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SAN FRANCISCO BAY: USE AND PROTECTION

An investigation into Man's activities and impacts on San Francisco Bay, government and private sector responses to those impacts, and prospects for its future use and protection

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FACTORS RELATED TO THE NUMBER OF STRIPED BASS IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

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Evidence over the past 40 years indicates that the striped bass population in the Sacramento-San Joaquin Estuary has been declining due to lack of recruitment (the number of young bass maturing annually) brought about by a deterioration in the environment. During this period, fresh-water flow into the estuary has been substantially reduced because of increased water diversions within the drainage basin. The effect of reduced fresh-water inflow has limited the carrying capacity of the estuary for striped bass. Water diversions have also directly removed both the young striped bass and their food supply. Which of these factors plays the greatest role in controlling production of young bass has yet to be determined; however, evidence indicates that spring flows play the most important role for striped bass young survival.

The numbers of young bass produced since the drought (1976-1977) have been especially low—lower than had been predicted based on previous experience. During 1978 and 1979, daily flow patterns during the spring, which were unlike those of the previous 20 years, may have contributed to the small number of bass produced. The entrapment zone of the estuary moved upstream into the Delta from Suisun Bay during the spring of both years. In 1980, the index of abundance of young striped bass was again low despite a high flow which should have resulted in a good year class. The low index may have been the result of much lower than normal spring water temperatures and/or a possible negative bias in the index.

The adult population is expected to decline to lower levels in the coming years. At some unknown lower population level, the capacity of the population to reproduce may become limited. At that point, the population decline would accelerate if conditions for young bass survival failed to improve. If conditions improve, the numbers of young and adult bass should increase because of the high reproductive capacity of the population.

A comprehensive review and analysis of the distribution and abundance of young striped bass and their food supply is needed to determine what factors control the production of young bass in the estuary.

Over the past 40 years, fresh-water flow into the San Francisco Bay (Sacramento-San Joaquin Estuary) has been significantly reduced by water diversions. Flow patterns have also been significantly altered by dams and reservoirs built on tributaries for water storage and hydroelectric power. Further changes are expected in the future as demand for water increases. The environmental effects of these changes have been, and are continuing to be, a serious concern. Much of the concern has centered on the aquatic biological community, and in particular, the striped bass—a fish which has been the subject of extensive study over the past 20 years.

During the past three years, I have been involved in a study to assess the impact of power plants and water diversions on the aquatic community and, in particular, the striped bass population of the estuary. The study was mandated by State and Federal regulations and funded by Pacific Gas and Electric Company for the purpose of obtaining National Pollution Discharge

Elimination System (NPDES) discharge permits for the Pittsburg and Contra Costa power plants which use water from the estuary for cooling purposes. The study program included an analysis of all factors which may be affecting the aquatic community of the estuary so that the effects of the power plants could be put in perspective with other factors controlling the system. Related aspects of the work were presented by Goyert (1980) and Sitts (1980).

BACKGROUND

Most of the research on the environmental requirements of the estuary has centered on the impact of State and Federal water projects on striped bass. The striped bass population has been the subject of extensive study by the California Department of Fish and Game (CDFG) since the late 1950s. Many early studies provided information on the life history, population dynamics, and basic environmental requirements of the bass. But it was not until a considerable data base was established that specific patterns were observed that associated the numbers of striped bass with environmental factors, such as the Sacramento-San Joaquin Delta outflow and water diversions.

Turner and Chadwick (1972) reported a positive correlation between the annual indices of abundance of young bass (derived from summer tow-net survey data for 1959 to 1970) and the mean daily June-July Delta outflow. The indices also correlated with the April and May outflows. In addition, the indices had a negative correlation with the percentage of Delta fresh-water inflow diverted at the Delta pumping plants of the water projects in June and July. The correlation with outflow suggested that outflow was related to some environmental factors such as food supply, while the correlation with percentage diverted suggested that loss of young at diversions directly affects the number of young produced.

Chadwick et al. (1977) and CDFG (1976) reported that indices for the years 1971 to 1976 were lower than expected as determined by Turner and Chadwick (1972). They attributed the lower production of young to increases in the Delta-water export rate especially during May from 1971 to 1976. The decline in numbers was apparent in the zone encompassing the Delta portion of the population. (The other portion of the population located in Suisun Bay remained as predicted from the earlier data). The decline in the Delta was attributed to the direct loss of young at the diversions and/or a reduction in the food supply because of the higher flows in the Delta channels resulting from the increased export rates at the Delta pumping plants. The relations (based on the index from 1959 to 1976) between the numbers of young bass, the outflow, and the rate of diversions at the south Delta pumping plants were used to evaluate the potential environmental impact of the Peripheral Canal (California Department of Water Resources 1976) and to derive water quality standards prescribed in the Delta Water Plan (California State Water Resources Control Board 1978).

