, and marine groups.

Freshwater	Estuarine	Marine
Carp *Cyprinus carpio*	Striped bass *Morone saxatilis*	Pacific herring *Clupea harengus pallasi*
Sacramento squawfish *Ptychocheilus grandis*	Splittail *Pogonichthys macrolepidotus*	Speckled sanddab *Citharichthys stigmaeus*
Sacramento blackfish *Orthodon microlepidotus*	Threadfin shad *Dorosoma petenense*	California halibut *Paralichthys californicus*
Hitch *Lavinia exilicauda*	American shad *Alosa sapidissima*	Shiner perch *Cymatogaster aggregata*
Goldfish *Carassius auratus*	Starry flounder *Platichthys stellatus*	Pile perch *Rhacochilus vacca*
Sacramento sucker *Catostomus occidentalis*	Tule perch *Hysterocarpus traski*	Surf smelt *Hypomesus pretiosus*
White catfish *Ictalurus catus*	Yellowfin goby *Acanthogobius flavimanus*	Northern anchovy *Engraulis mordax*
Brown Bullhead *Ictalurus nebulosis*	Delta smelt *Hypomesus transpacificus*	White croaker *Genyonemus lineatus*
Black bullhead *Ictalurus melas*	Longfin smelt *Spirinchus thaleichthys*	Bay pipefish *Syngnathus griseolineatus*
Channel catfish *Ictalurus punctatus*	Threespine stickleback *Gasterosteus aculeatus*	Pacific tomcod *Microgadus proximus*
Prickly sculpin *Cottus asper*	Steelhead rainbow trout *Salmo gairdneri*	Plainfin midshipman *Porichthys notatus*

Table 1. Continued

Freshwater	Estuarine	Marine
Black crappie *Pomoxis nigromaculatus*	White sturgeon *Acipenser transmontanus*	Pacific staghorn sculpin *Leptocottus armatus*
Bluegill *Lepomis macrochirus*		
Sacramento perch *Ambloplites rupestris*		
Largemouth bass *Micropterus salmoides*		
Mosquitofish *Gambusia affinis*		

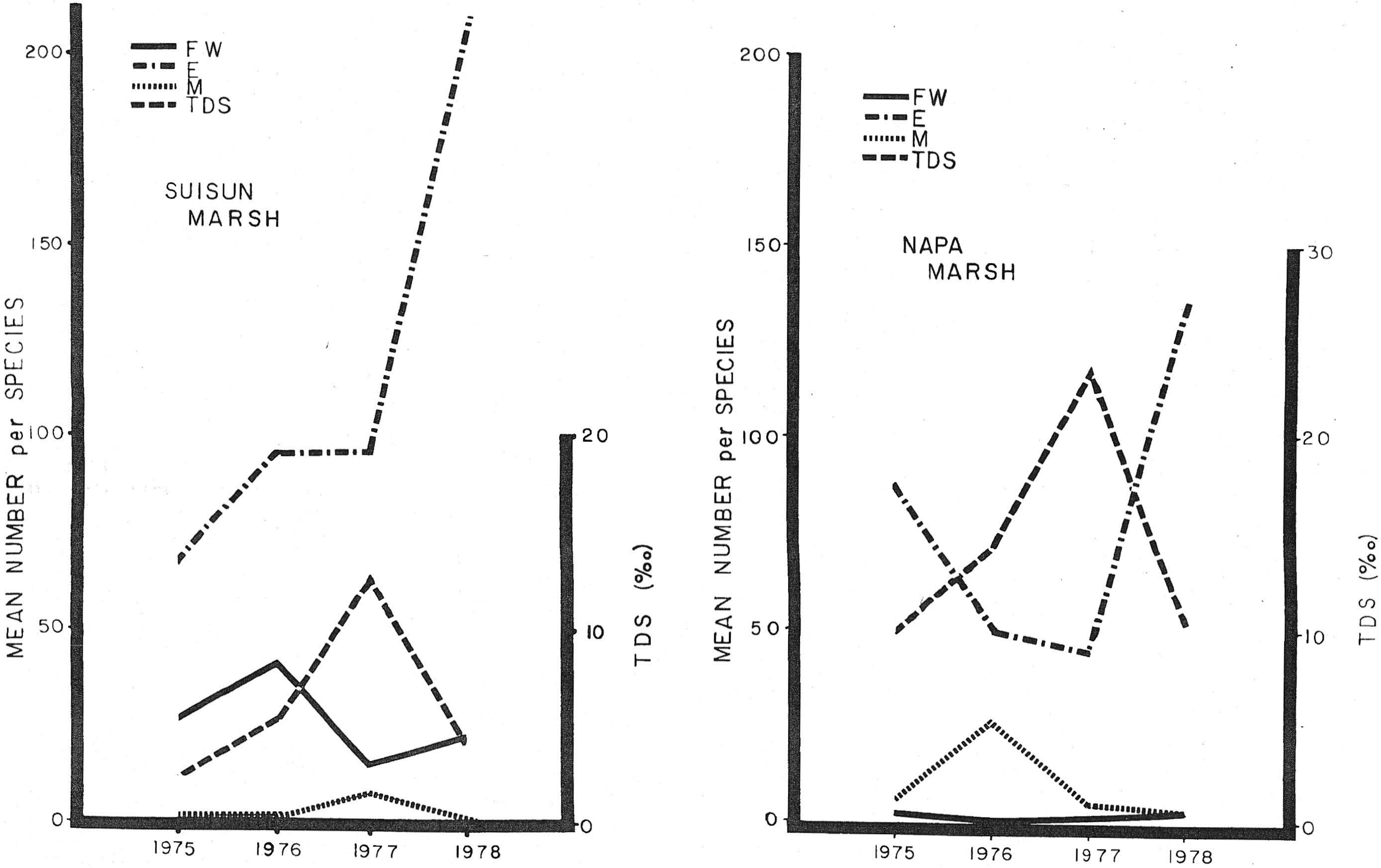

Figure 4. Changes in abundance of fishes, grouped by salinity tolerance, in Suisun and Napa marshes, 1975-78. Salinity or total dissolved solids (ppt.) shown for comparison. FW - freshwater species; E - estuarine species; M - marine species.