The number of young bass in 1977, 1978, and 1979 averaged 32% lower than had been expected from the regression equations developed from the 1959 to 1976 data base (Stevens 1980). Chadwick (1979) reported that both the Suisun Bay and Delta indices were substantially lower in 1978 than expected. The decline was related to unusually low numbers of *Neomysis*—a shrimp that is a major food item of the young bass—possibly brought on by the drought of 1976-1977. Stevens (1980) suggested that a fundamental change in the factors controlling the bass population occurred because of the severe drought in 1977.

Studies by CDFG on *Neomysis* since 1968 have indicated that its abundance is a function of habitat size and food supply (Orsi and Knutson 1979). Habitat is controlled by Delta outflow. Phytoplankton, the principal food of *Neomysis*, is also controlled by Delta outflow. Arthur and Ball (1979) suggest that the quantity of phytoplankton, zooplankton (including *Neomysis*), and possibly the number of striped bass, is increased when the null or entrapment zone (mixing zone between the fresh-water and salt-water portions of the estuary) is located in Suisun Bay rather than upstream in Delta channels. Fairly high flows (110 to 700 m^3/sec) are required to keep the entrapment zone in Suisun Bay. At lower flows, the entrapment zone is located upstream in Delta channels where a minimum of shoaling occurs.

In 1980, the number of young striped bass in the estuary was again lower than expected (Don Stevens, CDFG, pers. comm.). Conditions in 1980 were considered excellent for striped bass young, yet despite high spring and early summer flows the surveys showed very few young bass. The numbers of young bass were nearly as low as during the 1976 and 1977 drought. The *Neomysis* population was not correspondingly low in 1980 and thus was not considered the cause of the small bass population in 1980.

Because of the importance of the striped bass estimates in resource-management strategies for the estuary, the CDFG has enlisted experts on striped bass populations from the East Coast to help determine the cause of the small numbers of young bass in recent years (Harold Chadwick, CDFG, pers. comm.). Possible causes of the decline include the increased effect of losses at water diversions (such as State and Federal Delta pumping plants and Delta agricultural diversions), power plants, pollution, a decline in the reproductive capability of the adult stock, or a fundamental change in the system brought about by the recent drought (Stevens 1980).

STRIPED BASS INDEX

To measure recruitment, CDFG has developed the striped bass index. The index is derived from catch data of the CDFG summer tow-net survey—a procedure which has been followed each year (except 1966) since 1959. The index is designed to be a measure of the number of young bass in the estuary when they reach a mean size of 1.5 in. or 38 mm. At this size, the young bass mortality is thought to be stabilized and the class strength set for the year. Analyses by CDFG indicate the index correlates reasonably well with the abundance of older fish (Stevens 1977). In 1976 the index was separated into a Delta index and a Suisun Bay index when it became apparent that the relation developed between the June-July Delta outflow and the index for the years 1959 to 1970 no longer held for the years 1971 to 1976 (CDFG 1976).

The index has one major bias. During wet years, an unknown proportion of the young bass in the estuary are found below Suisun Bay in San Pablo Bay (CDFG 1976). In such years, flows are sufficient to carry many young bass into San Pablo Bay and the Napa River. Since the CDFG survey does not include these areas, the index is thus an underestimate by some unknown proportion during these years. The extent of this bias in each year depends on the duration of the high flows, the timing of the flows, and the magnitude of flows during the survey period.

Other problems with the index were noted by Goyert (1980), who proposed an alternative index derived from the same data. Goyert developed an index of young bass abundance for all years except those which had high spring-summer flows—years when young bass were found below the survey zone. Although his index was not substantially different from CDFG's, there are some differences in conclusions.

EFFECT OF DELTA OUTFLOW ON YOUNG STRIPED BASS

The studies by CDFG indicate a definite relationship between Delta outflow and the number of young bass in the estuary. June-July flows were considered important for young striped bass in Suisun Bay and May-June flows in the Delta (California Department of Fish and Game 1976; Chadwick 1979). The June-July outflow was also found to correlate with a recruitment index derived from party-boat catch data (Stevens 1977) three years later. In all of these studies, Delta outflow for each of the months from April through July was correlated with the abundance of striped bass.

Analyses performed by Goyert (1980) also indicated a correlation between the number of young bass and Delta outflow. The best correlation was found between May outflow and the

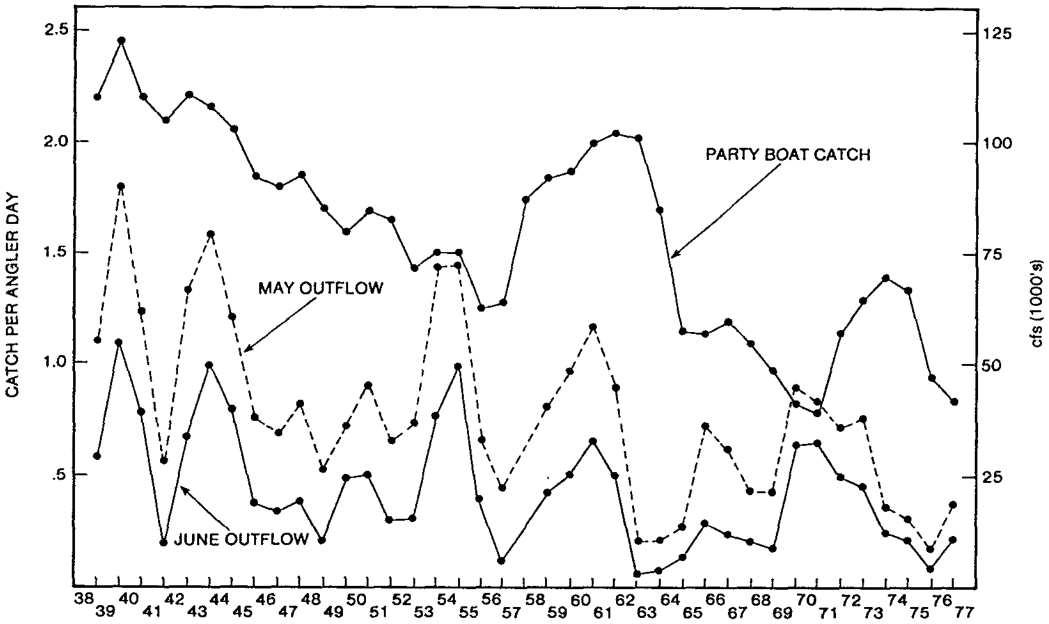


Fig. 2. Party boat striped bass (from Stevens 1977) and Delta outflows for May and June from 1938 to 1977. All data points are two-year moving averages. Flows are lagged two years before 1957 and three years after 1957. (Two-year-olds before 1957 and three-year-olds after 1957 were the most abundant age groups. Since 1965 the average age has increased to five- to seven-year-olds [Stevens 1977]).

vulnerability of the young to water diversions and may be important to sustain an abundance of zooplankton necessary to feed the young bass. Furthermore, July flow patterns have changed little over the past 20 years compared to May and June flows, thus the effect of July flows is not as obvious. The effect may also change depending on the May and June flow.

In 1978, 1979, and 1980, the number of young bass was much lower than expected (Stevens 1980; Goyert 1980). Both 1978 and 1980 were wet years and an abundance of young bass was expected. In 1979, a dry year, even the modest number expected was not achieved.

In 1978 and 1979, abnormal flow patterns may have contributed to higher-than-expected mortality. In both 1978 and 1979 sharp reductions in flows in late May and June and an associated rapid upstream movement of the entrapment zone from Suisun Bay to the Delta occurred (Fig. 3). The estimated movement of the entrapment zone for 1978 and 1979 (Fig. 3) is based on a relationship established between the Delta outflow index and the salinity (conductivity) distribution in the estuary (Ostrye 1980). In June of both years, the entrapment zone was confined to Delta channels. Both the striped bass and their food supply (copepods and *Neomysis*), confined by the hydrodynamics of the entrapment zone, were forced up into the Delta from Suisun Bay, where conditions were crowded (Arthur and Ball 1979). The pattern of 1978 had not occurred in any of the wet years from 1959 to 1977. In 1979, conditions were considered more like a below-normal year than a dry or critical year because of a short burst of runoff in mid-May. The average monthly conditions used to establish relationships between Delta outflow and the abundance of young striped bass do not accurately reflect the unusual conditions in 1978 and 1979.

For 1980, no explanation for the lower-than-expected numbers of young has been offered. The flows in 1980 were sufficient to keep the entrapment zone downstream of the Delta during most of the May-through-July period. The high outflow in 1980 may have distributed many young abundance of young bass over the entire estuary. May outflow also was found to be more closely related to the CDFG three-year-old index than the June-July outflow (Fig. 1a, 1b). The long-term party-boat catch trend also correlates with the May and June outflow data (Fig. 2).

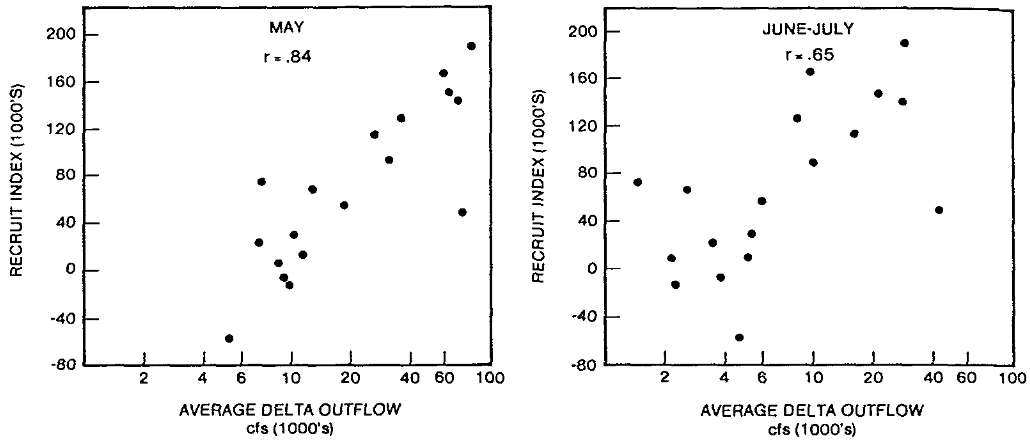


Fig. 1. (a) Relationship between average May Delta outflow (1956 to 1973) and index of three-year-old striped bass three years later. (b) Relationship between June-July Delta outflow (1956 to 1973) and index of three-year-old striped bass three years later. (Index data from Stevens 1977, 1980; outflow data from DWR unpublished data.)