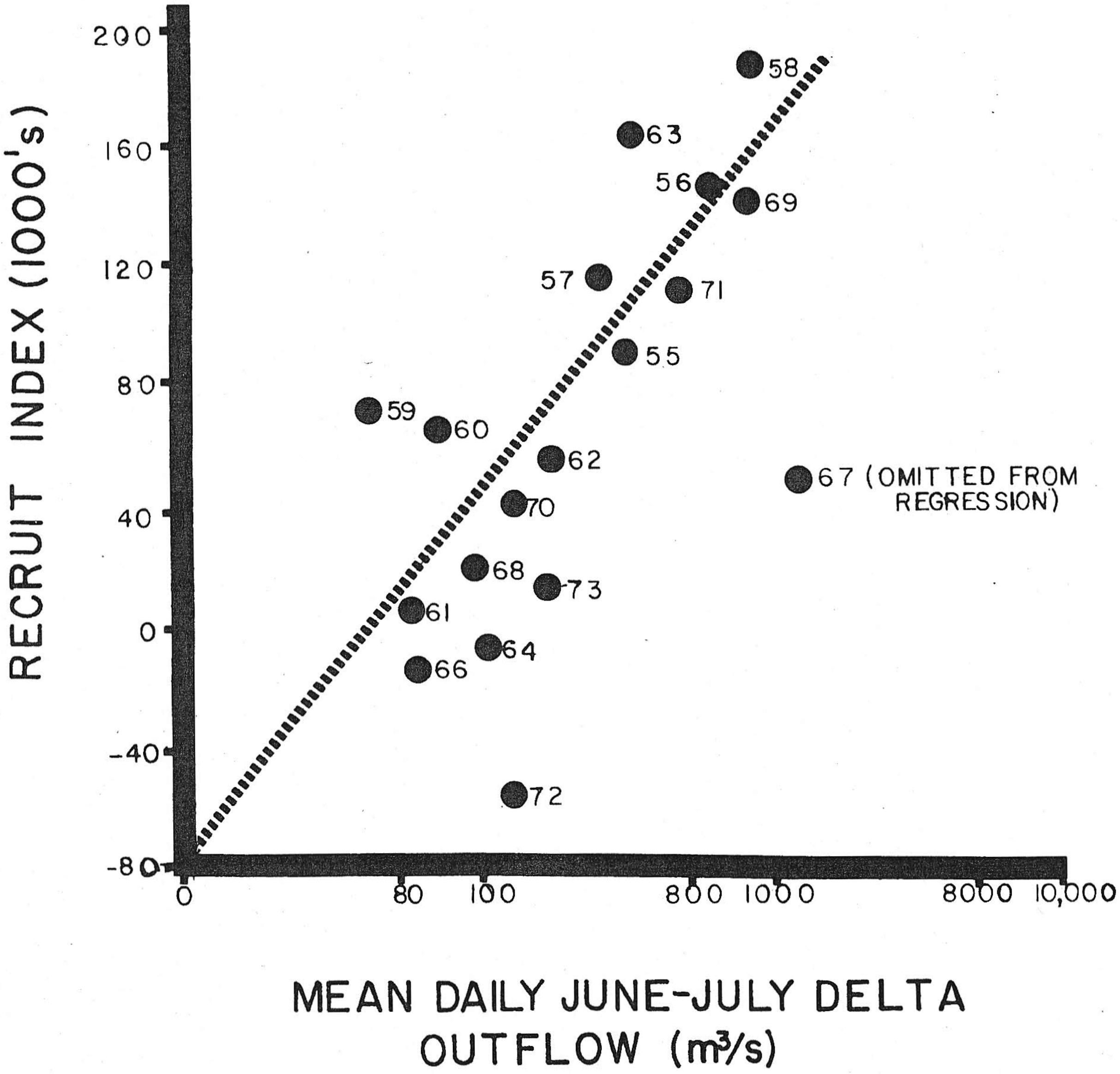

Figure 5. Relationship between index of abundance of three year old striped bass and mean daily freshwater outflow from the Sacramento-San Joaquin Delta during June and July, three years earlier. Numbers adjacent to points indicate year classes over the period 1956-73.

FUTURE ACTIVITIES

Since the turn of the century, freshwater flows into the estuary have been substantially reduced in fall, winter, and spring while summer flows have increased slightly. Overall flow reductions are projected to continue (Figure 6) and will impact the estuarine ecosystem. To date documentation of the importance of freshwater flow in this system has been concentrated in the fresh and brackish water areas; however, studies to evaluate potential adverse effects in the saltier San Francisco and San Pablo bays is justified by many unanswered questions about the biological-hydrological dynamics of the total system. Hence, our department, in conjunction with the other three Ecological Program agencies has initiated a long-term study to determine the importance of freshwater flow for San Francisco and San Pablo Bay fish and wildlife resources.

The Delta Outflow/San Francisco Bay Study will concentrate on how outflow-related changes in hydraulics and salinity will affect fish and wildlife distributions and survival in San Francisco and San Pablo bays. The objectives will be met initially by carrying out seven field and analytically oriented study elements. The program will investigate the effects of reduced flow on circulation patterns, salinity gradients, nutrients, organic detritus, suspended sediments, and silt loads. Simple field techniques (e.g. drouges, etc.) will be used to investigate current patterns and attempts will be made to improve the technical understanding of existing simulation models (both physical and numerical) and the estuary. We anticipate that the improved understanding of the hydraulics of the bay and delta and the importance of that to the biological systems will allow us to project the effect of various hydraulic schemes on bay fish and wildlife.

The biological components of our program include a monthly field sampling effort to obtain information on fish and invertebrate population dynamics and distributions at 35 locations in the system. Adult fish are sampled with otter and midwater trawls; larval fish, fish eggs, and some invertebrates are collected with an egg and larval net; and beach seine samples are taken at 28 sites along the shoreline. Information collected includes species composition, size distributions, and food habits. A major component of the investigation will be the development of abundance indices for Crangon and Pala-mon shrimp. These shrimp indices will be used as an indicator of the health of the system, as it is perturbated by flow alterations.

The Delta Outflow/San Francisco Bay Study is scheduled to continue for at least six years. During this time the program undoubtedly will evolve in response to early findings.

LITERATURE CITED

Arthur, J.F.; Ball, M.D. Entrapment of suspended materials in the San Francisco Bay-Delta Estuary. Sacramento, CA: U.S. Bureau of Reclamation, Mid-Pacific Region; 1978; 106 p. Available from: U.S. Water and Power Resources Service, Sacramento, CA.

Ball, M.D. Phytoplankton growth and chlorophyll levels in the Sacramento-San Joaquin Delta through San Pablo Bay. Sacramento, CA: U.S. Bureau of Reclamation. 1977; 96 pp. Available from: U.S. Water and Power Resources Service, Sacramento, CA.