A number of reasons have been offered to account for the relationship between outflow and numbers of young striped bass. The CDFG (1976) suggests that outflow controls numbers of young bass as follows:

1) At low outflows, spawning habitat is reduced thus resulting in decreased egg production;
2) At low outflows, young spawned up-river in the Sacramento River are not transported to nursery areas in the Delta and Suisun Bay where food is more plentiful;
3) Increased outflow reduces competition and increases food availability by dispersing eggs and young through the estuary;
4) Increased outflow brings more nutrients resulting in increased food supply;
5) High outflows dilute toxic waste discharges
6) High outflows increase turbidity which minimizes predation of young bass;
7) High outflows are generally associated with lower water temperatures which result in later spawning which, in turn, coincides with greater food availability when young start to feed;
8) High outflows reduce the loss of young and their food supply at Delta diversions.

In most of these cases, outflow during May and June would appear to be the most important. Spawning and early development generally occur during May and June. The critical period of first feeding when the young depend on an abundance of food is also in May and June. Most of the dispersion of young occurs in May and June when they are planktonic; larger young are better able to maintain their location and tend to move toward the shore. The vulnerability of young is greatest in May and June when they are small and less able to avoid predators. Loss of young at diversions would be minimized if high May-June outflows initially disperse young downstream of the Delta diversions. Outflow in July, although apparently less important than that for May and June, may yet be important. One reason the July outflow relationship is not as strong as that for May and June may be that since the index is generally determined during July, there may not have been adequate time for the fish population to respond. July outflows certainly affect the

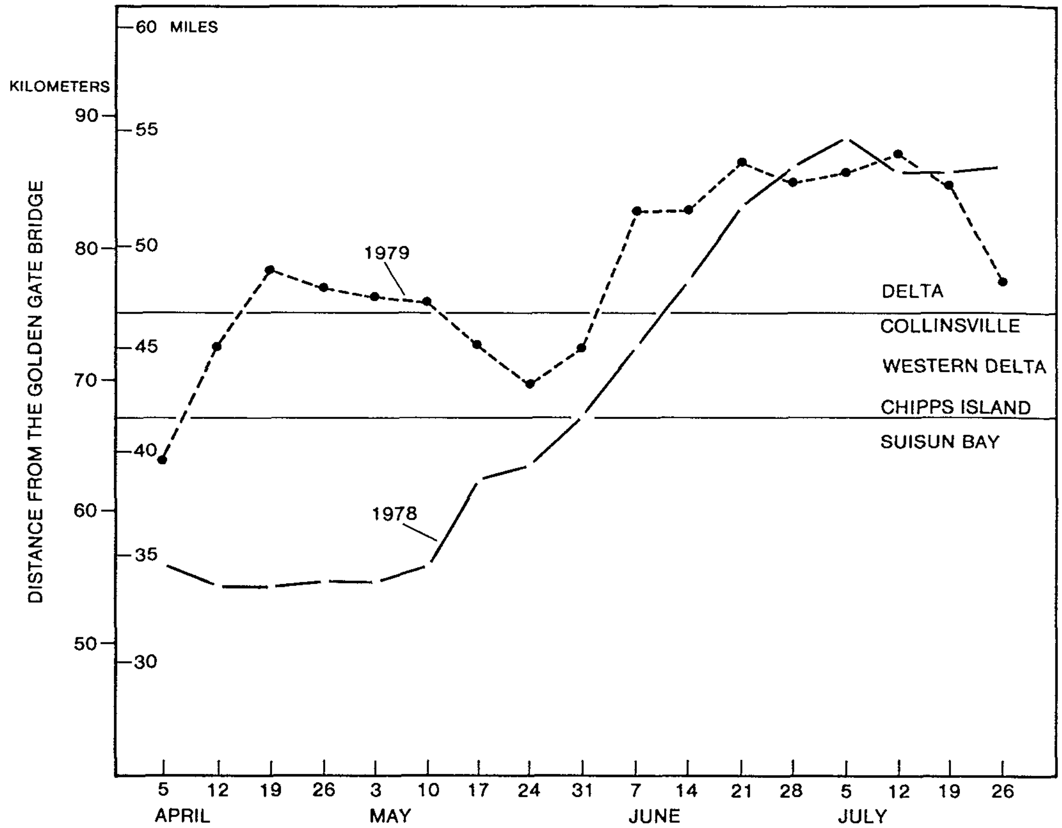


Fig. 3. Location of the 2.0 mmhos/cm electrical conductivity at high tide in the Delta between April and July of 1978 and 1979, based on average weekly Delta outflow relationship between conductivity and Delta outflow (from Ostrye 1980).

bass below the summer two-net survey sampling area and thus the index was underestimated. Very high flows keep the entrapment zone downstream of Suisun Bay and may hinder productivity (Arthur and Ball 1979). High spring flows, late runoff, and cooler weather in the late spring and early summer of 1980 resulted in below-normal water temperatures in the estuary which may have affected the growth and survival of young striped bass and the timing of zooplankton production. Each or all of these factors could be related to the low index in 1980. A zooplankton survey from 1980 may provide some clue as to what happened to the striped bass food supply. No survey of egg and larval striped bass was undertaken in 1980. Abundance and distribution patterns from the previous ten years of eggs and larvae may provide some clue as to what occurred in 1980.

EFFECT OF FOOD SUPPLY ON YOUNG STRIPED BASS

Many environmental factors may directly or indirectly control the productivity of the estuary. Various factors tend to work with or against each other. The problem is to differentiate the effects of each and to determine their importance. For the striped bass, the production of young is probably controlled directly by food supply and available habitat.

In many fish populations, recruitment is the result of density-dependent processes in growth and mortality and their modulation by density-independent factors such as food supply (Cushing 1977). Mortality rates are related to the food supply. A good food supply accelerates growth, and larger, more developed individuals are better able to avoid predators and use available food supplies (Cushing and Harris 1973). The limit or carrying capacity of the system for larvae is probably determined by the availability of food (Jones 1973). The timing of the peaks in zooplankton production and the critical stages of larval fish development may also affect productivity and recruitment (Cushing 1969, 1974). Food and larval fish must grow together (Jones 1973).

The principal foods of young striped bass are zooplankton and *Neomysis* (California Department of Fish and Game 1976). Zooplankton, including copepods and cladocerans, is the primary food source of larvae; *Neomysis* is the principal food source of juveniles. The principal foods of the striped bass young in the entrapment zone are the copepod *Eurytemora hirundoides*, and *Neomysis* (Heubach, Toth, and McCready 1963). These organisms are most abundant in the entrapment zone (Arthur and Ball 1979). Experimental studies have shown that larval striped bass require high densities of zooplankton (greater than 1000 copepod nauplii per liter) to sustain themselves (Miller 1976, 1978: Doroshev 1970). High concentrations of the copepod *E. hirundoides* often exist in the entrapment zone of the estuary, especially when outflow is sufficient to keep the entrapment zone in Suisun Bay (Arthur and Ball 1979). The location of the entrapment zone in Suisun Bay appears to stimulate the production of phytoplankton (Arthur and Ball 1978), which are the principal food of the copepods.

The timing and extent of phytoplankton blooms and associated copepod blooms in the estuary may be the critical factor in the survival of young striped bass. Declines in standing crops of phytoplankton and zooplankton in 1976 and 1977 in the estuary were partially attributed to the upstream movement of the entrapment zone into the Delta channels from Suisun Bay (Arthur and Ball 1978). These movements took place early in spring, thus by late spring poor food supplies were available for the striped bass larvae. The early spring movement of the entrapment zone into the Delta in 1979 (see Fig. 3) may have also resulted in inadequate food supplies for the striped bass from May through July. Declines in the standing crop and density of *Neomysis* have also been found when the entrapment zone has moved upstream into the Delta (Orsi and Knutson 1979); the poor production of striped bass in 1978 may be related to declines in *Neomysis* during late June and July because of the movement of the entrapment zone into the Delta. Such a decline in *Neomysis* did occur in the early summer of 1978 (CDFG *Neomysis* survey, unpublished data) and was noted by CDFG as a possible cause of the poor striped bass production that year (Chadwick 1979).

EFFECT OF DELTA DIVERSIONS AND POWER PLANTS ON YOUNG STRIPED BASS

The major Delta water diversions that may affect the abundance of young striped bass and their food supply in the estuary are the State and Federal pumping plants, the Delta Cross-Channel, Delta agriculture diversions, and power plants (Fig. 4). Flow rates for the various diversions are given in Table 1.

The percentage of striped bass diverted in the Delta is potentially highest during low flow when young striped bass are concentrated in the Delta and diversions make up a high percentage of Delta inflow. Such conditions would occur during June, July, and August when young bass are most abundant and Delta inflow is at a minimum. During the period 1959 to 1979, these conditions existed in every year except 1967 and 1969—two extremely wet years when summer inflow was high and less than 20% of the Delta inflow was diverted in June and July. In all other years the percent of Delta inflow diverted ranged from 35 to 78%, with 60 to 70% diverted during dry years and 35 to 48% diverted during wet years (CDFG 1976).