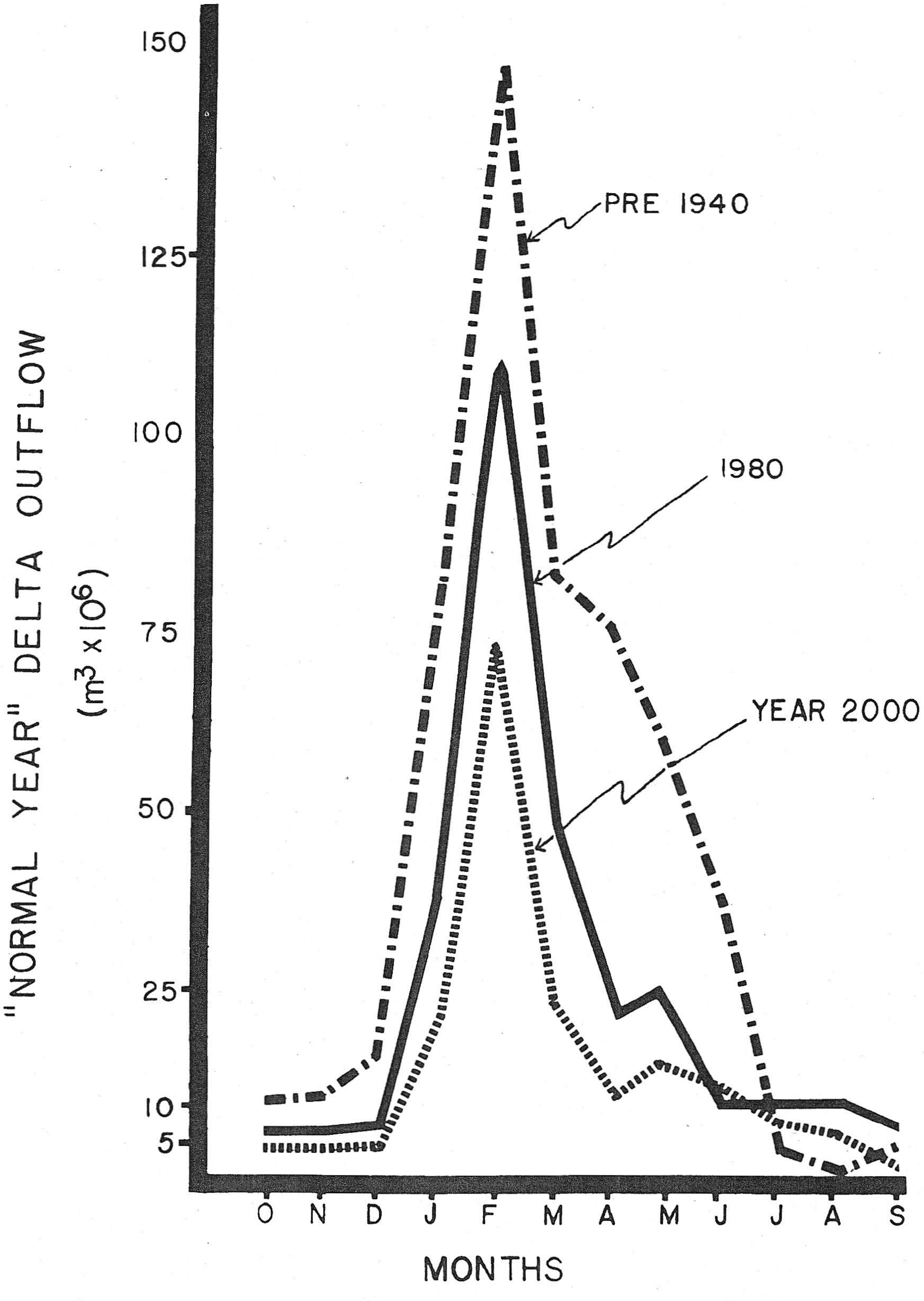

Figure 6. Trends in freshwater outflow from Sacramento-San Joaquin Delta. Values are for "normal year". (Based on October - September 1936). Figure adapted from Association of Bay Area Governments Environmental Management Plan, June 1978.

Chadwick, H.K.; Stevens, D.E.; Miller, L.W. Some factors regulating the striped bass population in the Sacramento-San Joaquin Estuary, California. Van Winkle, W.,ed. Proceedings of the Conference on Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations. May 3-6, 1977 Gatlinburg, TN: Pergamon Press; 1977: 18-35.

Conomos, T.J. Properties and circulation of San Francisco Bay waters. Conomos, T.J., ed. San Francisco Bay: the urbanized estuary. Pacific Division, Am. Assoc. Adv. Sci. June 12-16; San Francisco: CA: San Francisco State University; 1979: 493 pp.

Conomos, T.J; Peterson, D.H.; Biological and chemical aspects of the San Francisco Bay turbidity maximum. Mem. Inst. Geol. Bassin d'Aquitaine 7:45-52; 1974.

Fischer, H.B., Kirkland , W.B. Jr. Flushing of south San Francisco Bay: results of dye concentration measurements in the bay-delta physical model. Report HBF-78/01: 1978 April. Available from: U.S. Water and Power Resources Service, Sacramento, CA.

Hallock, R.J.; Elwell, R.F.; Fry, D.H. Jr. Migrations of adult king salmon (Oncorhynchus tshawytscha) in the San Joaquin Delta, as demonstrated by the use of sonic tags. Calif. Fish and Game, Fish. Bull. 151; 1970.

Hazel, C.R., Kelley, D.H. Zoobenthos of the Sacramento-San Joaquin Delta. Kelley, D.W., ed. Ecological studies of the Sacramento-San Joaquin Estuary, Part I. Calif. Dept. Fish and Game, Fish. Bull. 133: 113-133; 1966.

Heubach, W. Neomysis awatschensis in the Sacramento-San Joaquin River estuary. Limnol. Oceanogr. 14 (4):533-546; 1969.

Kelley, D.W. Description of the Sacramento-San Joaquin Estuary. Kelley, D.W., ed. Ecological studies of the Sacramento-San Joaquin Estuary, Part I. Calif. Dept. Fish and Game,Fish. Bull. 133: 8-17, 1966.

Kjelson, M.A.; Fisher, F.W.; Raquel P.F. Influences of freshwater inflow on chinook salmon (Oncorhynchus tshawytscha) in the Sacramento-San Joaquin Estuary. Cross, R.D.; Williams, D.C. eds. Proceedings of the National Symposium on Freshwater Inflow to Estuaries. September 9-11, 1980. San Antonio, Texas; Washington, DC: U.S. Fish and Wildlife Service, Office of Biological Services; 1981.

Orsi, J.J.; Knuton, A.C. Jr. The role of mysid shrimp in the Sacramento-San Joaquin Estuary and factors affecting their abundance and distribution. Conomos, T.J., ed. San Francisco Bay: The urbanized estuary. San Francisco, CA. Pacific Division, Am. Assoc. Adv. Sci: 1979: 401-408.

Peterson, D.H., Conomos, T.J.; Broenkow, W.W.; Doherty, P.C. Location of the non-tidal current null zone in northern San Francisco Bay. Estuarine Coastal Mar. Sci. 3:1-11; 1975.

Porterfield, G., Hawley, N.L.; Dunnam, C. A. Fluvial sediments transported by streams tributary to the San Francisco Bay area. U.S. Geol. Surv. Open-File Rep. 70 pp; 1961. Available from: U.S. Water and Power Resources Service, Sacramento, CA.

Skinner, J.E. A functional evaluation of a large louver screen installion and fish facilities research on California water diversion project. Jensen, L. D., ed. Proceedings of the Second Entrainment and Intake Screening Workshop. The Johns Hopkins University Cooling Water Research Project Rep. No. 15; 1974:225-249.

Stevens, D.E. Striped bass (Morone saxatilis) year class strength in relation to riverflow in the Sacramento-San Joaquin Estuary, California. Trans. Am. Fish. Soc. 106(1):34-42; 1977.

Stevens, D.E.; Chadwick, H.K. Sacramento-San Joaquin Estuary--biology and hydrology. Fisheries 4(4):2-6; 1979.

Turner, J.L. Seasonal distribution of crustacean plankters in the Sacramento-San Joaquin Delta. Calif. Fish and Game, Fish. Bull. 133:95-104; 1966.

Turner, J.C., Chadwick, H.K. Distribution and abundance of young-morone saxatilis, in relation to river flow in the Sacramento-San Joaquin Estuary. Trans. Am. Fish. Soc. 101(3):442-452; 1972.

DISCUSSION

Question: Norm Benson, Fish and Wildlife Service: Perry, when you say habitat availability has increased, you mean by the size of the entrapment zone?

Answer: When large amounts of freshwater moves into the system, it moves into the system, the location of the entrapment zone moves further towards Suisun Bay and San Pablo Bay. If you remember the map, those areas are flatter and broader; therefore, the actual area of the zone is increased. During low flow years, like 76-77, the entrapment zone was up in the narrow river channel where the area is not nearly as great. Another factor is some of the salmon work that Stevens and Miller have been working on. This work shows that those increased flows also improve the areas where fish are spawning. So outflow improves that habitat as well as increases the area available for fish.