Surveys of fish salvaged at the intake screens of the State pumping plant at Byron (CDFG unpublished data) provide data on the numbers of young striped bass diverted and salvaged from 1968 to the present. The numbers are greatest during the months of June through August, July being the peak month in most years. Estimates of the numbers of young bass diverted range from

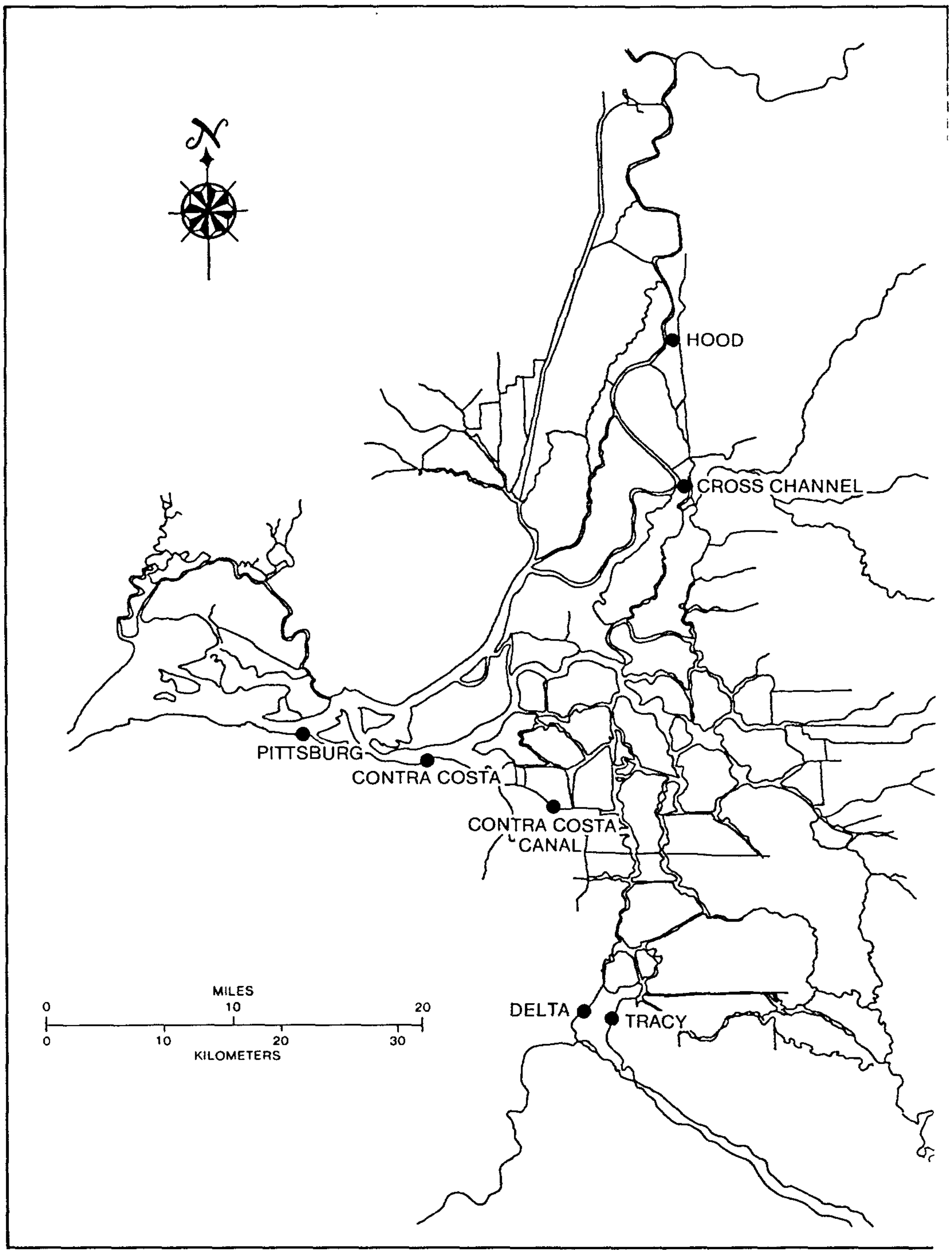
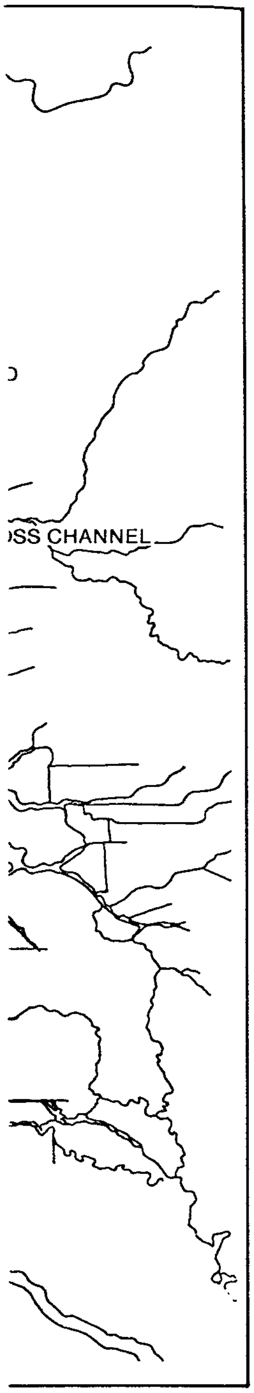


Fig. 4. Location of major water diversions in Sacramento–San Joaquin Delta.



Delta.

TABLE 1. MAJOR DELTA WATER DIVERSIONS (GREATER THAN 100 CFS) AND THEIR RESPECTIVE CAPACITIES

Consumptive Source	CFS
Delta Pumping Plant (SWP)	3,000 - 10,000
Tracy Pumping Plant (CVP)	3,000 - 4,600
Delta Agriculture	2,000 - 5,000
Contra Costa Canal	200 - 350
Non-Consumptive Source	
Delta Cross-Channel	3,000 - 10,000
Pittsburgh Power Plant	1,600
Contra Costa Power Plant	1,500

several million to nearly 80 million (Chadwick et al. 1977). The highest numbers diverted from 1960 to 1977 were in 1965, 1968, and 1970-1974, which were years with moderate to high populations of young bass and moderate to high summer flows. The lowest numbers diverted occurred in wet years (1967 and 1969) and in dry years (1976 and 1977). Unpublished CDFG data for 1978 indicate high numbers were diverted.

An unknown number of young striped bass are diverted during the egg and early larval stages at the Delta pumping plants. The early stages are not sampled in the CDFG survey. These losses may be less important than those of the older fish because the eggs and early larvae are distributed over a much wider range of the estuary and most are found in the Sacramento River. Still, the losses could be substantial at least for the San Joaquin spawn, especially in dry years.

The Delta Cross-Channel, built to supply cross-Delta flow of Sacramento River water to the Delta pumping plants, also diverts large numbers of young striped bass, eggs, and larvae from the Sacramento River. Although these young are not all lost to the estuary as at the Delta pumping plants, their survival in the interior Delta channels is unlikely because of low food supply and because many are exported at the Delta pumping plants (CDFG 1976). The diversion at the Cross-Channel may reach 50 to 60% of the Sacramento River flow (CDWR unpublished data). During May, when most young bass are being transported down the Sacramento River, 20 to 50% may be diverted to interior Delta channels. The percentage diverted in May usually increases as outflow decreases. The amount of Cross-Channel flow is presently restricted when young striped bass are abundant in the Sacramento River during all but dry and critical years (State Water Resources Control Board 1978).

Delta agriculture diversions divert an unknown but substantial number of young bass (Allen 1975). The actual numbers diverted depends on the distribution of the young bass in relation to the distribution of the diversions in the system. Since most of the young bass eventually concentrate in low-salinity areas (entrapment zone) where little agricultural diversion occurs, and since much of the agricultural diversion occurs in the interior Delta channels where there are fewer bass, the effect of the agricultural diversions may be minimal.

Entrainment of young striped bass in the cooling water of Delta power plants is another source of mortality. The water pumped at the power plants is only at 30% of that of the Delta pumping plants (Table 1); however, the number of young bass per unit volume is probably greater, because the power plants are located in the western Delta close to the entrapment zone during low-flow periods. Since the plants return the water to the estuary, the numbers lost depend on the survivability of the bass as they pass through the plants. Studies by CDFG (Stevens and Finlayson 1978) indicate that survival rates are generally high except during periods of peak summer loads when the inplant and discharge temperatures reach lethal levels. The losses have been increasing in recent years as greater demand for power is causing lethal temperatures to occur more frequently (Stevens 1980).

The effect of removing large numbers of young striped bass from the estuary has been the subject of extensive study. The CDFG (Chadwick 1979; Stevens 1980) believes that the difference in recruitment between the 1960s and 1970s was caused by increased diversion rates. Although the combined loss of young bass probably exceeds 50% of the total produced during all but wet years, there is a question as to the effect on the population.

Three possible consequences to the loss of young striped bass to diversions are: (1) the remaining bass would have a higher survival rate due to decreased competition and greater food availability and so would partially or completely compensate for the diversion losses; (2) the numbers lost would result in a proportionate loss in adult fish thus reducing the potential sport catch; and (3) the loss would be compounded over the years because losses in the adult segment of the population would result in further future declines in the number of the eggs spawned and the subsequent number of young produced.

Which of these possible consequences may be expected under present and future conditions is difficult to determine. The subject has received considerable attention over the past ten years (Van Winkle 1977). Most scientists would agree that populations, especially those like striped bass with high reproductive capability and multiple age groups, have a strong compensatory capability and that at least modest cropping can be withstood (McFadden 1977). So far there has been no evidence linking the number of eggs spawned to production of young or recruitment to the fishery in the striped bass population in the Sacramento-San Joaquin Estuary or in East Coast estuaries, thus the third consequence seems least likely. Under the second consequence, the health of the population would not be in question; only a lower population level and a resulting lower sport catch would be expected. Under the first consequence, the population level would only be partially affected or not at all as a result of diversion and power plant losses; the number of adult striped bass available to the fishery would be determined primarily by environmental factors and only to a limited extent by diversion losses.

EFFECT OF ADULT POPULATION OF STRIPED BASS ON PRODUCTION OF YOUNG

Stock size has declined from several million adults to about one million adults (Stevens 1980). Poor survival of young in recent years will cause further declines in stock size. At lower stock sizes, numbers may be limited by poor egg production. The lower level of stock size where recruitment would be affected is not known.

Some scientists believe that by the time a downward trend in recruitment attributable to reductions in stock or reductions due to fishing or related mortality has been noted, it is too late to take the necessary action to stop a population crash or drive toward a lower population level (Cushing 1977; Murphy 1977; Larkin 1977; Gulland 1978). Such declines are often brought about by decompensatory mortality where at low population levels, predators (including man) tend to take what they did before by exerting greater effort. Populations may also change migratory or spawning behavior, making them more vulnerable to exploitation (Murphy 1977). Increase in the harvest rate of the stock could lead to sharp declines in stock (Gulland 1978). The environmentally determined element of recruitment is also variable enough to mask any changes due to fishing or other related mortality (Cushing 1977). To date, the exploitation rate on the striped bass in the estuary has declined with the population (Stevens 1980).

The size of the spawning stock of striped bass in the estuary will probably decline significantly during the next four years due to poor recruitment over the past five years. If the level of stock remains sufficient to provide adequate egg production, then the effect of continued reductions in recruitment will be a proportionate reduction in the stock size. If the stock declines to where stock size affects recruitment, then the long-term effect will be compounded, and the stock will decline at a greater rate than that caused by reductions in fresh-water flow or diversion losses. The threat of extinction of the population is minimal, since striped bass have a tremendous reproductive capacity, as exemplified by their rapid expansion in the estuary after the introduction of only several hundred fish in the 1880s. If conditions are improved and the carrying capacity of the estuary for striped bass is increased, recruitment should increase and the adult stock should expand.

SUMMARY AND CONCLUSIONS

Evidence over the past 40 years indicates that the striped bass stock in the estuary has been declining because of deterioration in the environment. This deterioration appears to be related to reduced fresh-water inflow into the estuary and to Delta diversions.

The mechanism by which the production of young bass has declined has not been established. The CDFG believes the decline is due to increased losses of young at Delta water diversions (Chadwick et al. 1977; Chadwick 1979; Stevens 1980). It is also the position of the CDFG that a cross-Delta water transfer facility known as the Peripheral Canal, which would virtually eliminate the diversion of young bass at the State and Federal pumping plants, would increase recruitment. However, if the true mechanism in the decline in productivity in the estuary is reduced fresh-water inflow, then increased spring-water diversions may cause further deterioration of the estuary environment and further lower the numbers of young striped bass.

Recent studies presented by Goyert (1980) indicate that most of the variability in the abundance of young striped bass in the estuary is associated with Delta outflow and not diversions. The numbers lost at diversions do not explain the variability from year to year. This conclusion seems valid because the greatest numbers of young bass were diverted in moderate or high-abundance years, while the lowest numbers were diverted in driest years. Since moderate-flow years were found to have widely varying diversion losses, the diversion-loss effect does not appear to have been masked by the outflow effect.

If recruitment continues to decline or remain low, striped bass stock levels are likely to decline further. At some point, the stock level may reach such a low level that the number of eggs spawned will be insufficient to meet the production capacity of young in the estuary, thus making return to higher stock levels difficult. In such a case, diversion losses and sport fishery catches would have to be curtailed or environmental conditions improved to protect the population from accelerated decline.

If conditions improve, then the stock should gradually increase.

RECOMMENDATIONS

What does control productivity of striped bass in the estuary? The answer to this question may lie in the existing data available to resource managers. Over ten years of data on phytoplankton, zooplankton, and striped bass have gone relatively unanalyzed over the years. Only bits and pieces, summaries, and indices have been obtained from the data.

A comprehensive review and analysis of the distribution and abundance of phytoplankton, zooplankton, *Neomysis*, and young striped bass is needed. After patterns are established, associations can be formed and hypotheses developed on how the system functions and how it reacts to environmental variability and change. Where answers are not apparent, further research may be warranted.

For striped bass in particular, the questions are: When does most of the mortality occur during the first few months of life? and can the level of mortality be associated with food supply, diversion losses, or other environmental factors? If the food supply is controlling young bass survival, what controls the abundance of the food supply? The answers to these questions lie in an analysis of the data on distribution and abundance of larval striped bass and their food supply during the months of May through July.

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